ROHINI COLLEGE OF ENGINEERING AND TECHNOLOGY

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Department of Mechanical Engineering

VALUE ADDED COURSE ON INDUSTRY 4.0

SYLLABUS

UNIT 1- INTRODUCTION TO INDUSTRY 4.0

Introduction, Historical Context, General framework, Application areas, Dissemination of Industry 4.0 and the disciplines that contribute to its development, Artificial intelligence, The Internet of Things and Industrial Internet of Things, Additive manufacturing, Robotization and automation, Current situation of Industry 4.0. Introduction to Industry 4.0 to Industry 5.0 Advances

UNIT 2- INDUSTRY 4.0 AND CYBER PHYSICAL SYSTEM

Introduction to Cyber Physical Systems (CPS), Architecture of CPS-Components, Data science and technology for CPS, Emerging applications in CPS in different fields. Case study: Application of CPS in health care domain.

UNIT 3- SMART ENERGY SOURCES

Energy Storage for Mitigating the Variability of Renewable Electricity Sources-Types of electric energy storage, Potential of Sodium-Sulfur Battery Energy Storage to Enable Integration of Wind-Case study. Electric Vehicles as Energy Storage: V2G Capacity Estimation.

UNIT 4- SMART GRID

Smart grid definition and development Smart Grid, Understanding the Smart Grid, Smart grid solutions, Design challenges of smart grid and Industry 4.0.

UNIT 5- SMART APPLICATIONS 9

Understanding Smart Appliances -Smart Operation-Smart Monitoring-Smart Energy Savings-Smart Maintenance, Case study-Smart Cars, Self-Driving Cars, Introducing Google‘s Self-Driving Car, Intellectual Property Rights.

1. Introduction

"An innovation is therefore recognized by what it generates in terms of individual and collective uses, which are all the more numerous and varied because it is important. But we can also argue that the characteristic of true innovation is to restructure the real needs of Humanity by opening them to the possible, by definition totally unpredictable". These sentences obviously situate the concept of Industry 4.0 in the fields of innovation seen as a conjecture in advance of the real practice, likely to generate the relationships of individuals and their societies with the future. But one would have spoken of Industry 4.0, if in 30 years the price of a gigabyte had not been reduced by a factor of 3,000,000! If, in 20 years, we had not multiplied by 100 the number of people or companies connected to the Internet in the world.

The word "revolution" denotes abrupt and radical change. Revolutions have occurred throughout history when new technologies and novel ways of perceiving the world trigger a profound change in economic systems and social structures. Given that history is used as a frame of reference, the abruptness of these changes may take years to unfold. The first profound shift in our way of living—the transition from foraging to farming—happened around 10,000 years ago and was made possible by the domestication of animals. The agrarian revolution combined the efforts of animals with those of humans for the purpose of production, transportation and communication. Little by little, food production improved, spurring population growth and enabling larger human settlements. This eventually led to urbanization and the rise of cities.

1.1. Historical Context

The agrarian revolution was followed by a series of industrial revolutions that began in the second half of the 18th century. These marked the transition from muscle power to mechanical power, evolving to where today, with the fourth industrial revolution, enhanced cognitive power is augmenting human production. The first industrial revolution spanned from about 1760 to around 1840. Triggered by the construction of railroads and the invention of the steam engine, it ushered in mechanical production.

The second industrial revolution, which started in the late 19th century and into the early 20th century, made mass production possible, fostered by the advent of electricity and the assembly line. The third industrial revolution began in the 1960s. It is usually called the computer or digital revolution because it was catalyzed by the development of semiconductors, mainframe computing (1960s), personal computing (1970s and '80s) and the internet (1990s).

Mindful of the various definitions and academic arguments used to describe the first three industrial revolutions, we are at the beginning of a fourth industrial revolution. It began at the turn of this century and builds on the digital revolution. It is characterized by a much more ubiquitous and mobile internet, by smaller and more powerful sensors that have become cheaper, and by artificial intelligence and machine learning. Digital technologies that have computer hardware, software and networks at their core are not new, but in a break with the third industrial revolution, they are becoming more sophisticated and integrated and are, as a result, transforming societies and the global economy. This is the reason why it is referred to this period as "the second machine age," the world is at an inflection point where the effect of these digital technologies will manifest with “full force” through automation and the making of “unprecedented things.”

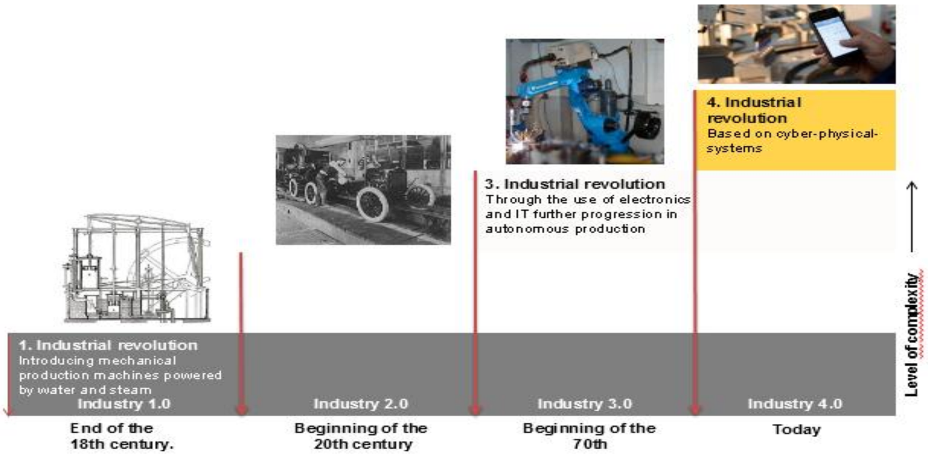


Fig 1.1 Historical Context

In Germany, there are discussions about “Industry 4.0,” a term coined at the Hannover Fair in 2011 to describe how this will revolutionize the organization of global value chains. By enabling “smart factories,” the fourth industrial revolution creates a world in which virtual and physical systems of manufacturing globally cooperate with each other in a flexible way. This enables the absolute customization of products and the creation of new operating models.

The fourth industrial revolution, however, is not only about smart and connected machines and systems. Its scope is much wider. Occurring simultaneously are waves of further breakthroughs in areas ranging from gene sequencing to nanotechnology, from renewables to quantum computing. It is the fusion of these technologies and their interaction across the physical, digital and biological domains that make the fourth industrial revolution fundamentally different from previous revolutions.

In this revolution, emerging technologies and broad-based innovation are diffusing much faster and more widely than in previous ones, which continue to unfold in some parts of the world. This second industrial revolution has yet to be fully experienced by 17% of world, as nearly 1.3 billion people still lack access to electricity. This is also true for the third industrial revolution, with more than half of the world’s population, 4 billion people, most of whom live in the developing world, lacking internet access. The spindle (the hallmark of the first industrial revolution) took almost 120 years to spread outside of Europe. By contrast, the internet permeated across the globe in less than a decade.

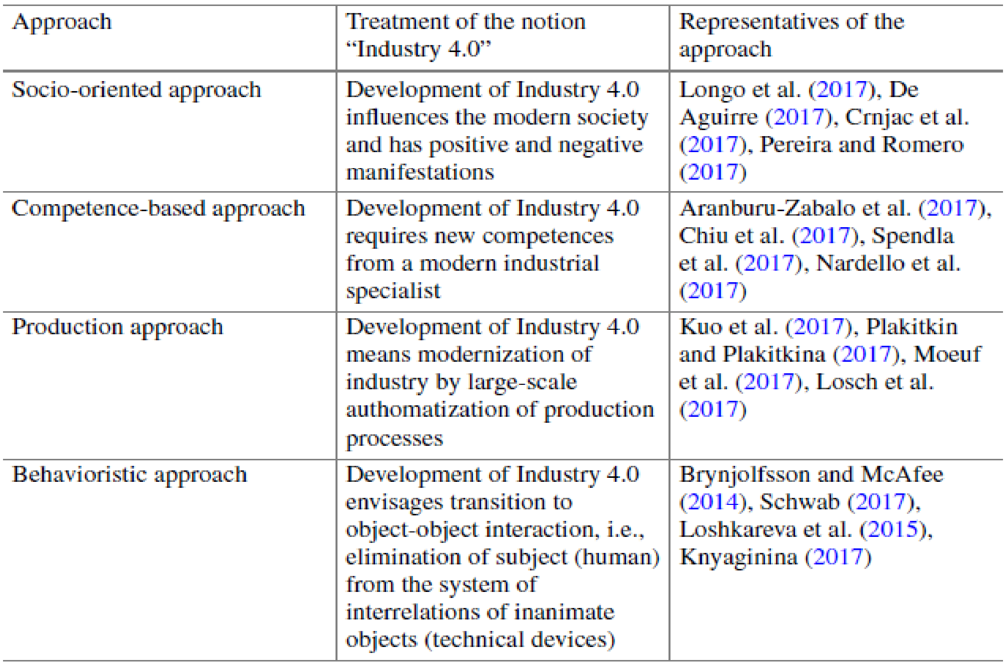
Still valid today is the lesson from the first industrial revolution—that the extent to which society embraces technological innovation is a major determinant of progress. The government and public institutions, as well as the private sector, need to do their part, but it is also essential that citizens see the long-term benefits. The fourth industrial revolution will be every bit as powerful, impactful and historically important as the previous three.

1.2. Definition of Industry 4.0

The scientific term “Industry 4.0” was first introduces in Germany in 2011 at the Hanover fair, where it was used for denoting the transformation process in the global chains of value creation.

In the report “The Fourth Industrial Revolution”, presented by K. Schwab at the World Economic Forum, it is stated that Industry 4.0 includes business processes in industry that envisage organization of global production networks on the basis of new information and communication technologies and Internet technologies, with the help of which interaction of the production objects is conducted.

Table 1 Conceptual approaches to treatment of the notion “Industry 4.0”



Approach	Treatment of the notion “Industry 4.0”	Representatives of the approach
Socio-oriented approach	Development of Industry 4.0 influences the modern society and has positive and negative manifestations	Longo et al. (2017), De Aguirre (2017), Crnjac et al. (2017), Pereira and Romero (2017)
Competence-based approach	Development of Industry 4.0 requires new competences from a modern industrial specialist	Aranburu-Zabalo et al. (2017), Chiu et al. (2017), Spendla et al. (2017), Nardello et al. (2017)
Production approach	Development of Industry 4.0 means modernization of industry by large-scale authomatization of production processes	Kuo et al. (2017), Plakitkin and Plakitkina (2017), Moeuf et al. (2017), Losch et al. (2017)
Behavioristic approach	Development of Industry 4.0 envisages transition to object-object interaction, i.e., elimination of subject (human) from the system of interrelations of inanimate objects (technical devices)	Brynjolfsson and McAfee (2014), Schwab (2017), Loshkareva et al. (2015), Knyaginina (2017)

Scholars from Massachusetts Institute of Technology, Erik Brynjolfsson and Andrew McAfee described Industry 4.0 as a golden age of machine industrial production, organized on the basis of digital technologies and fully automatized (Brynjolfsson and McAfee 2014).

According to the Russian scholar V. N. Knyaginina, the most important specific feature that distinguishes Industry 4.0 from the traditional industrial production is absolute integration (close interconnection) and interactivity (adaptation to the situation in real time) of all production processes of an industrial company, ensured by means of modern digital technologies (Knyaginina 2017).

Russian scholars E.Loshkareva,O.Luksha, I. Ninenko, I. Smagin, and D. Sudakov defined Industry 4.0 as a revolutionary method of organization of industrial production, based on wide digitization and authomatization of production and distribution processes in industry that erases limits between physical objects, turning them into a comprehensive complex system of interconnected and interdependent elements.

1.3. The Basic Characteristics of Industry 4.0

– transition from manual labor to robototronics, which ensures automatization of all production processes;

– modernization of transport and logistical systems, caused by mass distribution of unmanned vehicles;

– increase of complexity and precision of manufactured technical products, manufacture of new construction materials due to improvement of production technologies;

– development of inter-machine communications and self-management of physical systems, conducted with the help of “Internet of things”;

– application of self-teaching programs for provision of constant development of production systems.

1.4 General framework

The Industry 4.0 Framework: Industry 4.0 is many things to many people. For our purposes, Industry 4.0 is a journey deeply involving various advanced technologies that help manufacturing operations become more reliable, productive, efficient, and customer-centric. Industry 4.0 (among a multitude of others) is the information-intensive transformation of manufacturing and other industries. The Industry 4.0 environment digitally connects data, people, processes, services, systems, and IoT-enabled industrial assets across cyber and physical worlds. The goal is to create, use, and take full advantage of actionable information. For some analysts, Industry 4.0 describes a future state of industry characterised by thorough digitalised production processes. For others, Industry 4.0 is already here, representing a new and higher level of organisation and control over manufacturing along entire value chains and product life cycles.

1.4.1 Pillars of the Industry 4.0 Framework

There are many Industry 4.0 frameworks. Each country engaged in systematically modernizing its manufacturing base has its own. As in Japan (Society 5.0), the scope of the framework might expand beyond manufacturing. National development priorities might focus on different sets of advanced technologies. However, countries engaged in Industry 4.0 programs and initiatives tend to emphasize a standard model, a set of advanced technologies, and concepts.

Industry 4.0 depends on not one but several advanced technologies. Some are familiar; others have been a commercial product for a short time. It’s the combination of these technologies in R&D, production, and post-production processes that will help make manufacturing more efficient.

Different analysts use slightly different lists of technologies. (Ours comes from a 2017 Boston Consulting Group study.) However, these are the technologies usually mentioned in Industry 4.0 frameworks:

- Big data/advanced analytics — The industrial world is filled with mountains of unanalysed product and process data. Analysing it and turning it into actionable information can optimise production quality, improve services, and enable faster and more accurate decision making.
- Advanced robotics — As robots become more flexible, cooperative, and autonomous, they will interact with one another, work safely with humans, and eventually learn from humans, too. Industry 4.0 provides a manufacturing context for these opportunities.
- Advanced simulations — In Industry 4.0 environments, 3D simulation of product development, material development, and production processes will enable operators to test and optimise processes for products before production starts.

- AI/cognitive computing — Cognitive manufacturing uses the assets and capabilities of the IoT, advanced data analytics, and cognitive technologies such as AI and machine learning. When used together these technologies will drive improvements in the quality, efficiency, and reliability of manufacturing processes.
- Industrial Internet of Things — In the IIoT, an ever-greater number of products will incorporate internet-connected devices, which link with each other with standard protocols. This approach to manufacturing will decentralise analytics and decision-making and enable real-time responses.
- Cybersecurity — Industry 4.0 environments include connectivity and communications protocols as well as sophisticated identity and access management systems. These technologies enable manufacturers to provide secure, reliable communications and data flow throughout Industry 4.0 systems.
- Additive Manufacturing — In Industry 4.0 manufacturing environments, these technologies are the best choice for producing small-batch, customised, and high-performance products.
- Cloud-based service-enabling technologies — Industry 4.0 manufacturing operations require more data sharing across sites and companies than earlier processes do. Shifting data storage and management to the cloud will drive the development of more manufacturing execution systems (MESs) that use cloud-based machine data.
- Augmented reality — AR provides an effective way to represent production processes by overlaying real-world views of production with virtual information. In ASEAN countries, the most likely role of AR lies in training future workers and technicians how production systems behave in real-time.

Figure 1.2 Emerging Technologies demonstrate the breadth of applications that make up Industry 4.0. In the world of Industry 4.0, technology doesn't operate in isolated factories or assembly lines. In fully realised Industry 4.0 environments, technologies connect with other entities, up and down production hierarchies, along value chains, and throughout product life cycles.

Fig 1.2 Emerging Technologies

Connectivity

In the globally interconnected world, data sent along digital networks link machines, production objects, internet-connected devices, their virtual representations, and humans. Critically, interconnected machines in Industry 4.0 systems interact with different levels of human involvement. For Industry 4.0 manufacturing and systems engineers, this ever-present connectivity has design and operational implications:

- Connectivity is related to interoperability — Shared communication protocols are not just becoming the norm. They are becoming essential parts of manufacturing process design.
- Connectivity enables cyber-physical systems — These are the systems that make smart factories possible. Cyber-physical systems connect intelligent production objects to embedded physical devices, which can store and process data.
- Humans are not always in the production control loop — Industry 4.0 production machinery no longer simply "makes" the product. The product communicates with the machinery to tell it exactly what to do.

Data that flows through Industry 4.0 systems does so in a systematic way, through production hierarchies, and along product life cycles.

Data integration: The broader Industrial 4.0 view

Integration addresses the flow of data between connected machines and devices at different parts of the product life cycle and levels of the production hierarchy.

Horizontal integration refers to the connection of and data flow through IT systems across all manufacturing-related production and business planning processes. Horizontal integration is, therefore, about digitising entire value and supply chains. From supplier to consumer, end-to-end horizontal integration maps IT systems and information flows with big data, analytics, and IoT devices.

In traditional thinking about manufacturing, the production process included all the steps that occur after components enter the factory floor and before they leave it as a finished product. Industry 4.0 concepts require a wider perspective.

Now, a product's life cycle begins with the first product development ideas and extends horizontally through development and production steps to sales and eventual product recycling or disposal.

Vertical integration refers to IT systems connected to machines and devices that operate at different levels of the production hierarchy. In traditional terminology, these hierarchical levels include:

- Field level — in which sensors convert environmental data to signals that are analysed and to actuators, which convert signals into actions.
- Control level — in which controllers gather process data from sensors and drive actuators.
- Production process level — in which automatic devices monitor, control, and adjust specific functions in production processes.
- Operations level — which includes functions such as production planning and quality management.

- Enterprise planning level — which manages the whole production system, enabling business functions such as production planning and market analysis.
- Connected world level — where traditional hierarchy is expanded by moving beyond isolated manufacturing facilities. In this level, network assets and processes connect and support data flow throughout manufacturing systems. Industrial communications networks tie all vertically integrated levels together, sending data from one level of the hierarchy to the other.

The production hierarchy, manufacturing processes, and product life cycle are familiar concepts. In the early days of Industry 4.0, the difficulty lay in how to combine these concepts in a way that was easy to understand and use.

1.4.4 . The Industry 4.0 Model Framework:

1.4.4.1. The RAMI 4.0 Model

The Industry 4.0 Model follows the outline structure of the RAMI 4.0 Model. The Reference Architectural Model Industrie 4.0 (RAMI 4.0) was developed in Germany as part of the country’s Plattform Industrie 4.0 initiative. As Industry 4.0 achieved more acceptances throughout Europe and beyond, the need for a clear and consistent vocabulary became increasingly important. The RAMI 4.0 goal was to create a uniform framework for national and international communications and ideas.

Rami 4.0 Structure

Targeting at a collective understanding of Industry 4.0, RAMI 4.0 is an idea map that describes manufacturing processes and production objects in a clear and systematic way. RAMI 4.0 ensure that those involved in discussions of Industry 4.0 will understand one another. In this model, each production object is defined with its related functions and data. The result is a complete, virtual description of the object. The RAMI 4.0 structure is built on a three-dimensional framework consisting of the Value stream and life Cycle, Hierarchy Levels and Layers.

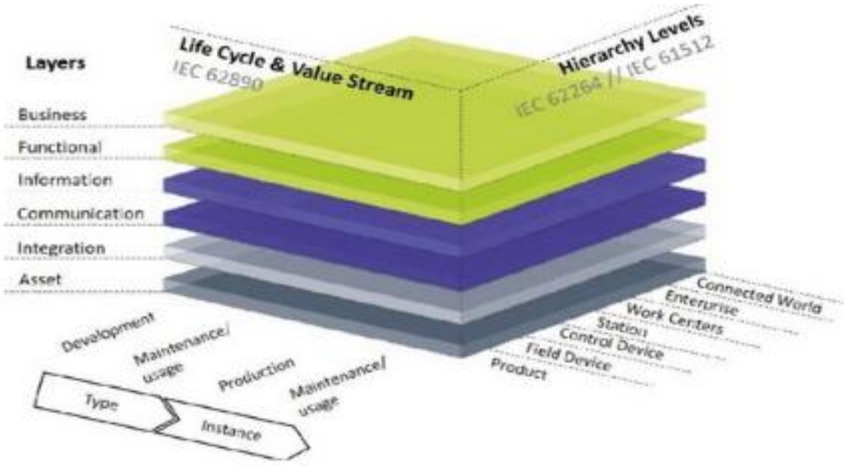


Fig 1.4 Three-dimensional framework

Dimension 1: Life cycle and value stream. In RAMI 4.0, each product is described and tracked from the first idea to the scrap yard by Life cycle axis based on IEC62890 standard. First of all, a specific product type consists of an identifier, meta data and associated certificates, while a product instance behaves as the instantiation of a product type, characterized by an instance identifier. Based on this definition, the life cycle of a product will detail the life cycles of both product type and instance. According to Rami 4.0 model, product type life cycle starts from the development phase throughout maintenance & usage stage. On the other hand, the product instance life time model starts from the production phase throughout usage stage which includes commissioning and disassembling or disposal of the instance.

Dimension 2: Hierarchy levels. The foundation of the axis description is IEC62264 and IEC61512 (also well known as ISA95 and ISA-88), representing different functional levels of a factory. To make it easier to talk about complex production processes, engineers and plant managers divide them into several categories:

- The connected world (new to RAMI 4.0) – visualises and describes the relationship of inter-connected assets, both internally and externally.
- The enterprise – the meaning in Industry 4.0 goes beyond traditional territory of enterprises, referring to both physical organisations and strategic initiatives or missions.
- Work centres – highest level of unified manufacturing production line. A good example can be the stamping line for a typical automotive factory.
- Machines or workstations – refers to the work cells carrying the operations with the resources such as machines, human labours and materials.
- Control devices – characterized by the typical control systems such as PLC and DCS.
- Field devices – field level installation such as sensors and actuators
- Products with expanded scope

Dimension 3: RAMI interoperability layers. This dimension represents different types of data and functions relevant to elements of Dimensions 1 and 2. These data and functions include:

- Business layer — represents business-related data exchanged in industrial processes. Allowing users to map regulatory and market-related policies, business models, products, and services of market participants. Data in this layer can also represent business capabilities and processes.
- Functional layer — supports the business layer by providing the runtime and modelling environment. Information layer — describes the data used and exchanged between functions, services, and components. This layer contains the data services such as provisioning and integration. The key value for this layer is its capability of receiving the events from physical asset via lower level layers and applies the adequate processing and transformation to support the upper levels.
- Communications layer — emphasises protocols and mechanisms for the interoperable exchange of information between components. The outcome is the unified data formats and interfaces that grant the data access, which has been the bottom neck to the Industry 4.0 adoption for long.
- Integration layer — describes physical assets as their digital equivalents. This layer shoulders the most important responsibility of representing the transition from physical world to the cyber space via various innovative approaches (comparing with

traditional integration methodologies) to work on documentation, software, control and monitoring mechanism.
- Assets layer — identifies and describes the real assets in the physical world.

With precisely defined contexts for Industry 4.0 ideas and production objects, users can work their way through the model knowing that other users have the same information, vocabulary, and contexts.

The RAMI 4.0 Standards

Developing consistency across RAMI users is essential to gain the most from the framework. For this, standards must be developed, adopted, and integrated into systems. In RAMI 4.0 context, there are a few standards that have been leveraged, expanded and presenting integrated value for Industry 4.0 development.

IEC 62264

IEC 62264 showcased in RAMI 4.0 architecture model is a standard for enterprise-control system integration, built on the well-known ANSI/ISA-95. Referenced in Figure: 3-2. ISO/IEC 62264 is an integral part of the RAMI model for Industry 4.0 development and has been singled out as a key standard for the factory of the future initiatives.

The ANSI/ISA-95 (better known as ISA-95) is an international standard developed by the International Society of Automation (ISA). ISA-95 provides standards for the development of automated interfaces between enterprise business and manufacturing control systems.The ISA-95 framework is used by manufacturers around the world to develop consistent data models and terminology. The primary goal of the standard is to enable smooth information flow across Enterprise Resource Planning (ERP), Manufacturing Execution System (MES) and Supervisory Control And Data Acquisition (SCADA) systems. ISA-95 supports interoperability in all industries and to every type of manufacturing process.

ISA-95 provides the concept of modular segments to define any manufacturing task. Where process designers can link several segments into an operation and perform, track, and schedule more complicated tasks. New generations of IIoT solutions and devices are coming to market and playing a larger role in factory operations. Device evolution is expected to flatten the structure of the ISA-95 model further.

IEC 61512: Good note to be taken is the IEC61512 which is commonly referred to as ISA-88 (IEC-61512-1) addressing batch process control with the description on equipment and procedures.

IEC 62890:As explained in the reference structure, IEC 62890 represents life-cycle management for the systems and products used in industrial process measurement, control and automation

1.5 Application areas

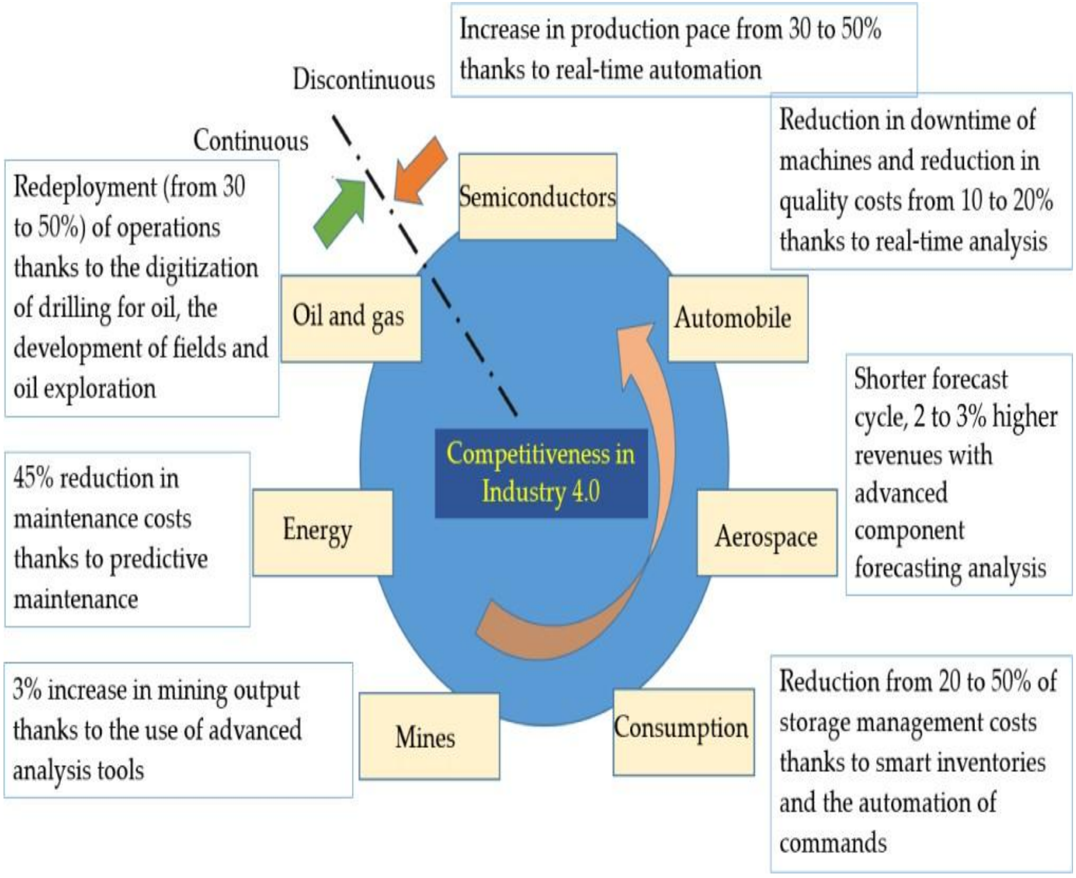


Fig. 1.5. Areas of application (outside services) and value creation in Industry 4.0

For McKinsey (2017), the main application areas in Industry 4.0 are shown in Figure 1.4. All areas of material production are and will be affected because digitization allows gains in productivity, immediacy and quality. The target areas, from McKinsey (2016), are shown in Figure 1.5.Nevertheless, according to Allianz (2018), this situation, because of AI,certainly promising, would not only have advantages.

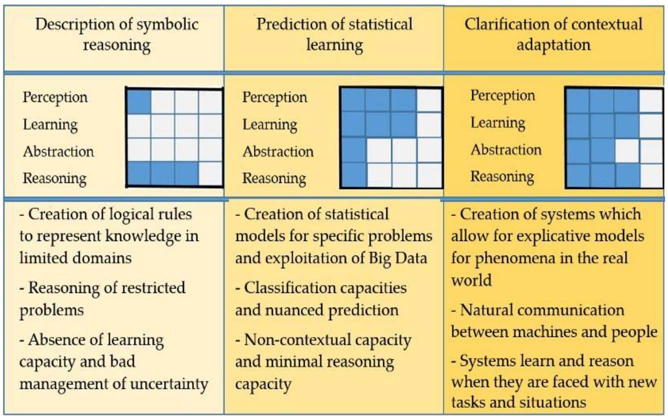
1.6 Dissemination of Industry 4.0 and the disciplines that contribute to its development

From a historical point of view, what we see is that each time one technological mode supplants another, older one. It spreads like a natural water network in most of the possible niches, as shown in Figure 1.6 (André 2006), to such an extent that it becomes increasingly difficult to find (or maintain) devices based on older models (see examples of recordings, now all digital). The increasing complexity of the industrial system cannot (or can no longer) be managed from a centralized organizational structure. Thus, decision making must be increasingly decentralized with, on the basis of available information, operators and/or equipment using AI as the main actor. With this obvious diversity, the scope of possibilities does not allow us, apart from very general aspects, to define a robust line of targeted actions. Nevertheless, spontaneous and/or stimulated actions have been implemented in companies for several years. It is a global and diffuse reality that is developed by self-reinforcement, whenever possible with an empowering effect, whatever the technical field concerned (Gabor 1972; Château 1994; Ellul 2004). The latter author considers that digital technologies ensure the closure of the technological system with an unequalled and omnipresent power, but, at the same time, the diffusion of a paradigm from nodes and digital networks can lead, as with GAFAM, to the presence of a dominant actor in the integrated system. Some will become (or are already) “more equal than others”...

For a long time, since the beginning of industrialization, we have been satisfied with a modest degree of automation, but without any particular margin of indeterminacy; this has been perceived in industrial concepts 1.0 to 3.0, each of these technological eras having their coherence and increasingly high degrees of automation. Simondon (2012) reminds us of its importance: “The machine, a work of organization and information, is like life and with life, which is opposed to disorder, to the leveling of all things tending to deprive the universe of powers of change”. Before the 19th Century, the craftsman, who trained “on the job”, in the working place, for many years, was the owner of the technique (see the French Encyclopedia of Diderot and D’alembert in the 18th Century), and then the tools were entrusted to the machines and in line work, the operator significantly lost their eminent role. In Industry 4.0, to put it simply, they would be at best the robot’s servant if they are not able to be a creative participant in the production system.

1.7. Artificial intelligence

Artificial intelligence (AI) is a wide-ranging branch of computer science concerned with building smart machines capable of performing tasks that typically require human intelligence.



Description of symbolic reasoning	Prediction of statistical learning	Clarification of contextual adaptation
Perception 🟦⬜⬜⬜ Learning ⬜⬜⬜⬜ Abstraction ⬜⬜⬜⬜ Reasoning 🟦🟦🟦⬜	Perception 🟦🟦🟦⬜ Learning 🟦🟦🟦⬜ Abstraction 🟦⬜⬜⬜ Reasoning 🟦⬜⬜⬜	Perception 🟦🟦🟦⬜ Learning 🟦🟦🟦⬜ Abstraction 🟦🟦⬜⬜ Reasoning 🟦🟦🟦⬜
- Creation of logical rules to represent knowledge in limited domains - Reasoning of restricted problems - Absence of learning capacity and bad management of uncertainty	- Creation of statistical models for specific problems and exploitation of Big Data - Classification capacities and nuanced prediction - Non-contextual capacity and minimal reasoning capacity	- Creation of systems which allow for explicative models for phenomena in the real world - Natural communication between machines and people - Systems learn and reason when they are faced with new tasks and situations

Figure 1.6. ***The three waves of AI.***

1.7.1 Emergence of AI:

Three waves

- the first began in the 1950s and concerned symbolic reasoning, such as the generation of evidence of all theorems in the *Principia Mathematica*;
- the second concerns statistical learning, which involves the development of models to learn from real data.
- The third is called the wave of explainable or contextual adaptation, in which it is tempting to combine perception and sophisticated reasoning with abstraction, in order to become closer to what is understood in human intelligence.

In addition, a set of supporting technologies has emerged over the past decade and, in some cases, continues to develop rapidly. These include, in particular:

– cloud computing;

– human–phone portable interfaces;

– advanced sensors for a wide range of applications and measurements (including so-called “smart” sensors);

– augmented reality (AR), virtual reality (RV), mixed reality, etc.;

– AI and learning via digital machines;

– massive digital data (Big Data) and advanced data analysis;

– wireless connectivity (LTE and 5G), allowing M2M (“machine to machine”) communication;

– advanced materials and nanomaterials (including so-called smartmaterials).

Two visions of AI exist,

one capable of manipulating symbols and creating knowledge,

and the other aimed at approaching what is understood about the operation of the human brain by connecting a network of agents, inspired by the neural network system. This form of AI is used for complex tasks, in decision support or for data interpretation. AI tends to complicate its modes of representation (semiotics, logic, mathematics, etc.) and movesto a distributed mode of operation for problem solving.

1.7.2.Neural networks:

These are highly processors operating in parallel: each processor calculates a single output based on the ir
Learning models in neural networks consist of several layers of electronic neurons. The neurons of a laye
previous layers and sending a new learning to the next layer, up to the final layer, which produces the f
example, determining the category of an image, such as face recognition.

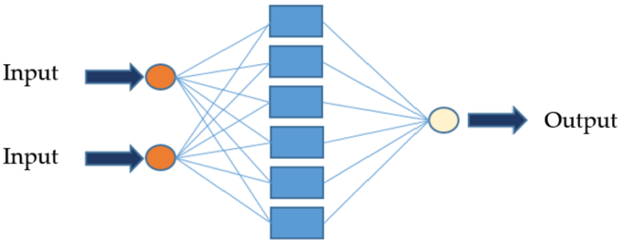


Figure 1.7. ***Artificial neural network.***

It is possible to use algorithms that improve their abilities by comparing them with reality through a learning process, comparing their results to those sought and then trying to get as close to them as possible. These networks exploit several layers of interconnected cells with the mission of artificially representing learning by the human brain. Unlike other parametric algorithms such as linear regression, they allow very complex and nonlinear models to be easily constructed. It is from this principle that they can enable recognition To produce such a system, it must be taught the connection weights by trying to minimize the prediction error through a training game based on an iterative process with feedback (see Figure 1.12) with several layers of neurons (see Figure 1.13). After each observation, it is possible to adjust the connection weights to reduce the prediction error.

"It is common to separate AI into two forms: "strong" and "weak". The first would be able to perform the same cognitive functions as a human being . Weak or restricted forms of AI focus on specific tasks, following given rules. In this way, they can achieve a degree of perfection for a unique task that would never be possible for a human being" Thus, the concept of strong AI refers to a system that can produce smart behavior, giving the impression of self-awareness and an understanding of one's own reasoning (self-learning). The notion of weak AI is an engineering approach to the construction of autonomous systems, algorithms capable of solving problems. So the machine simulates intelligence and it seems to act as if it were intelligent.

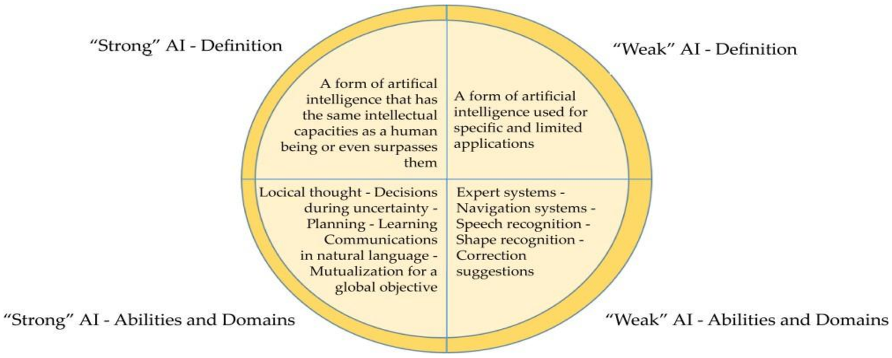


Figure 1.8. Artificial intelligence "strong" and "weak".

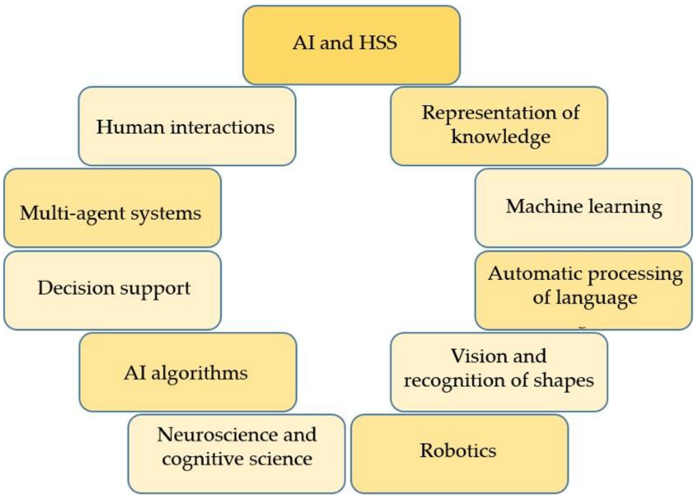


Figure 1.9. Areas of AI intervention

1.7.3. Current limitations of AI

Business leaders, sometimes poorly informed, have difficulty knowing in which areas AI can accelerate their productivity and income growth and in which other areas it cannot create value. For McKinsey (2018a), the limits are as follows:

data categorization: current AI models are generally developed through "supervised learning" with data categorized (labeling) and classified foroptimal use in the execution of tasks. The McKinsey report (2018) notes that in some cases, categorization efforts may require considerable human resources while presenting risks of error or inaccuracy;

– the availability of massive training data sets: deep learning requires datathat are well categorized, but also large enough and comprehensive enough for these models to ensure accuracy in filing tasks. We are talking about millions of data records to get closer to the “functioning” of human beings (e.g. the autonomous vehicle);

– the problem of explicability or the possibility of explaining in human terms why a certain decision was made, especially when it occurs in real time;

– generalization of learning: AI models, unlike humans, have difficulty transferring their experiences from one application context to another. As a result, today, companies must invest heavily to develop an AI model that is applicable to their specific needs, even when use cases are close.

1.8 The Internet of Things

The **Internet of Things** (**IoT**) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.

History of IoT

- 1999- The term "Internet of Things" was used by Kevin Ashton during his work at P&G which became widely accepted
- 2004 - The term was mentioned in famous publications like the Guardian, Boston Globe, and Scientific American
- 2005-UN's International Telecommunications Union (ITU) published its first report on this topic.
- 2008- The Internet of Things was born
- 2011- Gartner, the market research company, include "The Internet of Things" technology in their research

How IoT works?

- 1) Sensors/Devices
- 2) Connectivity
- 3) Data Processing
- 4)User Interface
- Sensors or devices are a key component that helps you to collect live data from the surrounding environment.

Figure 1.10. ***Components of IoT***

- All this data may have various levels of complexities.
- It could be a simple temperature monitoring sensor, or it may be in the form
- The sensors should be connected to the cloud using various mediums of communications.
- These communication mediums include mobile or satellite networks, Bluetooth, WI-FI, WAN, etc.
- Once that data is collected, and it gets to the cloud, the software performs processing on the gathered data.
- This process can be just checking the temperature, reading on devices like AC or heaters.
- However, it can sometimes also be very complex like identifying objects, using computer vision on videoThe information needs to be available to the end-user in some way which can be achieved by triggering alarms on their phones or sending them notification through email or text message.
- The user sometimes might need an interface which actively checks their IoT system.
- For example, the user has a camera installed in his home. He wants to access video recording and all the feeds with the help of a web server.
- A lightbulb that can be switched on using a smartphone app is an IoT device, as is a motion sensor or a smart thermostat in your office or a connected streetlight.
- An IoT device could be as fluffy as a child's toy or as serious as a driverless truck.

Some larger objects may themselves be filled with many smaller IoT components, such as a jet engine that's now filled with thousands of sensors collecting and transmitting data back to make sure it is operating efficientlyThe applications of the Internet of Things (IoT), that is, the exchange of information between real-world devices and the Internet, seem virtually unlimited. This technology can be found in waste management , smart city design, emergency services and environmental sustainability, among many other areas.

Challenges of Internet of Things

- Insufficient testing and updating
- Concern regarding data security and privacy
- Software complexity
- Data volumes and interpretation
- Integration with AI and automation
- Devices require a constant power supply which is difficult
- Interaction and short-range communication

The industrial IoT, a concept that is more than 15 years old, will change the way in which automated systems work by linking machines together (M2M). “For the required international standards to come into force and for the IoT to reach its full potential, an additional 15 years may still be needed”. Current IoT solutions use information capture systems (sensors) that are instead added and linked to existing production systems, preferably to completely rework the processes, which allows for controllable incrementation and perhaps the impression of better security, because the process is incremental. In any case, the measured approach is a way to really engage in the IoT process. Figure 1.19 shows the role of the IoT in the Industry 4.0 system The IoT covers an ultra-connected environment, with capabilities and services that allow interaction with and between physical objects and their virtual representation.

1.9 Additive manufacturing

3D printing is now considered as one of the digital technologies that can profoundly transform production methods and, consequently, current economic models. With growth rates of over 20%, 3D printing is growing at an almost exponential rate and now has its place in many industries. Originally , in the 1980s, when the constituent elements of the 3D process were developed,

French and American pioneers produced proofs of concept demonstrating the potentialities of assembly by adding material from “rustic” processes (processes that persist, but with many refinements in terms of processes, materials, design, etc.).

Thus, the production of objects without machine tools (the ones that remove material) is developing more and more from so-called “additive manufacturing” processes.

The addition of a second layer, then a third layer, and so on, made it possible to create the prototype part in the same way as a mason builds a wall. This base still serves as the foundational concept for additive manufacturing technologies.

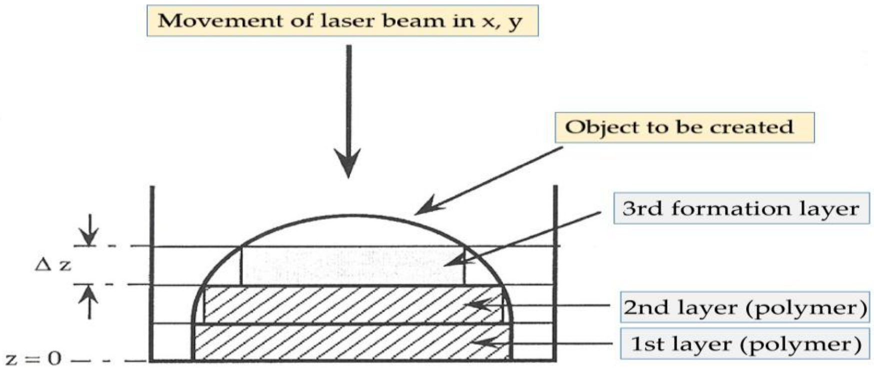


Figure 1.11. ***Historical diagram of the principle of making an object layer by layer***.

Additive manufacturing is part of the Industry 4.0 concept and is based on various skills from the other constituent domains.

One of the strengths of additive manufacturing devices, outside the considerable scope of the personal initiatives allowed by this technology, is that what was expensive in traditional processes (machining, for example) becomes almost free. According to Anderson (2012), the arguments are as follows:

– “variety is free”: because of computer technology, it is possible to easily produce different unique pieces or to integrate them into mass production;

– “complexity is free”: it is the set of 2D displacements that defines the time required to produce a part in a laser scanning process, it is even shorter if irradiation is carried out through a mask; it is even less so if the installation of layers can be eliminated (André *et al*. 2016/2017), etc.;

– “flexibility is free”: great ability of IT to modify one or more parameters without the machine itself being modified.

1.10 Robotization and automation

Automation is the process of using physical machines, computer software, and other technologies to perform tasks that are usually done by humans. Basically, traditional automation is the process of performing a repetitive task without human intervention, all by using physical machines, computer software, and other technologies. You'll find traditional automation in a ton of product workflows in different businesses, and it can be very simple or very complex depending on the need. Traditional automation will typically involve application integration, specifically at a database level or at the infrastructure level. Automation software can take quite some time to implement, up to months.

To paint a better picture of how automation works, let's look at an example. Let's say you run a startup that produces an application for businesses. Because of the nature of your product, you need customer support to be available around the clock. This isn't feasible, however, because your business does not have that kind of funding. This is where automation comes in via chatbots. Chatbot software can be integrated into one's website and mimic real human beings, all while accessing your platform's knowledge base to provide answers to customer questions.

The Benefits of Using Automation

There are many benefits to using automation, including:

- Improved reliability in terms of ensuring that each task is performed exactly the same way.
- Consistency with your clientele. For example: You can automate your follow-up process after a customer engages with customer support, ensuring that they know the business cares about them.
- Time saved by rerouting manual, tedious tasks.
- Improved metric visibility.
- Improved operational efficiency.
- Improved competitive advantage.
- Money saved on accidents that were caused by human error, as well as overall reduced cost.
- Significantly reduced turnaround times on projects.
- Reduces the need for paper documents.
- Improved employee time utilization.
- Easier to define your business processes.
- Make better projections for your business.
- Open the door for more business opportunities by configuring and supporting assets that you couldn't focus on with human-only resources.

Robotization

Robotics is the process of designing, creating and using robots to perform a certain task. Robotization, which we can refer to as Robotic Process Automation (RPA), is an application governed by business logic with the aim of automating business processes. RPA tools can make it possible for businesses to configure software to robots in order to interpret applications for processing things like transactions, data, triggered responses, and general communication with other integrated systems.

There are many examples of robotization out there today. Common RPA scenarios can involve from simple automation response generation to an email, all the way to deploying a significant amount of bots that are programmed to automate jobs via an enterprise resource planning system. Commonly, you’ll see RPA used for call center operations, data migration and entry, forms processing, claims administration, onboarding employees, help desk services, sales process support, scheduling systems, and expense management,

Nora Schlesinger, COO of Growth Machine, noted the value of RPA in a writeup for Growth Machine. “When you do the same task over and over again, you risk leaving out information or even explaining something in a confusing way,” said Schlesinger, “Automating these kinds of tasks decreases the potential for human error.”

This is very true for both traditional automation and RPA, but RPA can take on this responsibility in a more independent, non-intrusive way.

Automation originated in the 1950s, when the computer was introduced into industry, but it saw a real development in factories in the 1960s when it was possible to integrate computers (of low digital power in the era of perforated cards) into the production process inside the manufacturing workshops, with the result that organizations were affected by new mass production technologies. Figure 1.28 reminds us of the processes, which are much less elaborate than the neural networks, involved in now classic approaches in automation, using feedback principles. But as long as the system remains stable, the feedback is fully operational. However, as soon as it evolves over time (process, input or output functions), the initial rules are no longer valid and new optimization criteria should be introduced into the regulated system, as shown in Figure 1.28.

There are many benefits to using RPA, including:

- It’s non-intrusive, as many RPA bots stay at the front-end of the system without having to interact with the back-end.
- It can work across multiple application types
- RPA bots can take action fairly quickly, as it is designed to mimic agents.
- Scalability is easily achieved.
- System integration is simple.
- Non-technical people can use RPA, as there is no code to learn.
- Improved commercial outcomes.
- Reduced costs and human-error operational risks.
- Employee engagement is improved with significantly improved customer experience.
- It’s flexible, simple, and fast to implement.
- Most RPA tools provide analytics and insights into how tasks are being reported and organized.
- Service becomes much faster when it comes to handling queries of users.
- Governance arrangements are very well-defined.
- New IT infrastructures is not required, as RPA tools do not need to be adopted in this way.

What is the Difference Between Automation and Robotization?

Traditional automation can takes months to properly implement, while RPA can be implemented very quickly. RPA also does not require application integration, and instead utilizes the graphical user interface (GUI) to perform its programmed tasks across various systems. Traditional automation integration can also take a very long time to complete.

RPA could also be considered a "quick fix." Since it can be implemented in mere weeks, it's a fast solution that traditional automation cannot provide. Just as well, RPA can also be used as a short-term solution while a traditional automation project is being implemented. However, traditional automation tools are rarely implemented as short-term solutions, as they take so long to implement.

RPA is also the superior choice when it comes to providing personalized engagements or tasks that are complex or difficult to execute across multiple applications. Because RPA can access multiple applications with ease, it's ideal for this use case when compared to traditional automation.

How are Automation and Robotization Similar?

Today's businesses want to make processes more efficient, allocate their workforce for decision-making and non-tedious tasks, and minimize errors and faults that typically come from people. RPA and traditional automation do all of this, although through different means. Traditional automation and RPA are similar in that they are both types of automation. Just as well, both are excellent tools to use to reduce overhead costs and to lessen operational risks.

Will RPA Cause the End of Traditional Automation?

In short-- not at all. You don't need to use beefy technology if the technology you have now is good enough. Traditional automation works for many businesses, while others struggle with its integration and choose to opt for RPA.

"Automation is good, so long as you know exactly where to put the machine," BM guru Eliyahu Goldratt once said.

According to Lorre, the added value of automation processes can be described in several items, with some problems such as:

– reduction of production costs with a quick return on investment;
– optimization of the manufacturing cycle by robots that increase production rates;
– quality improvement with specific tasks performed on the productionline;
– saving space making the process flow more efficient;
– waste reduction with robots that can save raw material;
– fewer specialized operators (Blandin 2017) working near productionline robots;
– a set of techniques that appear to carry a tangle of interdependent systems (interdependencies) with risks of degraded modes and failures;
– the reduction of production times and costs with a more attractive price-quality ratio.

1.11 Current situation of Industry 4.0

The headlong rush
What if things go slower than expected
A war between different AIs
And other areas of Industry 4.0
Difficult promises to keep

1.12 Introduction to Industry 4.0 to Industry 5.0 Advances

Less than a decade has passed since talk of Industry 4.0 first surfaced in manufacturing circles, yet visionaries are already forecasting the next revolution — Industry 5.0. If the current revolution emphasizes the transformation of factories into IoT-enabled smart facilities that utilize cognitive computing and interconnect via cloud servers, Industry 5.0 is set to focus on the return of human hands and minds into the industrial framework.

Industry 5.0 is the revolution in which man and machine reconcile and find ways to work together to improve the means and efficiency of production. Funny enough, the fifth revolution could already be underway among the companies that are just now adopting the principles of Industry 4.0. Even when manufacturers start using advanced technologies, they are not instantly firing vast swaths of their workforce and becoming entirely computerized.

The cost of a new product can be determined with the help of costing software for manufacturing industry. It automates the costing processes and accelerates the time to market on new products.

Overall, the development of Industry 5.0 could prove to be the full realization of what the architects of Industry 4.0 had only dreamed of at the dawn of the 2010s. As artificial intelligence improves and factory robots assume more human-like capabilities, the interaction between computers, robots and human workers will ultimately become more meaningful and mutually enlightening.

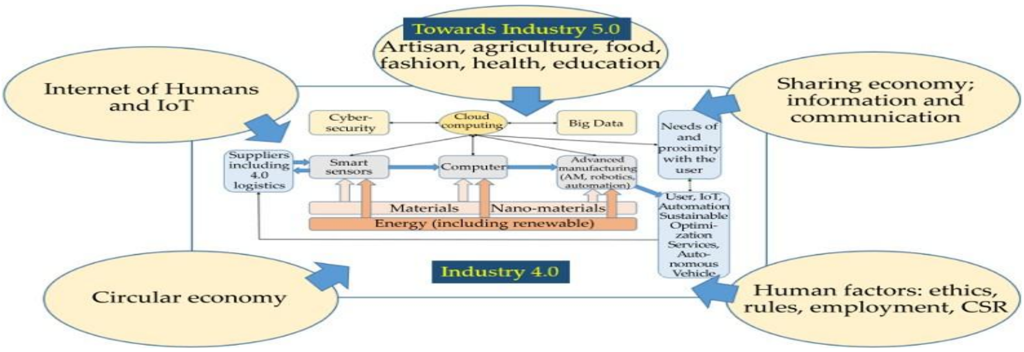


Fig 1. 12. Toward Industry 5.0

Part A

1. Define Industry 4.0
2. State the pillars of Industry 4.0
3. What is the difference between Robotization and automation
4. List any four application area of Industry 4.0
5. What is the current situation of Industry 4.0

Part B

1. Discuss the general frame work of Industry 4.0
2. What are technological pillars of Industry 4.0 Discuss in detail.

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2.1 INTRODUCTION

A Cyber Physical System (CPS) is a mechanism controlled or monitored by computer-based algorithms, tightly integrated with internet and its users. It is an engineered system that are build from, and depend upon, the seamless integration of computational algorithms and physical components.

In general Cyber means computation, communication, and control that are discrete and logical. Physical means natural and human-made systems governed by the laws of physics and operating in continuous time. Computing and communication systems bridges with the physical world are referred to as Cyber Physical Systems.

CPS are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core.

Examples of CPS include medical devices and systems, aerospace systems, transportation vehicles and intelligent highways, defense system, robotics system, process control, factory automation, building and environmental control and smart spaces.

CPS must interacts with the real world with proper security, safely and efficiently.

The term "Cyber Physical Systems" emerged around 2006, when it was coined by Helen Gill at the National Science Foundation in the United States. During World War II, Wiener pioneered technology for the automatic aiming and firing of anti-aircraft guns.

Although the mechanisms he used did not involve digital computers, his control logic was effectively a computation, albeit one carried out with analog circuits and mechanical parts. Today, people are aiming to give an IoT backbone to CPS. This thought has emerged as a necessity driven concept. People imagined having automated cars which will have very less accident rates than human driven cars. The future road networks may also be connected with internet and therefore may reduce traffic congestion. These ideas for a better life gave birth to CPS.

In today's context, CPS are emerging from the integration of embedded computing devices, smart objects, people and physical environments, which are normally tied by a communication infrastructure. These include systems like Smart Cities, Smart Grids, Smart Factories, Smart Buildings, Smart Houses and Smart Cars where every object is connected to every other object.

They are aimed to provide an adaptive, resilient, efficient and cost effective scenario. Let us imagine the case where a road-accident patient is rushed to a hospital only to be asked to go to a police station first. If these systems are interconnected, then there will be very less chances of delay in the treatment. However, these objects should have a valid relationship in physical world too. For example, a traffic light can in no way be linked to a microwave. Connecting these two may overburden the data store as well as the network. So, we need a thoughtful connection between the objects in a CPS. CPS is like a reality to virtual mapping where the real physical world is linked to the virtual world of information processing through some sensors and actuators. The sensors are continuously spewing real time data. CPS is therefore a massive generator of data and needs real time processing.

These big words may sound like the futuristic wave of talking refrigerators and self-driving taxis. But, it means much more than that. CPS or anything related to smart objects is about devices, data and connectivity. Data – big and small – is the front and the center in the world of connected devices. The CPS as a whole along with its individual components and devices at its backbone will generate huge volumes of real time data. Storing these data for analytics may not always be feasible and immediately analyzing them will also be too difficult. Traditional analysis tools are not well suited to capture the complete essence of this massive data. The volume, velocity and variety is too large for comprehensive analysis and the range of potential correlations and relationships between disparate data sources are too great for any analyst to test all hypotheses and derive all the value buried in the data.

A good machine learning systems in order to deal such Data require

(i) data preparation capabilities

(ii) algorithms – basic and advanced

(iii) automation and iterative processes

(iv) scalability

(v) ensemble modeling and

(vi) real-time decision making.

This means we want the system to make all the decisions for us and take necessary actions quickly. For example, we want a smart hospital system to immediately send necessary information to a smart police station in case of road-accident. Machine learning algorithms already has some good capability of letting computers do the heavy thinking for us. But, we are striving for more to deal with large volumes of such data in a short time.

To capture such large scale concept, we will need millions of data generating smart objects. These will act like the building blocks of such a big network. Smart Objects (SOs) are Digital Entities (DEs), augmented with sensing, local processing, storing and networking capabilities. SOs may act as intelligent agents with some level of autonomy, cooperate with other agents and exchange information with human users and other computing devices within the CPS. DEs can be viewed as users in the context. A Physical Entity (PE) can be represented in the digital world by a Digital Entity which is in fact its Digital Proxy. There are many kinds of digital representations of PEs that we can imagine: 3D models, avatars, objects or instances; even a social network account could be viewed as such.

The combination of IoT technologies and Data Science and predictive technologies in any organization may at first seem like a “egg-chicken” dilemma. Those which do not have the infrastructure of IoT may have sophisticated algorithms for data analytics. For other companies who have adopted IoT technologies with the ultimate goal of optimizing physical processes (CPS) or providing predictive analytic solutions still have an opportunity to use data and analytics to advance their business. In some industries like fleet management, the useful life of the data may be too short to justify keeping it. In others, like broadcasting, files may be too large to store for long periods. Microsoft research has found that about 23 percent of enterprises use data for basic reporting functions – and that seems to be a good start for the optimists. Keeping data on hand leaves room for more sophisticated analytics later, as business needs and capabilities grow. Typically, the progression of data analysis mirrors the same evolution we see from our IoT customers, from reactive to proactive and ultimately to predictive analytics using machine learning.

The Cyber Physical System consists of cyber components and physical components, so we call it as cyber physical system. CPS is based on an information processing computer system, which is embedded into a product, like a car, plane or other device. These computer systems are used to perform specific tasks.

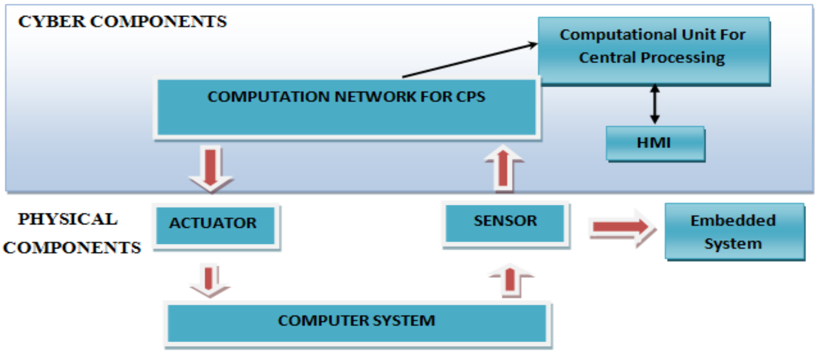

Fig. 2.1 General block diagram of Cyber Physical system

For Example, in a car an embedded system would be the ABS (Anti-lock / Anti-Skid Braking System) to control break force. This computer system interacts with the physical environment by means of Sensors and Actuators. These embedded systems are no longer standalone, they share their data via communication networks such as the internet with cloud computing where data from many embedded systems can be collected and processed. There by creating a system of systems. Connected embedded systems can be controlled and decentralized by a computational unit. The collected data can be processed automatically or by Human Machine Interface (HMI). IoT is a technology, in which devices are connected through the internet and enables the remote collection of real time information which can them be processed or shared with other devices.

The growth of information and communication technologies (ICT) in the industrial growth results in Industry 4.0 with cyber-physical systems (CPS). The major factors influencing Industry 4.0 are interpretability, information transparency, and decentralized decisions.
1. Interpretability: The capability of physical systems and humans to connect and communicate with each other through communication protocols.
2. Information transparency: The capability of cyber systems to build a cybernetic copy of the physical system (cyber twin) with the enhancement of sensor data. The information requires for processing from sensor data to higher context data.
3. Technical assistance: Two phases of technical assistance exists in Industry 4.0:
    a. Initially, the capability of a system to support humans by comprehensively collecting the data for decision-making and rigorous fault clearance in the physical systems.

    b. Then the ability of the system is analyzed by creating faults in cyber-physical systems to identify the human interaction.

4. Decentralized decisions: CPS has the ability to make a verdict autonomously and on its own. In case of exceptions, conflicts or interferences, the tasks are decided at higher level.

The definition of cyber-physical systems (CPS) is the integration of physical process with embedded computation, controller, and network monitoring along with the feedback loop from physical systems. In other words CPS is given by 3C's,

- Computations
- Communications
- Control

The advantages of implementing CPS to the physical device are:

1. Interaction between human and systems: For decision-making, the observing changes in physical device and fixing the boundary level is critical. CPS is required to analyze such complex systems. CPS has a two-way communication between the target and users (man to machine and vice versa).
2. Better system performance: CPS has the capability to provide dynamic response by feedback and reconfiguration for the sensor data and cyber infrastructure. CPS ensures the better computation of data with multiple sensors and communication devices.

3. Faster response time: Due to presence of fast communication capability of sensors and cyber infrastructure, it enables the dynamic control of physical device for proper utilization of collected resources from the physical device.
4. Uncertainty: It enables the promising behavior due to high degree of inter connectivity for a large-scale CPS coupling.
5. Scalability: CPS has scalability properties based on demand, and users can acquire additional infrastructure with existing cloud computing. It combines physical dynamics of the target with computational models. The communication infrastructure with software model is combined in cyber domain. The sensor data with electrical, mechanical, biological, and human comprise the physical domain.
6. Certainty: It ensures the CPS design is valid and trustworthy. CPS has the capability of validating the system behavior of an unknown system.
7. Capability: CPS allows the user to add the additional capabilities to the complex physical system.
8. Computing and communication with physical processes: CPS has an efficient and safest computing and communication system that reduces the need of a separate operating system for CPS.

CPS’s are powered by two types of computing system:

(i) Notebooks, Desktop servers and PCs. Computers at every desk to do business activities
(ii) Embedded Computing - Transformation of Industry and Invisible part of Environment.

The main characteristics of CPS are:

(i) Intelligence - Adaptive and Robustness
(ii) Network – Communication, Cooperation and Cloud solutions
(iii)Functionality
(iv) User friendly.

2.2 Architecture of CPS

The architecture of cyber-physical systems should be universal and/or an integration of models such as

1. Ambient intelligence: The embedded system is sensitive and responsive to the physical systems. In the cyber-physical environment, the physical devices, sensors, and actuators work together with humans (man to machine and vice versa) using communication protocol.
2. Semantic control laws: Control law should work as occurrence– state–exploit-type law, and it practices the core of CPS control unit.

3. Networking techniques: Wired/wireless networks with secured connection to protect system from cyber-attacks.
4. Event driven: The data from the sensors are recorded as events and actions are carried out by actuators. The data are the abstraction of physical device collected by the CPS units
5. Quantified confidence: The data from the sensors of physical device hold the raw data for processing.
6. Confidence: The data/information should be confidential and protected from cyber-attacks.
7. Digital signature and authentication code: The data/information from the CPS should be authenticated by the publisher.
8. Criticalness: This specifies the critical perseverance of each event/ information from the sensor data from physical device.

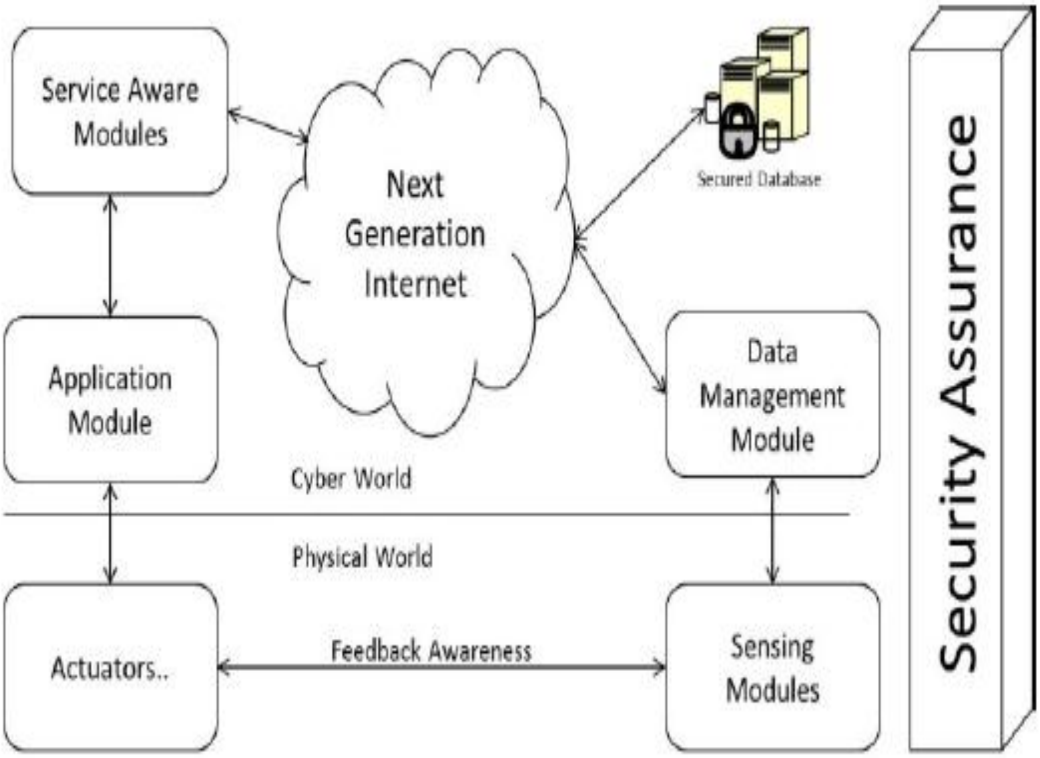

Fig 2.2 General architecture of CPS

2.2.1 Sensing Module: For data collection from physical world through sensors, the main function of this module works for environment awareness which is achieved by preliminary data preprocessing. The data is provided to the Data Management Module (DMM). The Sensing module supports multiple networks. It depends on nature of networks that is deployed. For example, in a WSN, each sensor node is equipped with a sensing module for real time sensing. Other network nodes can also operate with a part of this module in different scenarios. In case of VCPS, VANETS nodes (i.e. cars) can be equipped with sensing module to sense data from physical world. In case of HCPS, using BAN, sensors attached with patients are equipped with sensing modules nodes to enable real time control.

2.2.2 Data Management Module (DMM):DMM consists of the computational devices and storage media. This provides the heterogeneous data processing such as normalization, noise reduction, data storage and other similar functions. DMM is considered as the bridge between dynamic environment and services as it is collecting the sensed data from sensors and forwards the data to service aware modules using Next Generation Internet.

2.2.3Next Generation Internet :A common feature of emerging Next Generation Internet is the ability for applications to select the path, or paths that their packets take between the source and destination. This dynamic nature of internet service is required for designing Cyber Physical System. Unlike the current Internet architecture where routing protocols find a single (the best) path between a source and destination, future Internet routing protocols will need to present applications with a choice of paths. For achieving this, research is still pending to find QoS routing. While QoS routing provides applications with a path that better meets the application’s needs, it does not scale to the size of the current Internet, let alone the Next Generation Internet. IPv6 and exploiting 802.16n and 802.16p are ongoing projects and expected to be included in Next Generation Internet services trial.

2.2.4 Service Aware Modules (SAM): Service Aware Module (SAM) provides the typical functions of the whole system, including the decision-making, task analysis, task schedule and so on. After receiving sensed data, this module recognizes and sends data to the services available.

2.2.5 Application Module (AM): In Application Module, a number of services are deployed and interact with NGI. Simultaneously, information is getting saved on secured database for QoS support. Database is maintained at local storage and on cloud platforms at the same time in order to keep data safe. We can use a concept of NoSQL for saving data [13]. Although the NoSQL systems have a variety of different features, there are some common ones. First, many NoSQL systems manage data that is distributed across multiple sites. This saved data over cloud system can be accessed from anywhere followed by authenticated access.

2.2.6 Sensors and Actuators: Actuators and the Sensing Modules are two different electronic devices which interact with the physical environment [5]; the actuator may be a physical device, a car, a lamp or watering pump. It receives the commands from the Application Module, and executes. The security assurance part is inherently important in a whole system, from the access security, data security to device security. We divide CPS security into different requirements in different scenarios. For example, as for military applications, the confidentiality feature is more important, but in the smart home system or

HCPS, the real-time requirements are more emphasized. Security of CPS can be divided into the following three phases: awareness security, which is to ensure the security and accuracy of the information collected from physical environment; transport security, which is to prevent the data from being destroyed during the transmission processes; physical security, such as safety procedures in servers or workstations. Feedback Awareness is one of the advanced level services to minimize the data processing by communication between sensor and actuator for executing required actions directly.

2.2.7 Communication Topology in CPS Architecture

we describe the interactions between modules in the proposed CPS architecture. First of all, the sensing module sends an association request to Data Management Module (DMM) and it replies with an acknowledgement packet. Once association between DMM and Sensing module is completed, nodes start sending the sensed data to DMM. Here, noise reduction and data normalization provide the bridge between the cyber world and physical world. Through QoS routing [section 4.1.C], data is transferred to Service Aware Modules using services of Next Generation Internet. Available services are assigned to different applications in Application Module. To ensure the security and integrity of data, during each network operation, data is sent to a cloud platform and also to a local database.

2. 3 Data science and technology for CPS

The development in information and communication technology (ICT) depends upon the future trend and pattern generated by data analytics and its models. The industrial revolution depends on the models and patterns that have been reliably generated by machine learning and artificial intelligence techniques. However, the domain has still been going in advancement with methods in deep learning and analytical tools with mathematical models, since mathematical model plays a significant role in supporting the proof- of-evaluation for the machine learning and deep learning practices that have been deployed for the industrial needs.

Based on the data generated by stream applications, the applicability of the analytical model varies in terms of parameters, platform, model selection, and visual data exploration. This has to be considered as an important phenomenon in CPS because it may lead to some erroneous evaluation with regard to the industrial needs and its applicability.With this consideration, the development of models with regard to CPS can be made specifically with mathematical formulations. The industrial revolution is targeted with a focus on new data models and its applicability to CPS. Meanwhile, the impact and consideration of data analytics play a significant role in prediction and data classification. This chapter explores all the possibilities and framework that can indulge data analytics with CPS in accordance with Industry 4.0 standards.

2.3.1 Data Analytics an Overview

Every day a vast amount of data gets generated which are in various forms and are all help to get valuable information from them. The unprocessed information is in raw format, need to convert it into useful information where the process called analytics. Analytics is nothing but a continuous processing of data with the help of analytics tools or the efficient application of the algorithms and methods to process the data to get information from them. This information helps us to make better and meaningful decisions to meet the business requirements.

Data are generated through our daily process and these data are in various formats. Generally, the data are classified into qualitative and quantitative data. In qualitative data, the quality of the data is gets measured whereas in the quantitative data, the quantity or the number of data matters. The data can also be divided into two forms such as continuous and categorical. In the continuous form, the data follow a sequence order. In the categorical form, the data are further classified into three forms which are nominal, ordinal, and binary. In nominal, the data are not in a meaningful sequence and in the ordinal, data exist in a meaningful order. In the binary, the data can only be in two forms alone. Analytics process starts its process from the raw format which is then moved to the data selection where the needed data are alone selected and moved to the preprocessing step where the data cleaning process takes place. It includes the missing tuples, outliers detection, the removal of duplicate values, and the numeric conversion of data.

After this preprocessing step, the data are transformed into another format. Finally, the interpretation and evaluation process is done, which is the outcome of the analytics process. Interpretation helps to interpret the result of the preprocessed data with the help of the facts, knowledge of the process, and the use of the appropriate methods. It can be applied to both qualitative and quantitative data formats. Evaluation of data is done with the help of various metrics and measuring parameters, which are applied on the data during the process of analytics. Various analytic tools are available to perform the intended function on the data. The tools range from the excel to the advanced big data analytic tool such as Hadoop. Some of the tools are R-programming, Rapid Miner, Tableau Public, SAS, and Splunk.

These tool helps to address the need of analytics in various fields, which also required large amount of data processing to provide the meaningful decision. The current trends of data analytics include a variety of technologies and fields. This analytic process helps to increase the accuracy of the data and also helps to increase the processing power of the data. It consists of Internet of Things (IoT), Machine Learning, Graph Analytics, Artificial Intelligence, and Augmented Reality and Cyber- Physical Systems, etc.

2.3.2 Types of Analytics and Its Applications

Analytic process is of various types which are descriptive analytics, predictive analytics, diagnostic analytics, and prescriptive analytics. Descriptive analytics is the most frequently used process where it performs analytics in a way that is easily understandable to humans and is in detailed described way. This type of analytics also helps to find the wrong things from the previous year’s data, which are very useful for future process. Predictive analytics helps to predict the future data with the help of the current events. This type of prediction is done with the help of the prob- ability of happening the events in the future process. Here, the accuracy of the predicted value depends on the quality and selection of data for the analytic process. Diagnostic analytics is done with the history of the processing data which are used to perform the analytic process.

This process requires a deeper analysis of the data which are further used for the diagnosis of the data. So for this type of analytics, there is a need of detailed information about the processing data for the better processing of data. Prescriptive analytics is generally done to prescribe the solutions and details for the particular problem that the model tries to solve. This analytics helps to provide the better solutions for the raised problems and also make the process more reliable to use and the process called as solution-oriented analytic process. These analytics types are used based on the need and the process is completely applicable to the related problems, which are dependent on the user’s needs. These analytics processes can be applied to a variety of problems and situations. Some of the most frequently used applications are recommendation systems, image and speech recognition, gaming, airplane travel planning, risk and fraud detection, self-care driving, customer interactions, and also in the field of robotics.

2.3.3 Data analytics and processing platforms of cps

Currently, Machines and devices are connected as a collaborative community in Industry 4.0 and play a vital role in industrial production. This encourages a computerized manufacturing in a way to make decentralized decisions. The challenge of cyber-physical system is to bring out more meaningful and intelligent insight and yields optimal decisions from the industry data because such a revolution in an industry will lead to generate a huge amount of data. With the help of big data, CPS will collect, store, and make analytics in a real-time. This will improve the efficiency of industrial production.10

Automated decision making is one of the features of CPS. The CPS has several objects interacting with one another which in turn produce massive amount of data in order to extract the hidden pattern to make optimal deci- sion and to enhance the quality of service. To bring big data environment into CPS, we need a resilient network. Big data processing platforms are varying for different system such as Hadoop for batch processing system, Storm for stream processing system, and cloud computing storage model.

2.3.4 Processing platform for cps

Hadoop is an open-source software framework for storing a massive amount of data and running the application which consists a cluster of commodity hardware. For handling such a quantity of data, it has a core element called Hadoop Distributed File System (HDFS) and MapReduce. This enables a distributed processing of a large amount of data and it can be processed in a reliable, scalable, and fault tolerance.

Apache storm is an open-source that processes real-time streaming data at a very high speed when we compared it with Hadoop. It is also used to create a complex event processing system, which is classified as computing and testing. Cloud computing is highly needed to process and analyze the distributed and enormous quantity of data. The cloud supports reliable architecture to perform analytics for CPS data on a big stream of data such as extraction and aggregation. Cloud computing for CPS big data has a better effect on the real-time needs. The cloud enables us to perform parallel computations on the CPS data items thereby, we can achieve speed. According to the cloud security alliance (CSA), most of the enterprises still not yet move to the cloud due to the security problem.

The design of CPS structure should consist of connectivity which ensures the real-time data streaming and there is a need for data analytics in an intelligent way. The 5C structure proposed by Lee et al.3 that show how to construct a CPS system from data acquisition, such as connection, conversion, cyber, cognition, and configuration level.

Connection: This is responsible for data acquisition and transfer to the central server.

Conversions: This is responsible for discovering meaningful insight. It converts the data to information with the help of intelligent algorithms and data mining techniques.

Cyber: This level consists of more enormous information which is needed to take intelligent decision and acts as a central hub. The flow of data mining and cyber-physical system is depicted in Figure 8.1.

Cognition: This creates knowledge of the monitored system by imple- menting CPS.

Configuration: It is the feedback from cyberspace to physical space. This is responsible for the machine to take self-configuration and self- adaptive by act as a supervisory control.

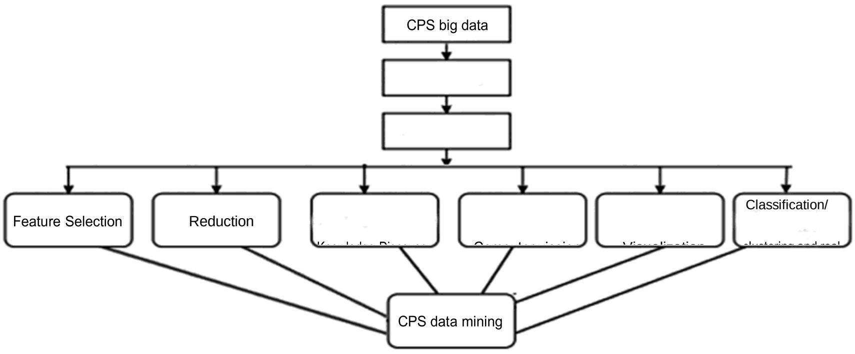

FIG 2.3 Data mining and CPS.

Atat et al.1 presented an overview of data collections, storage, access, processing, and analysis for CPS taxonomy. From Figure 8.1, CPS data mining: Extracting useful information from the CPS data collected from the various sensor or device. Before mining CPS data, we need to apply some processing steps such as features selection, preprocessing, and transformation of data. The reduction is the technique used to reduce the dimensionality of the data this can be done by Principle Component Analysis (PCA). Knowledge discovery is highly used in different CPS scenarios to find out the unknown correlations in CPS data. Classification and Clustering are the two different mining techniques which make the CPS smarter.

Lee et al.2 address the trends of service transformation in big data environment and the smart predictive tools to manage big data. They stated that health awareness analytics of machine with the self-learning Knowledge base. If the health information of a machine is a need then the Knowledge base will generate the necessary information and the predic- tion algorithms. For creating clusters autonomously for different working regimes and machine conditions, an unsupervised algorithm is highly used such as Self-Organizing Map (SOM) and Gaussian Mixture Model (GMM).

Rehman et al.6 have proposed a framework to handle big data for cyber-physical system and this framework considers the possible solution such as standardization, cloud computing, online, and data stream learning to analyze and process a CPS data. Their proposed framework addresses a challenge on big data for CPS such as real-time, infrastructure, data quality, and security.

2.3.5 Machine Learning Techniques In Prediction

Machine learning is a concept comes from artificial intelligent. Without any explicit program or instruction, the computer machine or a comput- erized device will perform a specific task efficiently. This is a study of algorithm and statistical model.

The machine learning algorithms for predictions are:

- Supervised machine learning.
- Unsupervised machine learning.
- Reinforcement machine learning.

2.3.5.1 Supervised Machine Learning

In supervised learning, the machine learns with the help of labeled data for training. There are two types of supervised learning such as Classification and Regression. When the output variable is in the form of real values then regression is used to predict. If the output variable is in the form of categorical then the classification is used to predict.

2.3.5.2 Unsupervised Machine Learning

In unsupervised machine learning, the machine learns without the help of labeled dataset. There are two types of unsupervised learning such as clustering, association and dimensionality reduction.

2.3.5.3 Reinforcement Learning

In reinforcement learning, the software agent plays a vital role to decide the next action based on their current state behavior. This learns by the trial and error method. Sargolzaei et al.5 proposed the neural network for fault detection in vehicular cyber-physical system. The fault detection technique is applied to detect and track fault data injection attacks on the cooperative adaptive cruise control layer of a platoon of connected vehicles in real time. Bezzo et al.4 has proposed a reach ability-based approach and a Bayesian Inverse Reinforcement Learning Techniques to predict a malicious intention in cyber-physical system under cyber-attack. The reachability is used to determine the set of possible states that the CPS may cover over a certain time horizon, because the input may be uncertain due to sensor noise. Then they apply the Inverse Reinforcement Learning in order to identify the intention of the attack.

2.4 Emerging applications in CPS

The application of CPS have the potential to introduce significant changes in information intensive technology sectors such as manufacturing, water distribution systems, transportation, healthcare and smart buildings.

2.4.1. Manufacturing:

In manufacturing environment CPS's are used for self-monitoring the production operations and control. CPS improves manufacturing processes by sharing information between machines, supply chain, suppliers, business systems and customers. Smart manufacturing provides high visibility controls on the supply chain which results in improving the traceability and security of goods. The impact of IoT and CPS in manufacturing industry is significantly growing. Sensors are used to predict equipment wear and diagnose faults. The analytics reduces the maintenance cost and increases operation performance.

2.4.1.1. Manufacturing industries works under a five-level architecture.

Connection- Data is generated by machines, tools and the product
Conversion- Using algorithms it converts the data to information.
Cyber- Processes the information and creates additional value. Cyber level acts a hub (cloud) and performs complex operations. Cyber level runs on sophisticated manufacturing methods, runs deep learning algorithms to identify large data patterns. This level focuses on standalone systems which uses the data from the system to attain additional knowledge.
Cognition- Converts machine signals to information to compare the information with other outcomes. In this level the machine monitors and diagnoses its own failures and become aware of potential problems.
Configuration- a machine can track and detect failures early and sends information to the operation level. Machines can amend their operation depending on workloads or malfunctions.

These measures produce a system in which machines can defend themselves from difficulties by finding alternate solutions and preventing operation failures.

2.4.2. The 5c structure uses different levels of operations:

Component level: Contains virtual twins that exists in cyber space. The twin models the critical components of a machine. It captures the changes in the operations on the cloud. The system would gain self awareness by this mechanism.
Machine Level: Incorporates the information gathered in the component level which is combined with machine operations to create new modules for each machine. Similar Virtual twins are compared with other machines to quantify performance.
Fleet Level: Optimize production processes through the performance of machines and component status from component and machine levels. These level result in self configuring and self maintenance and has the benefit of maximizing the life span of all components, leading to increased production quality.
Enterprise Level: This level incorporates the outcome of previous levels to produce a high-performance production rate.

2.4.3.Water Distribution Systems:

Water Distribution systems are becoming increasingly automated. These systems consist of reservoirs, tanks, pumps, wells and pipes that deliver water to our taps. As well as devices to monitor activity such as sensors to detect the level of overflow of water from a tank or the pressure from the pipe. And programmable Logic Controls which can automatically open valves and supervisory controls and data acquisition systems that monitor controls all the devices in the network. While all these innovations allow the system to run more efficiently and reliably. They also expose the system to potential attacks on the software that controls it. If the hacker can remotely access the components of the CPS, they could do all sorts of damage ranging from stealing data, cutting of water supplies, damaging the equipment or even releasing chemicals used in processing into the system. Hackers can spy on the system with eavesdropping attacks or by initiating deception attacks.

It is difficult to detect the attacks on the system by human oversight and by machine detection algorithms. In order to overcome these attacks two types of tools are used. The first one is an ‘Attack Model’ the other is a ‘Toolbox’. The Attack model describes the different way the hackers might compromise the system and the Toolbox runs on a MATLAB which is widely used engineering computing software. The Toolbox gathers the attack models and automatically runs on Epanet. An Epanet is an industry standardized software modeling tool which describes how water flows through the system. The Epanet utilizes the CPA toolbox to track the actual physical status of the system and the reported cyber status of the system which detects external changes introduced by the hackers.

2.4.4.Smart Greenhouse:

CPS play a vital role in the field of agriculture; it improves productivity and prevents starvation. The system focuses on an adaptive method with several parameters such as temperature, humidity, irrigation and amount of light. This responds to the parametric changes according to specific computer programs which are designed to ensure a better growth. Further it reports feedback continuously to the users to keep them informed about the condition of the greenhouse. Feedback can be managed easily by remote locations using network service. The design consist of sensors which act as a station sensor which includes temperature, humidity, soil moisture and light sensors and it adds other sensors like temperature and humidity control system in which the fan, sprinklers and other devices can be used for increasing and decreasing the temperature.

Benefits:

- It saves the farmers money, time and effort
- Provides better environment and increases in productivity
- The amount of water needed is controlled and supplied automatically

2.4.5.Health Care:

Most of medical systems use cyber physical systems, they use real time monitoring and remote sensing of physical conditions of the patients. This leads to improved treatments for disabled and elderly patients and limits patient hospitalization. In future these systems will be combined into a network closed loop system incorporating a human loop to improve the safety and workflows.

2.4.6.Transportation:

Vehicles can communicate with each other by sharing real time information such as traffic, locations and issues to prevent from accident and improve safety. Vehicles function will be executed in a distributrd manner by enhancing performance and emission reduction. For example, the branking system not only stops the car also it avoids a potential collision.

2.4.7.Buildings:

CPS enabled buildings are called “smart buildings”. The function significantly improves energy efficiency and decreases energy consumption and greenhouse gas emissions. A network is used to sense the temperature, humidity and operate actuators (HVAC, fans, water heater) is embedded into the building to detect changes in the environment.

2.4.8.Claytronics:

Claytronics – a technology to create virtual reality with which human interaction is possible. IT combines nano scale robots and computer theory to make nanometer-scale systems called claytronic atoms / catoms. These catoms can interact with others to make 3D structures. The goal of claytroics is to create dynamic motion in three dimensional objects. Two types of algorithms are being used in Claytronics, shape sculpting and localization. The collective actuation and hierarchal planning require shape sculpting algorithms by which it converts the catoms into the desired structure and dimension. The localization algorithm enables the positioning of catoms in the ensemble.

2.5 Domain applications of CPS in health care unit

To explain the working of cyber physical systems, we use the example of the healthcare domain. The Medical CPS (MCPS) can collect and process data from the clinical and wearable sensors worn by the patients. The biosensors have the potential to sense the critical physiological parameters of the patient and send them to the computing and analytics unit for further processing. There are multiple advantages of biosensors, which include noninvasive delivery of drugs (in the form of smart pills) and sensing of blood glucose parameters. Hussain and Park [67] proposed a portable EMG-based gait monitoring system. They further identified the effectiveness of myoelectric biomarkers for the classification of stroke-impaired muscular activity. Similarly, there are several other wearable devices such as EMG, ECG, and EEG devices, and sensors such as blood flow sensors and chemical sensors for identifying chemical concentration, PH value, and glucose concentration in the blood. Force sensors are used in kidney dialysis devices. The biosensors are used to sense enzymes, antibodies, and other microbes within the human body. Petropoulos et al.

in [68] discussed an IMU-enabled posture monitor for identifying the wrong sitting posture through motion sensors attached to the back of the users. These devices and sensors are used in the medical CPS to provide valuable information about the condition of the patients. With medical CPS, the sensed data are cleaned, standardized, and finally forwarded to the processing and analytics unit to perform analysis. The type of processing depends upon the services required. For example, for realtime requests and queries, the data need to be processed as close to the source (of data generation) as possible. It is vital to provide an immediate response for the requested services. Further, processing the data close to the source reduces network latency and communication bottlenecks, if any. To do so, the MCPS uses an edge computing paradigm in which the sensed data are processed at the edge of the network to provide realtime or near realtime services [69]. Similarly, for non-immediate requests and services, the processing is completed on the cloud. Since moving the sensed data to the cloud is a bandwidth-hungry process, optimal routing and congestion controlling mechanisms are needed to reduce the time of data transfer.

Wang et al. in [70] proposed an edge computing-based approach for mitigating coupling issues in CPS. The different wearable point-of-care devices, which are also equipped with miniature sensors are used to provide monitoring and analysis on the go or at homes as well [71–75]. Figure 5 shows a typical medical CPS. A medical CPS as a whole consists of several components which include sensing, analysis, security, storage, and management. Each of these units has its specific functionality. The data collected from the patients in some cases are highly sensitive and thus must be protected from any kind of theft or hacking. To do so, the medical CPS makes use of different cryptographic techniques to encrypt the data before sending them across the network. Casalino et al. in [76], proposed the concept of fuzzy inference systems in telehealth for critical disease care. Similarly, there are several data management and storage techniques employed within the CPS, which provide optimal data storage and fetching as and when required by the care providers.

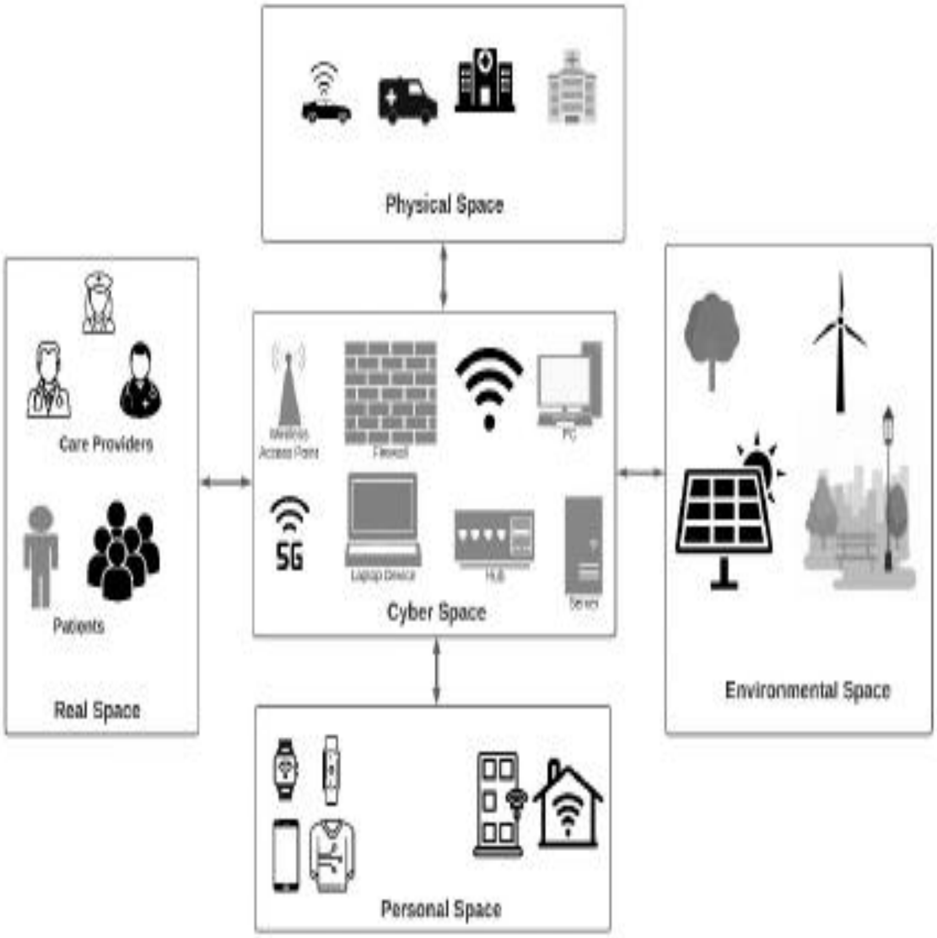

Figure 5. A typical medical CPS [45].

Fig 2.4 CPS for health care

With the advancement in technologies including IoT, WSN, big data, and enhancement of computational capabilities, the concept of CPS is widely implemented across multiple domains. The applications of CPS can be found in diverse areas such as aerospace, healthcare, energy, transportation, manufacturing, etc. [77–81]. Smart city ecosystems can be viewed as a large-scale CPS implementation that facilitates the cooperation between various computational, communication, and physical aspects and also helps to provide a better quality of life. These CPS are an integration of components of different natures, which aim to control, manage, and monitor a physical process and also adapt to the changes based on the feedback. A CPS can be thought of as a driver of the smart city services having the capability to completely transform the way of life of the inhabitants. A CPS may be used to collect and share data about realtime traffic conditions, health conditions of the patients, environmental phenomenon, land-use planning, air/water/soil quality, structural health of buildings, roads, and other structures such as bridges, rail tracks, monuments, etc. Since it involves a complex integration of multiple miniature devices (sensors, actuators,and ICs) and larger devices (mobile phones, servers, and clouds), securing such systems is a very challenging task. There are always chances of data leakage and or security breaches from one or the other vulnerable systems or devices. Therefore, it is of utmost importance to implement granular and layered security mechanisms for such types of complex CPS. MFA can greatly help in providing an extra layer of security to the CPS, but we need to make sure that implementing this extra layer of security is not an overhead and oes not increase latency, thus compromising the primary aim of the CPS systems.

Part A

1. What is CPS
2. State four applications of CPS
3. What are the advantages of CPS
4. Mention the components of CPS
5. What is a sensor

Part B

1. Describe the Cyber physical system pertaining to health care application.

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3.1. Energy Storage for Mitigating the Variability of Renewable Electricity Sources

3.1.1 Introduction

There has been a growing interest in applying electric energy storage (EES) for facilitating the large-scale integration of variable renewable electricity sources (VRES), such as wind and solar power, into electric power systems. Large-scale integration of VRES introduces significant uncertainty into operation and planning of electric power systems. Electric energy storage is considered a tool for mitigating the impacts of VRES uncertainty.

3.1.2 Criteria when considering and choosing EES technologies for a specific application:

Those criteria include life- time, life cycle, power and energy, self-discharge rates, environmental impact, cycle efficiency, capital cost, storage duration, and technical maturity.

Based on these criteria, the appropriateness of EES for various applications has been evaluated such as, for flexible alternating current transmission systems, small-medium-large-scale applications, system efficiency, emissions control, peak shaving, and deferring facility investments in peaking generators.

3.1.3 Variable Renewable Electricity Sources-Overview

With growing concerns about the environmental impacts of the electricity sector, there has been increasing interest to invest in wind and solar power.

The 121 GW of global wind-installed capacity in 2008 produced 260 TWh of electricity and saved 158 million tons of CO_2.

It is estimated that the worldwide wind cumulative capacity reached 318 GW in 2013.

In the same year of 2008, nearly 6 GW of new photovoltaic and thermal solar to power installations contributed to the cumulative installed capacity of 14.7 GW.

In recent years, installed solar to power capacity has been growing very fast (e.g., 8% growth in 1992 and 46% in 2008), and reached 139 GW in 2013.

However, the variable nature of these renewable resources introduces a new source of uncertainty in the operation and planning of electric power systems.

Variations in VRES depend on the size of the evaluated system and the timescale of wind variations. Proportionately, small wind farms tend to have larger expected hourly variation than variations from an entire area.

For example, in Western Denmark, it can be reasonably expected that wind power may vary by 3% of its 2400 MW capacity, whereas a 5 MW wind farm in the same area may vary by 12%.

VRES timescale variations can be characterized as microscale, mesoscale, and macroscale. Microscale variations primarily affect regulation (seconds to minutes), while mesoscale variations affect the load-following timescale (minutes to hours), and macroscale variations affect the unit-commitment timescale (hours to days).

While microscale fluctuations are smoothed to a significant extent across a typical wind-power array, mesoscale and macroscale fluctuations can be significant for wind farms and even for an entire region.

The impact of large-scale VRES variations on power systems differs by time-scale. In microscale, large-scale integration of VRES may require significantly more regulation reserves and frequency control depending on the power systems characteristics. For example, a study conducted for Ontario Power Authority indicates that integration of 10,000 MW wind-power capacity into the Ontario system of 26,000 MW peak demand would require an 11% increase in regulation requirements.

In mesoscale, VRES variations impact the balance between the supply and demand, and thus, may require a significantly increased amount of operating reserves. The same study for Ontario shows that a 47% increase in operating reserves is necessary in order to deal with mesoscale variations of wind under a 10,000 MW wind-integration scenario. In macroscale, VRES variations impact unit commitment and scheduling of conventional generators, and unpredictable variations may result in significant economic costs.

In practice, large variations of VRES, particularly wind, have led to operational difficulties in some cases. As an example, on February 26, 2008, an unexpected 1,400 MW drop in wind-power generation coincided with an unexpected load increase and loss of a conventional generator in Texas. These events forced the Electric Reliability Council of Texas (ERCOT) to take emergency steps and cut 1,100 MW firm load in order to restore system frequency.

In addition, wind generators were dispatched down three times in 2008 in the Irish power system for security reasons. Such events and considerations are the basis for limiting large-scale wind-power integration in some power systems. For instance, a 362 MW wind-power restriction is in effect on the 800 MW peak load power system in the Canary Islands. In the province of Alberta, Canada, the electric system operator put a 900 MW cap on wind-power integration because of “operational concerns”.

Although this cap was later removed, the system operator has been continuously looking for solutions to deal with the variability associated with wind power in Alberta, such as significant investments in a central wind forecasting project.

Some utility studies have concluded that the grid can absorb wind energy up to 10% of the system load without major technical changes or significant costs .

However, the same studies have also recognized the importance of evaluating the impact of larger scale wind integration in electric grids. Wind-power variations may currently be smaller than variations from large plant-forced outages, typically, 20% over 30 minutes for the former compared to 100% over seconds for the latter. However, with the expected 22% wind-power annual growth, innovation to reduce the impact of variable and distributed energy resources may become increasingly necessary.

To deal with the variability of wind and solar to power electricity generation at large scale, several methods are proposed, where each attempt to solve one aspect of integration challenges. For example, expanding transmission and trade allows higher VRES penetration by providing higher flexi- bility, but is expensive due to the magnitude of energy exchange required to make them profitable. Improving VRES forecasting reduces system dispatch errors, but does not give full economic opportunity to the VRES power generator. Increasing dispatchable back-up power generation may improve the system's ability to cope with dispatch errors at the cost of greenhouse gas emissions, since these units generally require fossil fuels for power]. Alternatively, hydro power responds quickly and can absorb some of the fluctuations in wind-power output; however, hydro resources are limited . Decoupling VRES generation from the grid removes power-quality problems associated to VRES at the cost of reducing the clean energy sources feeding the grid. Although the above solutions solve several challenges presented by VRES, they are insufficient to mitigate every challenge. Electric energy storage (EES), although generally expensive, has the ability to address several VRES integration issues.

3.2 Types of EES

3.2.1 Pumped Hydro Storage

Pumped hydroelectric storage (PHS) stores potential energy from height differences in water levels, and differs from ordinary hydroelectric power because it has the ability to pump water from the lower reservoir to the upper reservoir. It is the most common form of energy storage, representing approximately 3% of the world's total installed power capacity, and 97% of the total storage capacity. The approximate 250 PHS plants have a cumulative 120 GW of generation capacity, and this capacity is growing at a rate of approximately 5 GW/year. The reason that PHS has been very popular as an energy-storage medium is because it can provide relatively high efficiency (65-85%), large power capacity (typically 100-1000 MW), large storage capacity (1-24 + hours), and a long life (30-60 years), at a low cycle cost (0.1-1.4 $/kWh/cycle)

There is considerable interest in investing more resources into PHS for grid reliability and wind variability applications. For example, the utility Xcel Energy upgraded a PHS system in Cabin Creek, Colorado, in the United States, to have 359 MW of PHS generation capacity to mitigate wind variability. In the past, the turbine and the pump were separate due to increased efficiency, but as technology has matured, one rotating machine is now used both as a motor and a generator to reduce costs. However, this tendency is not universal. For example, the Kopswerk II pumping station in Austria, inaugurated in May 2009, has a separate 525 MW turbine from the 450 MW pump. Its purpose is to increase the efficiency of each process and to increase ramping speed for peaking and for integrating renewable energy, since both the turbine and generator can be ramping at the same time.

PHS is generally limited to high-power applications only for several rea- sons, such as its high capital cost ($100 million - $3 billion US or 600 - 2,000 $/kW), the resulting environmental damages by flooding 10-20 km^2 of land to make reservoirs, and its long project lead time (typically 10 years). The low modularity of PHS systems at small-scale power (kW to MW range) can limit its ability to be used to solely mitigate wind fluctuations. If a wind farm is not sufficiently large enough, it would be necessary to use the PHS system for multiple purposes (peak shaving, grid stability) to justify the PHS installation, as it is not feasible to have two large reservoirs to mitigate fluctuations in a small wind production.

When using a PHS to level VRES power variations, it is important to ensure that the ramp rates are high enough to level the production. This is generally not an issue, but it is something that will gain importance as the penetration of these sources increases.

3.2.2 Compressed to Air Energy Storage

A typical compressed to air energy-storage (CAES) system uses an existing underground site (e.g., a salt dome, a rock cavern, or an abandoned mine), and stores gas at approximately 4 to 8 megapascals. CAES and PHS are the only storage technologies that are currently suitable for large-scale power and high energy-storage applications. Research shows that CAES is a viable method to mitigate wind variability for wind levelling and energy management purposes. For example, the McIntosh plant, which has a 134 MW generation and 110 MW compression rating, can swing from full generation to full compression in less than 5 minutes, and back to full generation in less than 15 minutes. There are currently two CAES plants in the world for a total capacity of 400 MW. The first is in Huntorf, Germany with a capacity of 290 MW for 2 hours. This site was installed in 1978 by Alstom. This system, initially built to support a nuclear plant, is now used for grid support 3 hours a day. It has demonstrated a 90% availability and a 99% starting reliability. The second CAES plant was built in 1991, in McIntosh, Alabama, in the United States, with a 110 MW capacity for 26 hours. This plant uses a recuperator, which reduces the fuel consumption by approximately 25% compared to the Huntorf plant. It has the purpose of complementing a coal plant in Lohman, Alabama. Neither of these two sites are used for variable energy sources.

Although there are only two CAES plants in the world, they have both demonstrated high reliability and economic feasibility, and have sparked considerable interest in constructing more in wind integration. For example, the Iowa Stored Energy Park, expected to be commissioned in year 2011 or 2012, would be the first plant to use wind-energy and off-peak electricity to store compressed air in an aquifer. This system, with a capacity of 268 MW/13,400 MWh, will get its energy from a 75 to 150 MW wind farm, and is expected to reduce emissions by 60% compared to a system that does not use the CAES through energy management. Due to large storage time, i.e., 50 + hours at full generation, it is expected that the system will cut down on wind dumping when energy demand is low, and will support shifting wind-energy production to periods with high grid emissions inten- sity. Another example is the Shell Luminant CAES plant in Texas, where TXU Energy and Shell Win dEnergy are working to build a 3,0 MW wind farm connected to a CAES system that will pump air into underground salt beds. The Shell-Luminant CAES plant will store 1,000 MWh of energy in Briscoe County. Finally, Magnum Energy is planning to create an integrated energy-storage facility that can store natural gas and compressed air to help improve the integration of wind and solar power in Utah, in the United States. Eight salt caverns have been identified as suitable, and the first CAES plant is planned be built for approximately $200 to $400 million after the first gas-storage cavern is operational in 2012..

CAES shares many of the same attractive qualities of PHS, such as high- power capacity (50-300 MW), large energy-storage capacity (2-50 + hours), a quick start-up (9 minutes emergency start, 12 minutes normal operation), a long storage period (over a year), and a relatively high efficiency (60-80%). It also suffers from some of the same problems, such as a reliance on favorable geography (proximity to underground storage area and availability of natural gas), a requirement for large power storage to make the system feasible, and low energy density (12 kWh/m^3).

However, there are also several features that make CAES very different from PHS. The capital cost of CAES is significantly lower (400-800 $/kW) and since the storage is underground, there is very little impact on the surface environment. In addition, appropriate sites are bountiful and virtually untapped; three quarters of the United States has the potential for this technology . This may sound promising, but site-specific data is required to evaluate the suitability of the site for CAES such as geography, accessibil- ity, economics, and correlation . The use of natural gas in the expansion cycle causes the system not to be carbon neutral, and the ability of CAES to quickly change output power generation is limited.

Although CAES is technically capable of increasing VRES penetration, it must be combined with other functions.For example, use the deterministic EnergyPLAN model to analyze the system-economic potential of a CAES plant in elec- tricity systems. In a CAES system with a 216 MW compressor, 360 MW turbine, and 1,478 MWh storage requiring an annualized 14 million Euro of capital investment and operational costs, created an annual 4-12 million Euro shortfall by selling electricity on the spot market. To gen- erate an annual profit of 1-3 million Euro proposed to make the turbine operate solely on the regulating power market for monthly availability payments of 3,330 Euro/MW, and make the compressor operate on the spot market while ensuring that the storage is never empty.

3.2.3 Batteries

The batteries discussed in this chapter store energy through a reversible chemical reaction.

3.2.3.1 *Lead-Acid Batteries*

Lead-acid batteries have been used for more than 130 years in many different applications and they are still the most widely used rechargeable electro- chemical device for small-medium scale storage applications. In China, lead-acid batteries are used in 75% of new solar photovoltaic systems, which was 5% of the entire lead-acid battery market in year 2007, and expected to hold 10% by 2011. Seventy percent of lead-acid batteries are used for vehi- cles, 21% for communications, and 4% for other applications. The larg- est lead-acid storage installation was a $18.2 million, 10 MW/40 MWh unit in Chino, California in July 1988 for load leveling It is currently operated by Southern California Edison Company. Moreover Lead-acid batteries have low cost (300-600$/kW), high reliability, strong surge capabilities, high efficiency (65-80%), and are usually good for uninterruptible power supply, power quality, and spinning reserve appli- cations. However, they are poor for energy management purposes because they have a short life (500-1,000 cycles), require regular mainte- nance, have low energy density (30-50 Wh/kg), emit explosive gas and acid fumes, and have a poor cold temperature performance, which requires a thermal management system. Although valve-regulated lead-acid batte- ries require less maintenance, create less gaseous emissions, and self-discharge they are primarily designed for back-up power supply and telecommunication applications due to their decreased cycle life.

3.2.3.2 *Nickel-Cadmium Batteries*

Nickel-cadmium (NiCd) batteries compete with lead-acid batteries because they have a higher energy density (50-75 Wh/kg) and have a longer life (2000-2500 cycles). They are good for uninterruptible power supply and generator-starting applications. In Golden Valley, Fairbanks, Alaska, the world's second most powerful battery bank is a NiCd type. The 27 MW rated battery in this site can provide 40 MW for 7 minutes, and is used for spinning reserves and grid stabilization in an electrical-island oper- ation mode.

However, NiCd battery sales declined for the period of 1995 to 2003 This may be attributed to increasing environmental controls for toxic cadmium, such as the 2006 European Union's directive on batteries and accumulators to ban NiCd batteries in September 2008, or because new bat- tery developments do not justify the cost of NiCd batteries (1,000 $/kWh) for certain applications. Concerning VRES integration, NiCd batteries have a unique feature that makes them unsuitable: the memory effect. If NiCd batteries are not fully discharged before being recharged, the battery will start losing its capacity. Since wind and solar power are non-dispatchable and include forecast errors, NiCd batteries can not operate economically without creating problems caused by the memory effect.

3.2.3.3 *Sodium-Sulphur Batteries*

In the last decade, sodium-sulphur (NaS) battery-based installations have grown exponentially from 10 MW in 1998 to 305 MW (2,000 MWh) at the end of 2008. NaS batteries are a very attractive emerging technology for VRES generation management, such as wind power, because they can be cycled 2500 times, have high-power density (150-240 W/kg), are efficient (75-90%), and have a 600% rated pulse power capability that can last 30 seconds. It is claimed that NaS batteries are the most economically feasible battery storage option for energy management, requiring electricity prices of 32 cents/kWh.

NGK Insulators Inc., the only NaS battery supplier in the world, has installed several batteries for VRES applications, and is considering ramping up their annual production capacity from 90 MW in 2009 to 210 MW in 2011. NGK has installed a 34 MW 245 MWh system in northern Japan for stabilizing a 51 MW wind farm. This is the largest energy-storage system in the world, discounting PHS and CAES systems. The utility com- pany Xcel Energy is exploring the viability of coupling a 1.2 MW/7.2 MWh NaS battery installation with the 11.8 MW MinnWind wind project. A 1.5 MW battery has been shown to work with 5 MW of solar to power stabilization. In May 2009, Electricite de France and NGK agreed on 150 MW of NaS batteries over the next 5 years to mitigate fluctuations in solar and wind-energy production on various Mediterranean islands in order to reduce carbon emissions.

NaS batteries are environmentally benign since the batteries are sealed and thus allow no emissions during operation. Also, more than 99% of the overall weight of the battery materials can be recycled. Only sodium must be handled as a hazardous material. Although NaS batteries can be modular down to 50 kW, the general sizes are approximately 1 MW.

However, the NaS batteries must be kept at approximately 300 to 350 degrees Celsius, and are subject to a high capital cost (2,000$/kW or 350$/ kWh). Beta R&D is hoping to compete with NGK Insulators Inc., with their sodium nickel-chloride batteries, known as ZEBRA batteries. ZEBRA batteries have similar characteristics as the NaS batteries (120 Wh/kg energy density and 150 W/kg power density), but can operate at temperatures from -40 to 70° Celsius.

3.2.3.4 *Lithium-ion batteries*

Lithium-ion batteries were commercialized by Sony in 1991, and the demand for these batteries has grown exponentially in several markets. This is attributed to the many desirable characteristics these batteries have, such as efficiencies of over 95%, long life cycle of 3,000 cycles at 80% depth of dis- charge, high energy density of 200 Wh/kg, and high-power density. These, along with fast-discharge capabilities have made them nearly ideal for portable electronics applications. The main hurdles for large- scale lithium-ion batteries are their high cost (above $1,200/kWh) and the cir- cuitry needed for safety and protection.A123 Systems and EaglePicher Technologies are two examples of com- panies that are developing lithium-ion battery technology for the power sys- tems industry. In May 2009, EaglePicher Technologies announced the construction of a 60 MWh battery, the size of a football field, to store wind energy in Kansas, United States]. A123 Systems is currently developing lithium-ion batteries for reserves, frequency regulation, and grid stabiliza- tion. However, most of the focus has been on the automotive sector. Lithium-ion battery production produces 70 kg CO_2 /kWh capacity; this is less the emissions produced by fossil-fuel alternatives after only 120 recharges of hybrid vehicles. However, lithium-ion reserves are limited and creating 800 million vehicles that use a 15-kWh lithium-ion battery each would deplete 30% of world’s lithium reserves.

3.2.3.5 *Zinc-Bromine Batteries*

Zinc-bromine (ZBR) batteries are a special type called flow batteries, which store at least one of its liquid electrolytes in an external storage tank that flows through the reactor to store/create electricity. As a result, the energy storage can be independent of the power capacity, depth-of-discharge can be ignored, and self-discharge is negligible. This makes flow batteries flexible for a wide range of applications including seasonal storage. With a sub- millisecond response time and pulse capability, flow batteries are more than capable for VRES following and power quality.

In low levels of wind penetration, flow-battery systems delivered the lowest cost per energy stored in a study that compared lead-acid batteries, flow batteries, flywheel, superconducting magnetic energy storage, CAES, hydrogen, and PHS, with a profitable price of 41 to 45 cents/kWh. In the case, a 600 kW/3,000 kWh battery was used for shifting the power generation of a single 2.5 MW wind turbine in ten bottom-up pric- ing scenarios, and it was found that that the minimum selling price of elec- tricity needed to be 45 cents/kWh. In, the levelized cost of storage was evaluated to be 41 cents/kWh, assuming a 10% wind penetration in the state of California using the HOMER model.

Since the development of ZBR batteries by Exxon in the 1970s, two companies have tried to develop the technology for commercial purposes, namely, ZBB Energy Corporation and Premium Power Corporation . ZBB’s commercial products include the ZESS 50 (50 kW/50kWh) and the ZESS 500 (250 kW/500kWh). Premium Power's commercial products include the PowerBlock 150 (100 kW/150 kWh) and the Transflow 2000 (500 kW/2.8 MWh). Although ZBR batteries are suitable for small-scale applications, medium-scale ZBR battery technology was tested as early as 1991 (e.g., at Kyushu Electric Power, 1 MW/4 MWh), and up to a total power capacity of 2 MW (e.g., at PG&E in California in 2005). By the end of 2009, it is estimated that there was 4 MW of installed capacity in the world, with a storage capacity of 8 MWh.

ZBR batteries have 75% efficiency, 200% peaking capacity, 3 to 4 hours recharge time, 75 to 85 Wh/kg, over 2,000 charge life cycle, and deep dis- charge capabilities. This, along with ZBB's "plug-and-play" capabilities make the technology suitable for small distributed energy storage.

3.2.3.6 *Vanadium Redox Batteries*

Vanadium redox batteries (VRB) are another type of flow battery that is suit- able for small- and medium-scale applications. Starting with the development of VRB technology by the University of New South Wales in the 1980s, there are now currently over 20 MWh of installed VRB in the world. The installed VBR batteries are used for load leveling, remote-area power systems, renew- able energy stabilization, uninterruptible power supply, back-up power, and power quality. The technology has been tested, proven, and installed in various locations, and has been characterized as a storage system with one of the lowest environmental impact. Plants can be upgraded at a relatively low incremental cost, by increasing the volume of electrolytes for more stored energy or by adding new cell stacks for additional power

The main VRB suppliers are Sumitomo Electric Industries and Prudent Energy who marketed VRB Power Systems in January 2009. The largest installation by VRB Power Systems is 0.25 MW/2 MWh. The largest installations by Sumitomo Electric Industries is a 4 MW/6 MWh unit in Tomamae Wind Villa in Japan, in 2005, which has been cycled over 270,000 times to various depths of charge within 3 years to sta- bilize a 32 MW wind farm.

VRB have been used to mitigate fluctuations in both wind and solar power. To understand the potential of VRB for wind and daily wind man- agement, the Institute of Applied Energy in Japan installed a 170 kW, 1 MWh VRB system in 2001. The Riso Research Institute in Denmark installed a 15 kW, 240 kWh battery in 2006 for the same purpose. For solar power, a 30 kW, 240 kWh, VRB system has been used for a solar photovoltaic- hybrid application at the Obayashi Corp's Dunlop Golf Course.

VRB are modular down to 5 kW/10 kWh, have an efficiency of 75% to 80%, and with proper annual maintenance, have a high cycle life of over 12,000 at 100% depth of charge because the electrolytes do not degrade. However, due to their low energy density of 16-33 kWh/m^3, they require a large amount of space, and are only suitable for small or medium stationary VRES applications.

3.2.4 Superconducting Magnetic Energy Storage

A superconducting magnetic energy-storage (SMES) unit is a device that stores energy in the magnetic field generated by direct current flowing through a sup- erconducting coil. SMES is a relatively new technology with low expo- sure to power applications, although one estimate reports that there may be as much as 100 MW capacity already installed in the world]. SMES units can only generate electricity at rated capacity for a few seconds, have strong magnetic fields, and are extremely expensive at 1,000 to 10,000$/kW due to the need for cryogenics to maintain superconductivity.

Micro-SMES devices in the range of 1 to 10 MW are commercially available, and over 30 devices with approximately 50 MW of total capacity are installed in different parts of the United States for good power quality or uninterruptible power supply. The largest installation includes six or seven units in upper Wisconsin by American Superconductor in year 2000. These units of 3 MW/0.83 kWh are currently operated by the American Transmission Company, and are used for power quality applica- tions and reactive power-support where each can provide 8 MVA. Although there is research examining the technical ability of SMES to integrate renewable energies, there is little indication that SMES has or can fill a unique niche. For most purposes, supercapacitors and flywheels can fill the same niches as SMES.

3.2.5 Hydrogen Storage

Hydrogen differs from the conventional idea of energy storage because it uses separate processes for hydrogen production, storage, and use. For hydrogen production, an electrolyzer produces hydrogen and oxygen from water by introducing an electric current. A hydrogen fuel cell converts hydrogen and oxygen back into water to release energy. Different strategies of integrating wind and solar energy with hydrogen storage are proposed in. Norsk Hydro and Enercon installed the first and largest wind-hydrogen plant in Utsira, Norway, in 2004, which operates as an isolated power system with 90% availability. It couples a 600 kW wind turbine with a 48 kW electrolyzer and a 10 kW fuel cell. Hydrogen is stored in a 12 m^3 tank, which is enough to power 10 houses for 2 to 3 days without wind. Grid stability and back-up are provided by a flywheel and a battery bank.

In the town of Nakskov, Denmark, a wind-hydrogen project has been successfully producing hydrogen since May 2007. It uses an 8 kW elec- trolyzer, a 10.5 kW fuel cell, and a 25 m^3 hydrogen storage tank. The hydro- gen is used to produce electricity when demand exceeds generation, and the excess oxygen is used for waste-water cleaning projects. To increase efficiency, fuel cells will be installed in 35 residential homes to be used as combined heat and power generation.

Hydrogen storage is estimated to cost between 500 to 10,000 $/kW. Because the capital cost is currently more expensive than other options and it has a low storage conversion efficiency (30-40%), hydrogen storage for inte- grating VRES can be expensive. A wind-hydrogen system should sell energy generated by the fuel cell at a price between 1.76 to 2.5 $/kWh to be com- petitive in energy-management timescales. Because hydrogen storage costs approximately 4.5 times more than natural gas, electrolyzer / fuel cell sys- tems are either inoperable or uneconomical at low levels of wind penetration. However, research suggests that replacing the fuel cell with a hydrogen internal combustion engine may be more viable, especially if mixed with natural gas. Fuel-cell technology may be a viable option for the future, as it is expected that the cost may drop to 15 to 145 $/kW by 2020. Hydrogen production and storage may currently be an option for certain applications, such as when grid reinforcement is expensive, when there are limiting environmental policies or concerns for other options, for isolated electricity networks with low flexibility generation and high variability in load and generation, or for small-scale self-sufficient power supply systems disconnected from the electric grid. However, many EES can be applied to these problems at a smaller cost.

Hydrogen may become competitive for seasonal storage of VRES. For applications in seasonal storage, EES requires large energy capacity and a very low self-discharge. For this application, only PHS, flow batteries, CAES, and hydrogen are technically viable. Due to the high seasonality of VRES, long-term storage may become more attractive as VRES penetration increases. For example, one study showed that hydrogen becomes an attractive option if wind penetration increases to 18% in Southern California by 2020. The hydrogen market may also expand if it enters the transport sector as an emissions-free alternative to gasoline.

Some research shows that hydrogen storage can drastically increase wind-energy penetration. This is because the excess wind after hydro- gen production can be used for purposes other than electricity, such as fuel- ing ferries or cars. A hydrogen storage system connected to both filling stations and electrical generators can be regarded as a future solution in areas where grid-connected wind generation is economically and/or technically viable. It may be possible to use hydrogen pipelines to connect stations into a network to provide energy for vehicles and electrical loads.

3.2.6 Flywheels

A flywheel is a mass that stores/retrieves energy according to its change in rota- tional velocity, and is a promising technology because of its long life of 15 to 20 years, long cycle life of 10,000 to 100,000, and high efficiency of 90 to 95%. However, the capital cost for flywheels is high in the range of 1,000 to 5,000 $/kWh. The self-discharge rate is between 55 to 100%/day.

Although flywheels are not yet widespread in the power industry, they are slowly penetrating the market, mostly for uninterruptible power supply, power conditioning and pulse power, and are starting to be used with VRES. For example, a 5 kWh, 200 kW flywheel is used to stabilize the 10-household grid in Utsira, Norway, in a wind-hydrogen system. In addition, Urenco Power Technologies has also installed some flywheels for smoothing wind turbine output and stabilizing a small-scale island wind supply. Beacon Power claims that flywheels can be used for cloud-cover effects mitigation for solar photovoltaic by preventing voltage disturbances, and as an energy buffer for mitigating wind-power ramping. Strategies have been suggested to combine the characteristics of flywheels, i.e., fast ramping and low energy, with another device, such as PHS, hydrogen, or diesel to remove the weaknesses of both devices for better VRES inte- gration. A unique strategy only applicable to wind is to use the rotating wind turbines as flywheels to remove the frequency variations to which the grid is susceptible.

3.2.7 Capacitors and Supercapacitors

Capacitors and supercapacitors store electric energy by accumulating posi- tive and negative charges. They can be charged substantially faster than conventional batteries and can be cycled over 100,000 times, but they have low energy density, so they are best used for fast cycling applications.

Capacitors accumulate charges on parallel plates separated by a dielectric. They last approximately 5 years, and have 60 to 70% cycle efficiency. In power systems, they are typically used for power-factor correction, voltage and VAR support, and harmonic protection instead of energy storage. A few energy-storage applications that can be used for VRES integration include increasing battery life, surge power, and dynamic voltage restoration.

Supercapacitors usually store energy by means of an electrolyte solution between two solid conductors. They have many similar characteristics as capacitors, but have several differences. Supercapacitors have a durability of 8 to 10 years, an efficiency of 95%, they are deep discharge/overcharge capable, and have an extremely high-power density of 10,000 W/kg. However, supercapacitors have a high energy dissipation rate of 5 to 40%/ day and their cost is estimated to be $20,000/kWh. There are currently no known installed high-voltage applications for supercapacitors.

By connecting capacitors or supercapacitors to the direct current link of an VRES generator, multiple benefits could be extracted. It removes the need for a DC/AC converter and some control equipment from the system; this is true for all direct current EES technologies. In addition, it is also capa- ble of providing low voltage ride-through and filtering higher frequencies to smooth VRES generation.

3.3 Potential of Sodium-Sulfur Battery Energy Storage to Enable Integration of Wind-Case study

3.3.1 Introduction

According to the data from the International Energy Agencyand the U.S. Energy Information Administration, fossil fuels-based electricity generation constitutes about 65 percent or more of the total installed capacity worldwide and in the countries with the highest production, namely China, U.S, and Japan. Among the fossil fuels used in electric-power generation, coal and natural gas are by far the dominant sources. Extraction and combustion of these fuels has been conclusively linked to climate change. Coal is especially hazardous since it also presents the risk of heavy metal pollution, radioactive pollution, and the release of nitrogen and sulfur oxides among other pollutants. Natural gas, while cleaner than coal, is imported by many countries and therefore the prices and availability are subject to geopolitical considerations.

Wind generation is among the leading alternatives for environmentally sustainable electricity and for energy independence, and is second only to hydroelectric power in terms of installed capacity . In addition, the growth in the installed wind power is much faster than hydroelectric, and wind has nearly tripled in less than a decade. Furthermore, this growth is not expected to slow down in view of the interest from major economies of the world.

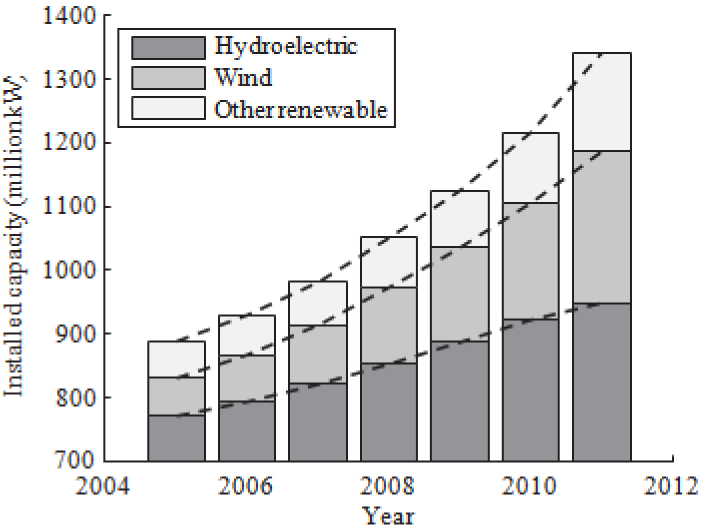

Fig 3.1 Contribution of wind power to the total installed renewable energy worldwide

Estimates by the Energy Information Administration indicate that the levelized cost of new wind generation is lower than any form of coal-based generation and lower than all fossil fuel generation equipped with carbon control and sequestration (CCS). These estimates also consider the transmission investment necessary for bringing the wind-generated energy to the load centers. These estimates do not include the potential production/investment tax credits that the new wind farms might receive that would further lower the cost of wind-generated power. It is notable that the levelized cost of wind generation is also lower than other renewable generation. Wind generation is listed as a “non-dispatchable technology.” The technical community in general recognizes that wind power is not as dispatchable as traditional generation since the output of a wind farm cannot always be forecast precisely or controlled over the operating range at will. Traditional power system includes intermediate generation, peaking generation, and operating reserves to compensate for the variability in load and contingencies. At lower penetrations of wind, the unforeseen variations in wind power can be compensated by the existing devices on the system. At higher levels of penetration, however, the management of wind generation either necessitates additional transmission and/or reserves, or places extra burden on the existing infrastructure

3.3.2.Energy Storage As An Alternative

The Danish system is unique since it enjoys strong interconnections to the larger systems in its vicinity. Furthermore, the significant hydroelectric power in the Nordic countries provides a simple solution to balance the generation and the load. In general, to support high amounts of wind on the system, a flexible power system is necessary that can adjust quickly to the unforeseen variations in generation and load. Traditionally, flexibility is achieved using operating reserves. Energy storage is an alternative toward adding flexibility to the current power system. There are certain advantages that are unique to energy storage compared to classical generation used for load following and operating reserves:

1. Avoided fuel cost and pollution from less efficient but fast-acting peaking generation; use of rigid but efficient units to serve base load while avoiding wind curtailment.
2. Eliminating the need for generators to compensate for fast variations that could otherwise cause rotor fatigue and impose additional costs.
3. Guaranteed availability of wind generation to serve peak load, establishing wind as a viable peak load resource/enhancing the dispatchability of wind.

Making wind generation available to serve the peak load using energy storage is equivalent to load leveling from the perspective of the remainder of the generation. Therefore, further benefits like deferred transmission and capacity upgrade, reduced T&D losses, and robustness could be realized.

3.2.3. Energy storage in electricity markets

The discussion above considers energy storage coupled directly to wind generation. Power systems worldwide are moving toward energy markets to efficiently and economically balance supply and demand of electric power. It is highly likely that different entities would own wind farms and energy storage, interacting only through the market. Even in this case, energy storage can facilitate the integration of wind by the following mechanisms:

The locational marginal prices (LMPs) in the energy markets are expected to exhibit higher variability with a higher amount of wind generation on the system. In the absence of enough transmission, the LMPs could become unstable - negative LMPs have been observed in regions with high wind generation but insufficient transmission . Market participants that own energy storage can take advantage of low LMPs during periods of high generation and low demand to charge the storage and discharge/sell energy when the demand is high.

This action will have a stabilizing effect on the LMPs, and will also mitigate the need for transmission upgrade imposed by additional wind.

Higher amount of wind on the system causes the operating reserve requirement to go up. In energy markets, this increased requirement would manifest as higher prices for reserves. Energy storage can take advantage of these higher prices while meeting the increased demand for operating reserves, thereby aiding the integration of wind.

Therefore, energy storage, whether coupled to wind generation directly, or interacting through energy markets has the potential to aid higher penetration of wind.

3.3.3 Sodium-sulfur battery -Principle

Sodium-sulfur battery operates on the principle of a reversible redox reaction between sodium and sulfur. The operating temperature of this battery is~300 °C and the sodium and sulfur electrodes are molten during operation. The electrolyte is solid beta-alumina of sodium-ion conductive ceramic.

The salient features of this battery technology are:

- 3 to 5 times the energy density of lead-acid batteries
- High pulse power capability and prompt response

- Long calendar and cycle life: 15 years and 4500 cycles for a 90% depth of discharge
- 85% round-trip DC efficiency

3.3.4. Target applications and existing installations

The superior efficiency, energy density, and cycle life of sodium sulfur- battery make it suitable for grid applications. Selected applications are summarized here:

Load-leveling and peak shaving
Smoothing the daily load profile
Avoiding higher tariffs at peak loads by utilizing stored energy
Transmission/distribution/generation asset optimization
Relieve transmission congestion
Avoid/defer transmission upgrade
Reduce generator cycling
Ancillary services
Spinning reserve
Frequency regulation
Black start
Volt-Ampere reactive support (using power electronic interface)
Renewable resource optimization
Short-term (second to minutes) smoothing to control ramp rates of renewable generation to comply with the grid code
Renewable resource generation shifting from off-peak to on-peak intervals
Hedging against forecast errors to avoid penalties in the market
Avoid output curtailment during off-peak intervals

3.3.5. The Sodium-Sulfur battery at Luverne, Minnesota- Case study

In 2008, Xcel Energy, a major U.S. utility installed a 1 MW, 7.2 MWh sodium-sulfur battery in Luverne, Minnesota next to an 11.5 MW wind farm owned by Min wind LLC. This project was titled the Wind-to-Battery (W2B) project with an aim “to evaluate the overall effectiveness of sodium- sulfur (NaS) battery technology in regards to its ability to facilitate the integration of wind energy onto the grid. The University of Minnesota was a partner in this project and was provided access to the data from the wind farm and the battery. Furthermore, the initial framework for the analyses presented here was set by Xcel Energy. However, the analyses were conducted solely by the University of Minnesota and Xcel Energy neither endorses nor denounces any opinions made or information presented.

3.3.5.1.Generation Shifting

In this section, the ability and the value of the sodium-sulfur battery in shifting wind-generated energy from off-peak hours to on-peak hours is evaluated. Results from the actual field operation are provided first to establish the ability of the battery to shift the generation from off-peak to on- peak Having established the generation-shifting capability of the battery, simulation using long-term data is used to draw further conclusions: the wind-farm power output is scaled to simulate scenarios with different storage-to-wind ratios, with the restriction that the battery could be charged using wind generation only.

Histograms of the daily maximum state of charge (SOC) are plotted.

Finally, the revenue and the savings generated by the battery are calculated for all scenarios, followed by a discussion on the optimal storage-to-wind ratio. wind generation at the Minwind wind farm along with the battery-power output and SOC for May 18, 2011i shown . The wind generation varies throughout the day and is generally higher during the night. It drops to zero for approximately 2 hours (~8:00 AM - 10:00 AM). The battery is charged during early AM and late PM, a period typically associated with light loads and is discharged between early morning and noon, a period typically associated with load ramp-up and peak load.

While sufficient wind generation might not always exist to charge the battery, in this specific example chosen for illustration, the wind generation during the battery charging period always exceeds 1 MW, the rated power of the battery. Therefore, this example operating day proves that provided enough wind generation exists to charge the battery during off-peak hours, the battery can successfully shift off-peak energy to on-peak. Having established this, we are ready to move to simulation using long-term data to analyze how often enough wind generation is available, and to calculate the value added by shifting wind generation to on-peak intervals.

The following data and parameters were used for simulating wind- generation shifting:

1 MW, 7.2 MWh battery with 85% round trip efficiency: the losses were assumed to be geometric between charging and discharging and a one- way efficiency of p0:85 was used.

2.Wind-generation data from the Minwind wind farm for the year 2007.

The data was available for 360 days and was scaled to generate scenarios corresponding to wind farms rated at 11.55 MW, 10 MW, 5 MW, 2.5 MW, and 1 MW for the same 1 MW battery.

3. Day Ahead and Real Time Locational Marginal Prices (DALMPs, RTLMPs) for the MINN hub of Midcontinent Independent System Operator (MISO) for the year 2009.

At the time of this analysis, year-long generation data was available only for the year 2007 but the price data was available for 2009 and later. Therefore, the generation data was treated as if it were from the year 2009 under the assumption that there was no significant change in the wind regime from the year 2007 to the year 2009.

Charging/discharging intervals

For this analysis, the minimum SOC was set at 10%, which corresponds to a cycle life of 4500 cycles. At this minimum SOC and the assumed efficiency, and the MWh/MW ratio, the battery would output its rated power for about 6 hours after being charged for a little under 8 hours.

The 8 designated charging and 6 designated discharging hours were cho- sen on a monthly basis using the load data from Xcel Energy’s territory under MISO footprint for the year 2009. Analysis of the value added by storage

The value in shifting wind generation is composed of several components:

1. Revenue from discharging the battery at peak load: the electricity prices tend to follow the load and it is reasonable to expect that prices would be higher at peak load.
2. Savings from avoiding costlier generation for serving peak load.
3. Inherent value in making wind generation available on-peak:
    a. Avoided greenhouse emissions from fossil fuel-based peaking gener- ators, avoided generator cycling, and earned carbon credits
    b. Maximization of the returns from the investment in wind power by avoiding curtailment
    c. Qualification of wind generation as a reliable system resource with guaranteed on-peak availability
4. Secondary benefits from storage: energy storage installed primarily to shift wind generation can simultaneously provide other benefits:
    a. Up/down regulation capability
    b. Ramp-rate limiting (discussed later)
    c. Wind-power forecast error mitigation

It is not straightforward to attach dollar values of some of the value propo- sitions above (e.g., environmental benefits), and some deserve independent analysis that has been reported in literature. For the purpose of this section, dollar values from the following propositions would be considered:

1. Transactions in the energy market
2. Avoided cost of peaking generation
3. Value in letting wind generators operate during low load, quantified in terms of the Production Tax Credit (PTC)

It should be noted that the type of transactions in the energy market considered in this analysis are based on maximizing the availability of wind generation on-peak. Considered on its own, energy storage might benefit from trading strategies developed specifically to maximize the revenue. *Procedure*

The battery is offered as a load for the 8 designated charging hours and as a generator for the 6 designated discharging hours:

1. The asset owner (AO) pays the Day Ahead Locational Marginal Price (DALMP) for the charging period and receives the DALMP for the discharging period.
2. If the battery attains 100% state of charge (SOC) before the end of the designated charging period, then the energy that has been paid for at the current DALMP is sold in the spot market at the current Real Time Locational Marginal Price (RTLMP).
3. Since the battery is allowed to charge only from wind generation, in the case of a generation shortfall the energy paid for at the current DALMP is sold at the current RTLMP in the spot market similar to above.
4. In the case of a generation shortfall as described above, the battery will not reach a 100% SOC necessary to meet the commitment made for the designated discharging period: in such case, the deficit energy is purchased in the spot market at the current RTLMP.

5. For every MWh generated that goes toward charging the battery, the total value of generation shifting is augmented by a PTC for wind generation. The value of PTC available from EIA (U.S. Energy In- formation Administration, defined in the Introduction) at the time of this analysis was 19 $/MWh in 2003 dollars that was adjusted to
22.23 $/MWh in 2009 dollars using an inflation rate of 1.17 from the Bureau of Labor Statistics (BLS).

6. Finally, it is assumed that the peak generation is served by combustion turbines in the absence of stored energy. Therefore, the savings correspond to the difference between the levelized cost of wind generation and com- bustion turbine-based generation for every MWh of on-peak load served.

a. At the time of this analysis, the levelized costs of generation available from EIA were 48 $/MWh for wind and 70 $/MWh for combustion turbines in 2003 dollars that were adjusted using the inflation rate from the BLS] should be referred to for the current estimate of these costs. + k2003, 2009 × E_WINDday, hour × PTC

The additional savings on the system level by avoiding costlier genera- tion would be:

The total value would be the sum of the revenue and the savings calculated above. Other quantities of interest are: the ratio of generation shifted – the ratio of energy served on-peak against the total wind generation off-peak; the ratio of storage utilized – the ratio of energy served on-peak against the maximum possible energy that could have been served on-peak; and the ratio of value against energy served on-peak. For every MWh served on-peak, the battery incurs loss in its lifetime and in that sense the ratio of value against energy served on-peak could be a measure of the return. The listed quantities can be defined as: REVENUE + SAVINGS E_PEAK

Thus use of sodium-sulfur battery directly coupled with a wind farm to provide generation shifting to serve peak demand and to limit the wind farm power output ramp rate was discussed. Results from the field operation of a 1 MW, 7.2 MWh sodium-sulfur battery coupled with an 11.55 MW wind farm were provided to validate the battery’s ability to successfully carry out both tasks. It was argued using simulation results that the tasks could be com- bined to achieve maximum benefit.

3.4. Electric Vehicles as Energy Storage: V2G Capacity Estimation

The rapid urbanization with increasing population and demand for a better quality of living has led to a greater usage of energy. This has resulted in escalating pressure on the use of available resources, which are mostly fos- sil fuels in the form of coal, oil, and gas, leading to uncontrollable rise in air pollution. In the last few years, there has been a prolific growth in the integration of renewable energy sources (RESs) into the distribution networks in various countries. It is expected that the penetration of RESs will increase significantly in the coming years. However, the current distribution networks are not designed to incorporate such a high penetration of RES without energy storage. The frequency and voltage fluctuations caused due to the intermittency in RES power generation have been widely reported in the United States and Europe .

Conversion of conventional fossil fuel-powered vehicles to electric vehicles (EVs) is considered as one of the best solutions to decreasing the emissions of the transportation sector and increasing the efficiency of the transportation system. EVs when aggregated can be treated as large smart energy storage (SES) and hence can be used to reduce the size of the energy storage required for RESs. SES can be used as a fast-responding energy source to overcome the intermittency of RESs. However, the increase in deployment of EVs will also eventually increase the load demand of the distribution network as a result of charging. Therefore, it is necessary to optimally manage the load demand, outputs of RESs, and charging/discharging of EVs to completely utilize their benefits. SES can be either used as flexible load to store power/energy when surplus power/energy is available from RESs or as a source when there is a power/energy deficit. For utilizing the SES as a source the vehicle-to-grid (V2G) capacity estimation is vital and with the help of scheduling SES can be made to behave like a flexible load.

3.5.1 Availability and Usability of EVs

Similar to RESs, large-scale penetration of EVs that behave like flexible loads will have a significant impact on the power system and the potential to increase peak load of the power system if not managed properly. Furthermore, if the problems are not addressed properly, it will result in decrease in power quality and increase in operation cost for the peak demand. Hence, to improve the power quality of the system, the problems should be properly addressed. The problems associated with the large-scale penetration of EVs are as follows:

a) Unpredictable increase in peak demand: The unpredictable charg- ing of the EVs due to various mobility patterns of EV users will result in an unpredictable increase in peak demand. The uncertainty in the arrival of EVs is the main cause of this problem . The various charging strat- egies available in the literature to mitigate this problem focus mainly on personal vehicles parked at individual houses and small buildings [12–17]. Such strategies are not suitable for urban cities where 70 to 80% of the buildings are high-rise multi-story buildings.

b) Voltage fluctuations and increased total harmonic distortion: EV charging involves the conversion of power through power electronic devices, which will result in increased voltage fluctuations, harmonic distortions, and power losses. The problems will be more serious if charging happens during peak demand [15]. All the methods available in the literature primarily focus on shifting the charging demand from peak period to off-peak period in order to reduce the problems related with EV charging. However, such an approach will not ensure an optimal solution to these problems. The increased power losses and total harmonic distortion (THD) problems associated with different battery-charging modes must also be considered.

However, if EV charging/discharging is managed properly, it is not only pos- sible to mitigate these problems but also possible to derive many auxiliary functions such as distributed reserves for renewable energy. For uti- lizing the EVs as SES, the availability of the EVs should be considered. The availability of EVs can be obtained from the traveling patterns of different types of EVs. EVs have traveling ranges usually between 90 to 160km, which is well within the average travel distance in urban cities. The availability of EVs has an inherent variability, but it can be predicted to a certain level of accuracy, which makes EVs highly suitable for being utilized as SES. Based on research conducted by the authors it was found that most EVs are immobile 90% of the day. It can be observed that the majority of the EVs are generally used for transportation to and from work between the hours of 8:00 am and 10:00 am and from 4:00 pm to 8:00 pm, respectively. These are the time periods when the EV availability as SES is low. However, during peak hours (i.e., between 10:00 am and 2:00 pm) and off-peak hours (i.e., between 10:00 pm and 5:00 am) the EVs are usually not used or immobile as they are typically plugged in for charging at the work- place and home car park, respectively. These are the time periods when the EV availability as SES is high. Hence, during off-peak hours, the EVs can be used as flexible load to store the additional energy generated by RESs, partic- ularly wind turbines, and can be used as a source during peak hours to accomodate for the intermittency of RESs, particularly solar.

3.5.3.V2G Capacity-Estimation Method

V2G is a concept in which energy from EV is supplied to the grid. Various other terminologies such as vehicle to home (V2H) and vehicle to building (V2B) are also commonly used. V2G can be used for many applications such as to supply additional energy during periods of maximum demand or high electricity price. However, as V2G requires using a fraction of battery life, EV users may be reluctant to enter into an agreement with building operators unless there are considerable monetary or convenience benefits. The V2G concept also enables the utilization of EV batteries as storage for leveling the intermittency of RESs. For utilizing EV batteries as SES, V2G capacity has to be estimated in real-time for efficient and optimum control of the V2G operation. The V2G estimation methods available in the literature mainly focus on determining the achievable power capacity for a group of EVs. Apart from the capacity estimation, other methods have been proposed for aggregating EVs and supplying V2G power to the grid . The aggregation process is also governed by the amount of power and energy that the EVs can supply during any given interval. The V2G capacity estimation can be based on many factors/constraints, but the two most important factors to be considered in V2G capacity estimation are discussed below

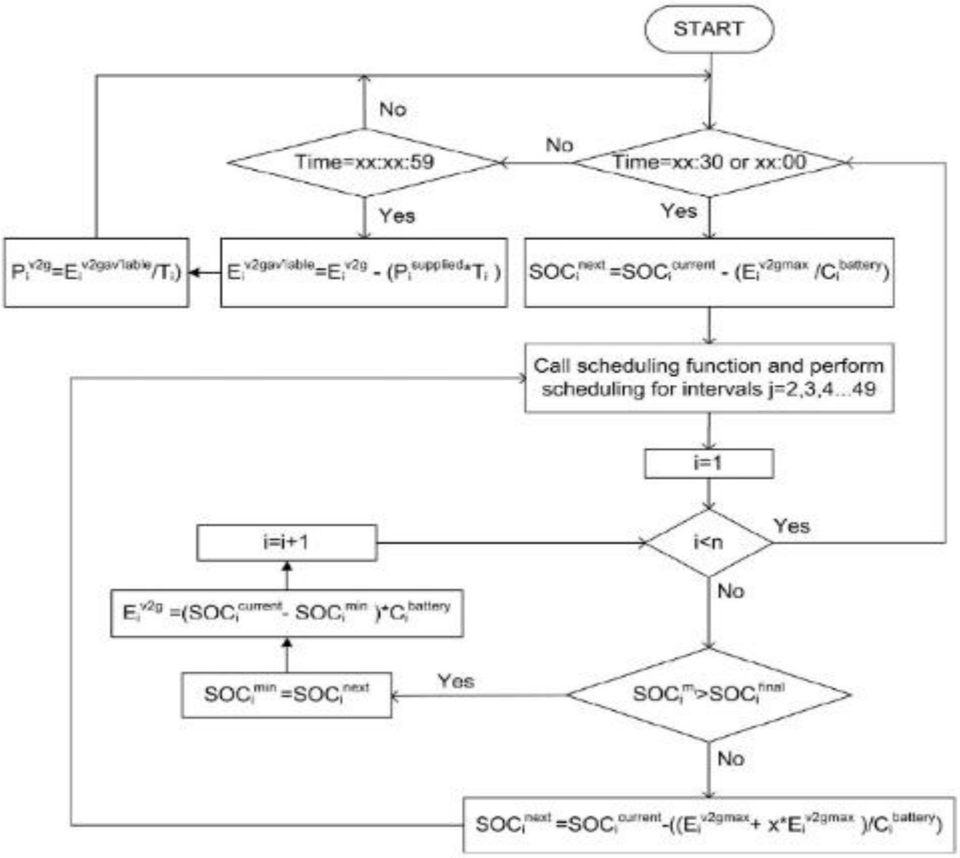

Fig 3.4. V2G capacity estimation algorithm

Part A

1. What are the different smart energy storage systems
2. List the advantages of Lithium ion battery
3. What is V2G
4. List the four problems associated with hydrogen storage
5. what is the current status of electric vehicle

Part B

1. Describe the different types of electric energy storage.
2. Discuss the potential of Sodium-Sulfur Battery Energy Storage to Enable Integration of Wind-
3. Explain V2G Capacity Estimation algorithm in detail.

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4.1. Smart Grid-Introduction

High-quality electricity is a necessity in the modern world, due to the innumerable applications demanding quality power, such as electronic manufacturing, microprocessors, and many sensitive devices being used by common man. Hence, it is imperative of the electric utilities world overto supply affordable, reliable, and quality electric power to all In a traditional power system, centralized generating stations generate bulk power which is transmitted to the consumers through a one-waytransmission and distribution system called the grid. Modernization of the grid is a priority for all the utilities, and governments are devising policies and practices driving the TRANSCO and DISCOs to moderniza- tion of the grid.

The motivation for modernization are many fold with specific goalsin mind

1. To make the production and delivery of electricity more cost- effective and efficient
2. To provide consumers with electronically available information andautomated tools to help them make more informed decisions about their energy consumption and control their costs
3. To help reduce production of greenhouse gas emissions in generat- ing electricity by permitting greater use of renewable sources
4. To improve the reliability of service
5. To prepare the grid to support a growing fleet of electric vehicles inorder to reduce dependence on oil
6. To facilitate the integration of distributed resources into the grid andprepare the grid for the challenges involved
7. To delay investment intended to add capacity to generation, trans-mission, and distribution networks

Smart grid is the solution to the above concerns and will be discussed in detail in the following sections.

4.1.1. Smart grid definition and development

A smart grid delivers electricity from suppliers to consumers using digital technology to save energy, reduce costs, and increase reliability. It connects everyone to abundant, affordable, clean, efficient, and reliable electric power anytime, anywhere, providing a way of addressing energyindependence and global warming issues.

Smart grid is a concept and may look different for different stakeholders. However, the envisioned smart grid concept will

- Motivate and include customers
- Resist attack
- Provide power quality for the 21st century
- Accommodate all storage and generation options
- Enable markets
- Optimize assets and operate efficiently

- Be self-healing

Smart grid is definitely the integration of the available electrical infrastructure with enhanced information capabilities, and it incorporates automation and information technology with the existing electrical network, so that the grid can operate in a smarter way. Smart grid implementations will provide comprehensive solutions that will improve power reliability, operational performance, and productivity for utilities. By making the grid smarter, energy use is managed efficiently, and customers will be able to save money without compromising on lifestyle. Optimal integration of renewables into the grid is a major benefit of smart grid implementation, and there will be substantial penetration of renewables in a smart grid scenario. Smart grid will provide meaningful, measurable, and sustainable benefits to all stakeholders by increasing energy efficiency and reducing carbon emissions.

A Smart Grid is an electricity Network based on Digital Technology that is used to supply electricity to consumers via Two-Way Digital Communication. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce the energy consumption and cost and maximise the transparency and reliability of the energy supplychain.

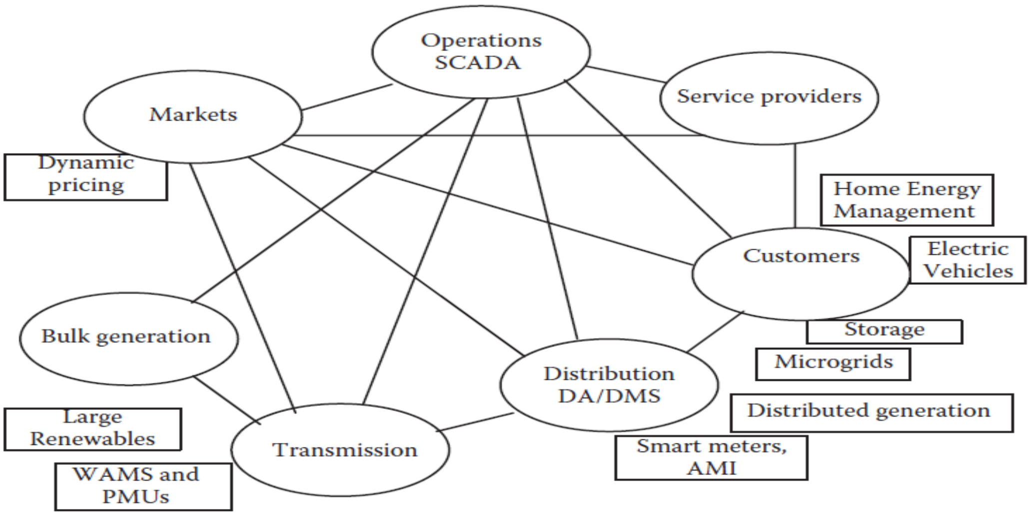

Fig 4. 1 Smart grid conceptual diagram

4.1.1 Application of Smart Grid

The areas of application of smart grids include: smart meters integration, demand management, smart integration of generated energy, administration of storage and renewable resources, using systems that continuously provide and use data from an energy network.

4.1.2.Benefits of Smart Grid

Reduction in AT & C losses

Reduction in CO2 Emission

Enabling Energy Audit
Reduction in Cost Billing
Remote Load Control

4.1.3.Advantages of Smart Grid

Improved Reliability
Higher asset utilization
Better integration of plug-in hybrid electric vehicles (PHEVs) andrenewable energy
Reduced operating costs for utilities
Increased efficiency and conservation
Lower greenhouse gas (GHG) and other emissions

4.1.4.Pillars of Smart Grid

Transmission Optimization
Demand Side Management
Distribution Optimization
Asset Optimization

4.1.5.Five Key Aspects of Smart Grid

The Five Key aspects of smart grid development and deployment are,
Computational Intelligence
Power System Enhancement
Communication and Standards
Environment and Economics
Test-bed

4.1.6.Features of Smart Grid

Reliability
Flexibility in Topology
Efficiency
Platform for advanced services

4.1.7. Challenges faced presently by the Indian ElectricitySystem

Shortage of power
Power Theft
Poor access to electricity in Rural areas
Huge losses in the Grid
Inefficient Power Consumption
Poor reliability

4.1.8.Self-Healing

A smart grid automatically detects and responds to routine problems and quickly recover if they occur, minimizing downtime and financial loss. Self-healing concept important to the Energy Infrastructure A secure architected sensing, communications, automation control, andenergy overlaid infrastructure as an integrated, reconfigurable, andelectronically controlled system that will offer unprecedented flexibility andfunctionality, and improve system availability, security, quality, resilience androbustness.

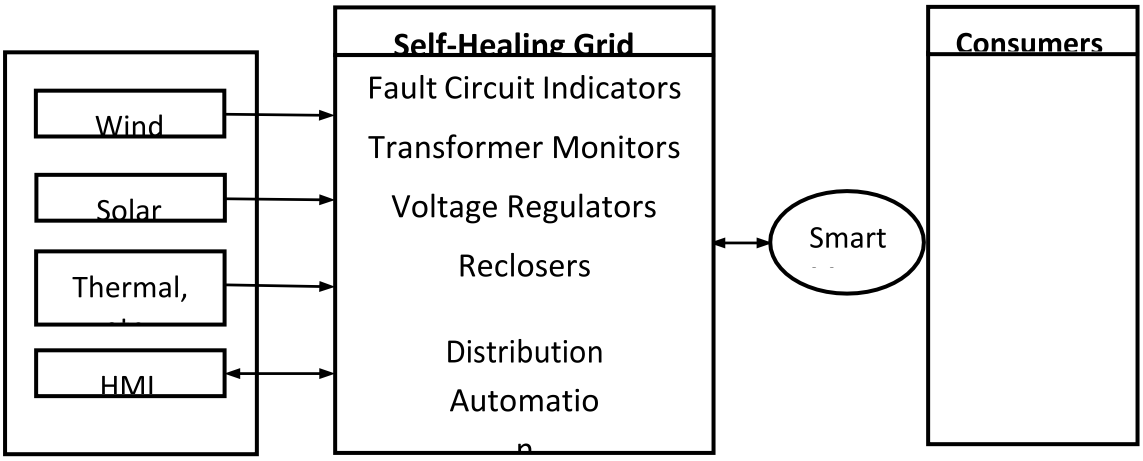

Fig 4.2. Self-Healing Grid

A smart grid automatically detects and responds to routine problems andquickly recovers if they occur, minimising downtime and financial loss. The Self-Healing Grid is a system comprised of sensors, automated controls, and advanced software that utilizes real-time distribution data to detect and isolate faults and to reconfigure the distribution network to minimize the customers impacted. One of the main goals of a Self-Healing Grid is to improve system reliability. This can be accomplished by reconfiguring the switches and reclosers installed on the distribution feeder to quickly isolate the faulted section of the feeder and re-establish service to as many customers as possible from alternate sources/feeders.

4.1.9. Requirements of Self-Healing Grid:

System topology representation
Feeders with single restoration path, generally open —tie switch‖
Pre-fault system status
Switch status (upstream and downstream information for devices)
Pre-fault system loading (capacity check for the restoration)
Fault detection
Based on recloser lockout status and reclosing counter value change, orsubstation breaker trip signal
Downstream node of the lockout switch is the fault location
Fault isolation
Downstream switch(es) of the fault location
Load restoration
Start from the downstream node of the isolation switches
Benefits
Allows utilities to focus investments on feeders that experience the mostoutages
Fast implementation

Initial low capital investment
Target solution appropriate for problem feeders
Smart Grid and the need of Smart Grid?
A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.
System (Generation, Transmission, Distribution) with an advanced two-way communications system
Enables real-time monitoring and control
Provide greater visibility and transparency
Consequently, enables cost reduction and efficiency improvement
Smart Grid is based on Digital Technology that is used to supply electricity to consumers via Two-Way Digital Communication. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce the energy consumption and cost and maximise the transparency and reliability of the energy supply chain.
The flow of electricity from utility to consumer becomes a two-way conversation, saving consumers money, energy, delivering more transparency in terms of end-user use, and reducing carbon emissions.
Need for establishment of Smart Grid:
A smart grid distribution system, whose objective is to develop a power grid more efficient and reliable, improving safety and quality of supply in accordance with the requirements of the digital age.
Higher Penetration of renewable resources or distributed generation
Extensive and effective communication overlay from generation toconsumers
Use of advanced sensors and high speed control
Higher operating efficiency.
Greater resiliency against attacks and natural disasters
Automated metering and rapid power restoration
Provided greater customer participation
Presently the Indian Electricity System faces a number of challenges such as:
Shortage of power
Power Theft
Poor access to electricity in Rural areas
Huge losses in the Grid
Inefficient Power Consumption
Poor reliability
To overcome these problems; smart grid is needed.
benefits of Smart Grid
Self-Healing :A smart grid automatically detects and responds to routineproblems and quickly recovers if they occur, minimizing downtime and financial loss.

A smart grid has security built in from the ground up.

Motivates and Includes the Consumer: A smart grid gives all consumers industrial, commercial, and residential-visibility in to real-time pricing, and affords them the opportunity to choose the volume of consumption and price that best suits their needs.

Reduction in AT & C losses,
Reduction in CO2 Emission ,
Enabling Energy Audit
Reduction in Cost Billing
Remote Load Control
Shifting of Peak requirement to non-peak time [Peak Shaving]
Integration of Renewable Energy
Clean Energy Development.
ProvidesPower Quality
Optimizes Assets and Operates Efficiently
Safety, Reliable and Efficient
Improved National Security
Improved Environmental Conditions
Improved Economic Growth

Smart Grid drivers?

Drivers of Smart Grid

Increasing demand:Information and communications technology, Measurement and control Demand response, Advanced metering infrastructure (AMI)
High Aggregate Technical &Non-Technical, Losses:18%-62%
Ageing Assets: Transformers, Feeders etc.,
Grid to carry more power: Need for, Reliability and greater Security
Billing and collections: Profitability of distribution companies
Energy mix: Need for Renewable Energy [Hydro Power, Solar ThermalEnergy, Wind, Biomass, Biogas] to reduce carbon footprint
Deliver sustainable energy:Voltage & VAR control, Resource planning, analysis, and forecasting tools, Fault Detection, Identification,and Restoration (FDIR)
Increased efficiency:Direct load control, Distributed energy resources,Distributed energy resources integration, Energy storage, Advanced metering infrastructure (AMI)
Empower consumers:Consumer education and awareness, Residentialconsumer energy management, Information and communications technology
Improve reliability:System wide monitoring, Measurement and control,Distributed energy resources, Distributed energy resources integration, Energy storage, Advanced metering infrastructure (AMI)

Stages on Evolution of Smart Grid

	Elementary Stage	Evolutionary Stage	Fully Integrated Smart Grid
Metering	Largely Manual Metering Some automated Meters for large industrial users	100% Smart meters with automated meter reading with real time display	Advance metering allowing real time ratechanges and remote On/Off capability
TransmissionGrid	Zero automation in transmissionlines, switches and substations	Ongoing automation ofHV system and substations	Full automation of HVSystem and Substations All switches and flowsremotely controlled
Distribution Network	Zero automation of distribution network including substations & circuit breakers Manual fault localisation	Partly automated switches & circuit breakers along MV linesfor fault identification Manual LV Grid	Fully remotely automated distributionnetwork with remote sensing and voltage control capability
Integration	Basic communication between grid components Limited ability to control dispatch	Online monitoring of flows in transmission grid and ability to balance system	Total integration ofsupply and use of electricity Ability to control dispatch and usageremotely

Comparsion between Conventional Grid and Smart Grid

Sl.No.	Smart Grid	Conventional Grid
1.	Self-Healing	Manual Restoration
2.	Digital	Electromechanical
3.	Pervasive Control	Limited Control
4.	Two-Way Communication	One-Way Communication
5.	Distributed Generation	Centralized Generation
6.	Network	Hierarchical
7.	Adaptive and Islanding	Failures and Blackouts
8.	Sensors Throughout	Few Sensors

9.	Remote Check/Test	Manual Check/Test
10.	Self-Monitoring	Blind
11.	Many Customer Choices	Few Customer Choices
12.	Extensive real time monitoring	Lack of real time monitoring
13.	Extremely quick reaction time	Slow Reaction time
14.	Energy Storage	No energy Storage
15.	Increased customer participation	Total control by Utility

Functions of Smart Grid Components

The areas of application of smart grids include: smart meters integration, demand management, smart integration of generated energy, administration of storage and renewable resources, using systems that continuously provide and use data from an energy network

Smart Devices Interface Component

Smart devices for monitoring and control form part of the generation components real-time information processes.

These resources need to be seamlessly integrated in the operation of both centrally distributed and district energy systems.

Storage Component

Due to the variability of renewable energy and the disjoint between peakavailability and peak consumption, it is important to find ways to store the generated energy for later use.

Options for energy storage technologies include pumped hydro, advance batteries, flow batteries, compressed air, super-conducting magnetic energy storage, super capacitors, and flywheels.

Transmission Subsystem Component

The transmission system that interconnects all major substation and loadcenters is the backbone of an integrated power system.

Transmission lines must tolerate dynamic changes in load and contingency without service disruptions.

Efficiency and reliability at an affordable cost continues to be the ultimate aimsof transmission planners and operators.

Monitoring and Control Technology Component

Intelligent transmission systems/assets include a smart intelligent network, self-monitoring and self-healing, and the adaptability and predictability ofgeneration and demand robust enough to handle congestion, instability, and reliability issues.

This new resilient grid has to withstand and be reliable to provide real - time changes in its use.

Intelligent Grid Distribution Subsystem Component

The distribution system is the final stage in the transmission of power to end users. Primary feeders at this voltage level supply small industrial customers and secondary distribution feeders supply residential and commercial customers.

At the distribution level, intelligent support schemes will have monitoring capabilities for automation using smart meters, communication links between consumers and utility control, energy management components, and AMI

Demand Side Management Component

DSM options provide reduced emissions in fuel production, lower costs, and contribute to reliability of generation. These options have an overall impact on the utility load curve.

Demand side management options and energy efficiency options developed for effective means of modifying the consumer demand to cut operating expenses from expensive generators and defer capacity addition.

The Challenges of Smart Grid Technology

Technology	Challenges	Obligations
Self-Healing Action	Security	Exposed to internet attacks (Spasm, Worms, virus etc.), question of National security
	Reliability	Failure during natural calamities, system outagesand total blackout
Renewable Energy Integration	Wind/Solar Generation	Long-term and un-predictable intermittent sources of energy, unscheduled power flow and dispatch
	Power Flow Optimization	Transmission line congestions and
	Power System Stability	Decoupling causes system stability issues causes reduced inertia due to high level of windpenetration
Energy Storage Systems	Cost	Expensive energy storage systems like Ultra-capacitors, SMES, CAES etc.
	Complexity	Complex customary design module and networks
	Non- Flexibility	Unique designs for all individual networks not ease adaptation.
Consumers Motivation	Security	Malware, data intercepting, data corruption, Illegal power handling and Smuggling
	Privacy	Sharing of data cause privacy invasion, etc.,
	Consumer awareness	Corruption and system threats like security andprivacy issues
Reliability	Grid Automation	Need of strong data routing system, with secure and private network for reliable protection, control and communication
	Grid Reconfiguration	Generation demand equilibrium and power systemstability with grid complexity

Power Quality	Disturbance Identification	Grid disturbances due to local faults in grids, loadcentres or sources
	Harmonics Suppression	System instability during sags, dips or voltage variation such as over-voltages, under-voltages,voltage flickers, etc.

4.2 Smart grid solutions

Migration to smart grid enhances the power system performance in many ways, and the major foundations of a smart grid implementation are the solutions. Traditional device and system development continues, but with smart grid the industry has transitioned to solutions. A solution is a set of technology components integrated to successfully interoperate to address the business needs of the electric utility customers. In general, the six solutions with the strongest business cases are

- Asset optimization
- Demand optimization
- Smart meter and communication
- Distribution optimization
- Transmission optimization
- Workforce and engineering design optimization

Shared Services and Applications					
Asset Optimization	Demand Optimization	Smart Meters and Comms	Distribution Optimization	Trasmission Optimization	Workforce and Engineering Design Optimization
Interoperability Framework					

Figure 4.3 Smart grid interoperability framework.

Figure 4.3 gives a clearer picture of the foundations, and the following sec- tions elaborate the functions of each foundation.

4.2.2 Asset optimization

Asset optimization includes proactive equipment maintenance via equip- ment condition monitoring and produces a lot of advantages for the power industry. Focused maintenance can be done on equipment, and asset opti- mization will definitely reduce outages and risks of failure as the assets are monitored and assessed continuously. This leads to better utilization of assets, and a utility can squeeze more capacity from existing equipment and devices. Savings are achieved due to the delayed investment in additional equipment. Asset optimization also includes use of intelligent sensors and equipment as discussed earlier and shown in Figure 4.4.

4.2.3 Demand optimization

Demand optimization is a major paradigm shift in the history of power distribution due to customer involvement. The main feature of demand optimization is the peak consumption reduction by consumers, thereby reducing the peak load and hence the generation at the utility. This is achieved through distribution management systems, in-home enabling technologies, such as smart meter, and the associated communication infrastructure, as shown in Figure 7.5.

Shared Services and Applications		
Intelligent Sensors	Monitoring and Diagnostics	Desision Engine

Fig.4.4 Asset optimization.

Shared Services and Applications		
DR Mgmt. Software (DRMS)	Comms. (ISP)	In-Home Enabling Technology
Interoperability Framework		

Fig. 4.5 Demand optimization.

For example, the United States has an installed capacity of 1,000,000 MW, and if 20% of this capacity is used only 5% of the time, this essentially means that 200,000 MW capacity generation, transmission, and distribution resources worth $300 billion are utilized for only 5% of the time. It may be worthwhile to see how these assets can be better utilized if we understand demand response by involving customers. This can be achieved by incentivizing the customers for opting for demand response while implementing automated load cuts from the substation along with additional incentives.

Thus demand optimization results in delay or avoidance of addi- tional investment; thus, better utilization of the existing infrastruc- ture is achieved. It also encourages customer empowerment, increases satisfaction and loyalty of the customers, and allows customers to save money by reducing electricity bills.

7.2.4. Distribution optimization

Distribution optimization revolves around the automation of the distri- bution system, as discussed in Chapter 6, which involves automating, the distribution substations, feeders, and the customers. Although cost intensive, the distribution automation brings added advantages to the utility as it opens the pathway to the smart grid implementation and all the associated functionalities.

Shared Services and Applications				
Feeder Automation	Substation Automation	Advance Distribution Applications	Distribution Management System	Adjacent Technology
Interoperability Framework				

Fig. 4.6 Distribution optimization.

Another important feature of distribution optimization is the renew- able integration at the feeder level and at the customer level. This inte- gration creates additional advantages like reduction in peak demand, deferred capital investment, satisfied customers, and so on. However, it causes integration and operational issues for the distribution system, unpredictable output of the renewable resources, storage problems, and finally the structure development. Distribution optimization will ensure less energy waste, with higher profit margins by reducing the losses in the distribution systems. Figure 7.6 shows the components of a distribution optimization solution.

Plugged hybrid vehicle integration is another aspect of distribution optimization. With more companies manufacturing electric vehicles, it is imperative for the distribution utility to utilize adequate charging facili- ties and infrastructure to cope with the growth.

Thus, distribution optimization allows cleaner, greener generation, which implies emission reduction with improved efficiency and reliability.

7.2.5 Smart meter and communications

Smart meter is the brain of customer automation and in a way the imple- mentation of demand optimization. Smart meter with well-defined func- tionalities at the customer premises enables both customers and the utility to reap the benefits of automation. A two-way communication infrastructure for the smart meter interaction with the utility is a challenge, because as in distribution systems, these have to be developed from scratch. Utilities are investing in this segment so that the benefits of smart grid can be reaped completely. Enabling technologies for network connectivity, consumer enablement, demand optimization, and improved

<table>
<tr><td colspan="4">Shared Services and Applications</td></tr>
<tr><td>Metering</td><td>Communication Network</td><td>Network Management System (NMS)</td><td>Grid Data Manager</td></tr>
<tr><td colspan="4">Interoperability Framework</td></tr>
</table>

Fig. 7.7 Smart meter and communication solutions.

operations are a few features of smart meter and communication optimization. Figure 4.7 gives the smart meter and communication infrastructure solution architecture.

4.2.6 Transmission optimization

Transmission optimization involves wide-area monitoring protection and control, and it improves the reliability and efficiency of the transmission. Earlier the state estimation and other related transmission SCADA applications were dependent on the 2 s status and 10 s analog data acquired by the SCADA system. With the deployment of phasor measurement units and phasor data concentrators, the state estimation and related applications produce more reliable and faster data, and the operators are better equipped to deal with contingencies. Great improvement in reliability and efficiency of the system is achieved by the WAMS implementation. Figure 7.8 shows the components of transmission optimization solutions. Another interesting feature of transmission optimization is the integration of large renewable energy sources to the grid, such as wind farms and solar farms. This leads to cleaner generation although it brings in a set of problems and challenges in operating the grid, mainly due to the uncertainty involved in the renewable energy prediction. 5.

<table>
<tr><td colspan="3">Shared Services and Applications</td></tr>
<tr><td>Substation Management</td><td>Grid Management</td><td>Adjacent Technology</td></tr>
<tr><td colspan="3">Interoperability Framework</td></tr>
</table>

Figure 4.8 Transmission optimization.

<table>
<tr><td>Shared Services and Applications</td></tr>
</table>

T&D Infrastructure Management	Workforce and Work order Management	Mobile Computing	Comms Infrastructure Management
Interoperability Framework			

Fig.4.9 Workforce and engineering optimization.

4.2.7 Workforce and engineering optimization

A rapidly evolving workforce is reshaping the risk profiles of power and utilities organizations, posing challenges to their traditional control and compliance capabilities. A more systematic approach to capturing and keeping core know-how and new ways of transmitting that knowledge to a younger generation are necessary. Approximately 40% of current employees and 60% of current executives are eligible to retire in 5 years in the USA for instance. Workforce-enabling technologies such as automated workforce deployment and field force automation have led to increased workforce productivity and work satisfaction. As discussed in Chapter 6, many utilities are engaged in updating and integrating the functional- ities in a distribution control room such as DMS, OMS, GIS, AMI, and so on, so that the dispatcher and other workforce get maximum information and effective tools for data usage. Data warehousing to help the different departments of the electric utility has already been discussed.

4.3Smart Grid and Industry 4.0 Challenges

Smart grid systems are complex, sophisticated, and they combine many interconnected components. These various components and the emerging nature of smart grids has introduced several challenges that must be addressed to ensure a robust, reliable and scalable grid. This section briefly presents the main challenges commonly discussed in literature.

4.3.1 Communication System Challenges

communication system challenges in 3 main issues, interference, the need for common standards and data transmission rates.

a. Interference can be caused by home devices' signals that interfere with smart meters, or by harmonics emission in the grid itself. Interference can be addressed using interference detection and channel switching techniques.

b. Standards for the smart grid are necessary to provide a framework for all the different components of the grid to work together. There are current efforts by various organizations, such as IEEE, or the American National Standards Institute, to develop such standards.

c. Data transmission rates can be managed by choosing the correct transmission protocol for each application.

4.3.2Big Data Challenges

Big data refers to the huge amounts of data produced by modern information systems and the processing power required to analyze and store that data. It is a known concept in ICTs that introduces a number of challenges that need to be addressed. Following is a brief discussion of some of the challenges that smart grid systems face in regard to big data.
a. Real-time applications: Smart Grids are meant to adapt to the consumers consumption levels, which is constantly changing, this requires real-time data collection from a large number of smart meters at varying rates. The grid must also be able to process that data and execute changes based on it in a near real-time operation. Some of the methods developed for IoT applications to address this issue can also be applied to the smart grid. For example, using predictive algorithms on house appliances to determine the levels of data to be expected from a smart meter at any time of the day which would help allocate processing resources accordingly.
b. Heterogeneous Data: The grid receives data from a number of different sources and in different formats, for example usage data, monitoring data, capacity levels, error message, authentication messages, metadata, etc. This data originates from different sources such as meters, sensors, actuators, stations, smart home devices, historical data, mobile applications and others. This is known as heterogeneity of data, meaning the grid has to handle structured, semi-structured, and unstructured data at the same time. There are several techniques to address this problem, such as data integration, data fusion and development of standardized software solutions that unify data formats across different devices

c. Data compression and visualization: The data collected in the grid require storage and could also provide valuable analytic information, requiring extra processing. Compression methods should be efficient and work in real-time. Visualization can present the data in understandable graphs and charts.The choice of the right visualization method and presenting the data in the right way is a difficult process that needs to be considered carefully. Both compression and visualization require ore research and development of standardized methods.
5.3. Challenges in Cloud Computing

Cloud computing technology offers an efficient solution for processing data in the smart grid, but there are some reliability issues when working in this context that should be accounted for. First, there are security concerns due to the lack of consistent policies regarding data location which can compromise privacy. Second, the lack of disaster ecovery plans, which can compromise availability. Other concerns include international laws in regards to data stored at different countries, error management, and data rates. Other issues related to CC are Cost, compatibility and quality of service .

Typically, those challenges must be addressed through careful selection of cloud service providers that offer support as well as drafting agreements with said providers to ensure hat international laws are upheld and service quality as maintained.

5.4. Security Challenges

Since smart grid systems are cyber-physical, they are vulnerable to cyber-attacks that can affect physical systems, making any security threat dangerous and highly impactful. Furthermore, there are many economic and political reasons that motivate targeting the smart grid in order to compromise the vital energy market. There is a wide range of threats to the security of the grid. [36] notes that different sources classify threats and attacks based on different variables., for example the exploited device (Sensors, Network devices, smart meters, etc.), the system architecture layers they target (communication layer, application layer, etc.), or on the security objective they disrupt (integrity, availability, confidentiality). Some attacks identified by researchers can describe multiple variations, for example Denial of service (DoS) attack can be an umbrella term for Jamming or flooding, at any level of the grid. Figure 3 summarizes the challenges in SGI 4.0 systems and applications.

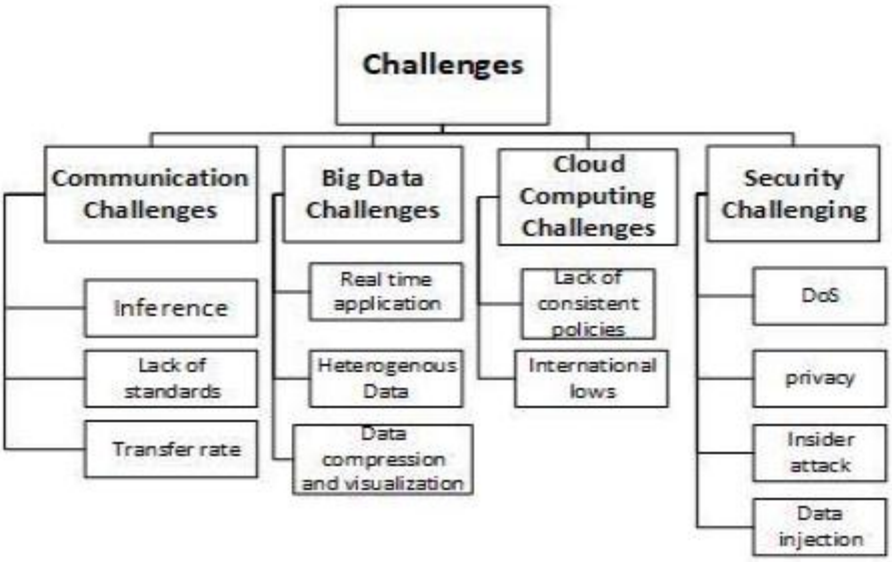

Fig 4.12 Challenges of I4.0 and smart grid integration

The following is a brief discussion of the main threats to the grid.
a. DoS attacks: Denial of service refers to a large number of attacks that cause a system to become overwhelmed and render it incapable of providing services required. This can be particularly threatening to a smart grid system because of its real-time operations. The control messages in the system are time critical and a few seconds delay can compromise all system operations. Advanced DoS attacks are hard to detect because they are disguised as legitimate traffic or are taking over trusted sources that it becomes hard to block all attacks. Furthermore, such attacks can come from different sources so it is impossible for one or several service providers to control. To reduce the impact of such attacks, the

development of cyber resilient systems capable of withstanding multiple relentless attacks is important [37]. Another mothod thatcan be used to reduce DDos attacks is IP fast hopping, which disguses the true IP address of a service so that it becomes harder to target by attackers .

b. Data injection: These attacks occur when a malicious entity alters codes and database ntries to disrupt thesystem. The smart grid is vulnerable to this kind of attack because of the various devices connected to it that provide access points for attackers. Moreover, this kind of attack can have a wide range of effects on power systems, from disrupting the real-time nature of the grid, to committing fraud by manipulating smart meter readings and power pricing [39]. Data injection attacks are hard to detect by nature d it's is betterto prevent them, using smart security systems with dedicated authentication to limit the probability of these attacks.

c. Privacy: Smart Grid systems collect a range of user data, such as location, payment nformation power usage and preferences. This information can be used maliciously to track and harm users. Even information that might seem irrelevant can be used against the customer. For example, a user's power usage trends can help predict what time they leave the house thus allowing thieves to target their house, or n electrical devices company can use preferences of the user to advertise directly to them and gain advantage. That is why protecting users' privacy and information is very important. Multiple methods can be used to preserve privacy in smart grids, such as anonymization of data, masking sources, encryption and aggregating data using various methods that disassociate users from data .

d. Insider attacks: Insider threats, or attacks committed by anyone with legal access to the ystem, are dangerous because traditional security measures such as firewalls and passwords cannot stop them from causing damage. Some hiring practices like background check can help limit insider threats. There are also some technological solutions such as anomaly detection systems that can spot any irregular behavior , or the use of authenticated access control via gateway devices and software solutions .

Part A

1. What is smart grid

2. List out the advantages of smart grid

3. compare conventional and smart grid

4. Give any four components of smart grid system

5. What is smart energy metering

Part B

1. Write a note on smar grid soultions
2. What are design challenges in smart grid and Industry 4.0 integration.

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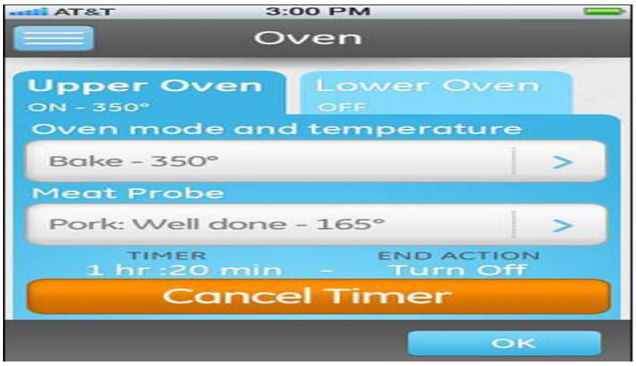
5.1 Understanding Smart Appliances

The use of the term “smart” is as much a marketing ploy as it is a true descriptor for anything connected to the Internet of Things. Different companies define smart in different ways, as do different industries. A smart TV might be more or less intelligent than a smart water softener or smart car, but they’re all equally smart in the eyes of the marketing guys .So what does it mean when we call an appliance “smart”? It all has to do with automating routine operations.

5.1.1 Smart Operation

The first thing that many will find smart about smart appliances is the ability to manage them remotely. We’re used to setting a timer or a given start time to fire up the oven or activate the dishwasher; this sort of timed start is useful for starting dinner before you get home from work, or running water-intensive appliances later at night when nobody’s taking a shower.

With smart appliances, this automatic operation gets more flexible. Instead of manually setting a timer on the front panel of a device, you can use an app on your smartphone or tablet to remotely press the start button on a given appliance. Some apps even let you program operations in advance—like setting a manual timer, but more sophisticated. For example, General Electric’s (GE’s) Brillion smartphone app, shown in Figure 4.1, offers remote operation of select wall ovens. You can be miles away at work, with a big pan filled with a roast in the oven (you put it there before you left in the morning), and all you have to do is tap the app to start up the oven and start cooking. Or maybe you want to preheat your oven to a certain temperature for use when you get home. In any case, it’s easy-as-pie remote operation, all thanks to a convenient mobile app and Internet connectivity.



Upper Oven ON - 350°

Lower Oven OFF

Oven mode and temperature: Bake - 350°

Meat Probe: Pork: Well done - 165°

TIMER 1 hr :20 min - END ACTION Turn Off

Figure 5.1 *Control your GE wall oven with the Brillion app.*

Even better is LG’s new HomeChat app, which lets you send text messages to your appliances just as if they were human. (HomeChat operates via the popular LINE messaging app.) As you can see in Figure 4.2, you use text messages to send commands to your appliances in plain English—and receive messages from them via text, as well. Right now, you can text basic operation commands, but you may eventually be able to text your fridge, "Is the milk fresh?" and receive an answer in return.

READ 8:30AM We will be going on a trip for 3 days.

LG HomeChat: Have a nice trip. 8:30AM

LG HomeChat: I am going to miss you! 8:30AM

LG HomeChat: Switch to Vacation Mode? 8:30AM

READ 3:31PM OK!

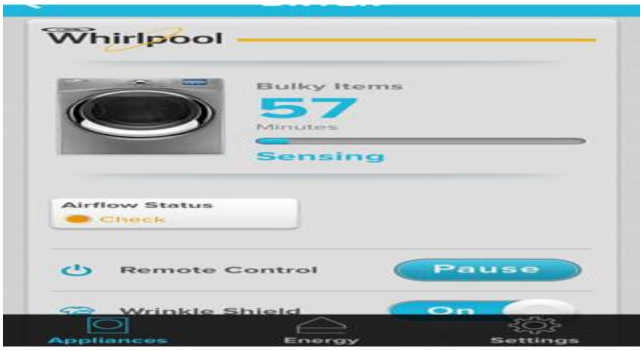
LG HomeChat: Initiating Smart Power Saving Mode. 8:31AM

Figure 5.2 *Chat with your appliances with the LG HomeChat app.*

5.1.2 Smart Monitoring

For a smart appliance to be truly smart, it must monitor its environment and operation to let you know about things you need to know about. That means sending out some sort of alert or notification when a given operation is done or when something unexpected happens. Today, appliances typically alert you with a loud buzzer or rinky-dink snippet of music. Smarter appliances will send out smarter notifications.

For example, a smart washer might send a notification to its corresponding smartphone app when the washing cycle is complete. Or maybe you'll get a text message notifying you that your dinner is finished cooking in your smart oven. Or how about an email alert if somebody leaves the refrigerator door open?The key is to use connected technology to notify you of important stuff happening in the kitchen or laundry room. We have the technology; we can do this.For example, Whirlpool's My Smart Appliances app, shown in Figure 4.3, lets you monitor the status of all your appliances on your smartphone screen. You can see how much time is remaining for your loads, get notified when a washing or drying cycle is complete, or see how cool your refrigerator is today. It's a lot better than hanging around the laundry room waiting for the buzzer to sound.



Bulky Items
57
Minutes
Sensing

Airflow Status
Check

Remote Control: Pause

Wrinkle Shield: On

Figure 5.3 *Monitor your laundry equipment with Whirlpool's My Smart Appliances app.*

5.1.3. Smart Energy Savings

Some of today's smart appliances use their smarts to cut down on energy usage. If an appliance knows when power consumption is lower or rates are cheaper, it can program itself to operate during those times. In addition, smart appliances typically include other energy-efficient functionality, such as a dishwasher using less water per cycle or a refrigerator incorporating more insulation to keep things frosty.

For example, LG's Smart Grid technology detects when local power consumption is lowest and schedules more operations during that time. Figure 4.4 shows one of the Smart Grid configuration screens. (Note that this feature is only available to those homes served by a Smart Grid power company.)

Smart Saving

Demand Response Functionality: ON [✓ OFF]

The Demand Response feature will lower energy usage based on signals from your utility company or energy service provider. When On, the feature is activated and Demand Response signals can be received. If you want to override or change the duration of an event, select the Smart Grid event below

Delay Defrost Capability: [✓ ON] OFF

The Smart Saving feature will lower energy usage at 6:00am-10:00am and 3:00pm-7:00pm daily as default. To change the time period, select the Smart Saving event below to a customized time period.

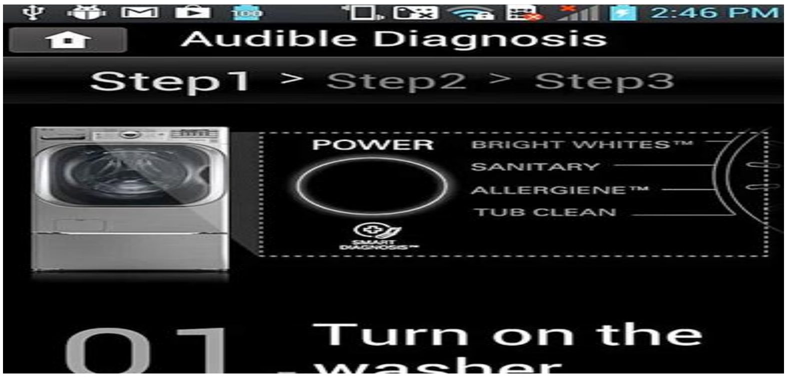
Figure 5.4 *Increase energy efficiency with LG's Smart Grid technology.*

5.1.4 Smart Maintenance

Then there's the process of keeping your smart appliance up to date and in tip-top operating condition. This involves having the right sensors within each appliance to determine when some maintenance needs to be done or when some function isn't properly functioning. Then, instead of just flashing a light on the appliance's front panel, you get notified (via app, text message, or email) about the issue at hand. Ideally, the message includes advice or instructions for what you should do next.

For example, you're probably used to seeing an alert light above your refrigerator's water dispenser when the water filter needs to be changed. With a smarter refrigerator, you'd get a text message or email to that effect instead. Same thing when you need to add more fabric conditioner to your smart dryer, or if the hot water in your dishwasher isn't getting hot enough.

It's all about smart diagnostics and alerts making you more aware of things you need to be aware of—and aiding in the diagnosis when things go wrong. For example, LG's Smart Diagnosis app, shown in Figure 4.5, helps you troubleshoot issues by transmitting relevant data over Wi-Fi to the related smartphone app. This data can then be passed on to LG's Call Center for their technicians to analyze. It certainly reduces the guesswork.



01 Turn on the washer

Figure 5.5 *Diagnose problems with LG's Smart Diagnosis app.*

5.1.5. Technical aspects:

IoT involves small devices, each with their own Internet Protocol (IP) address, connected to other such devices via the Internet. In other words, lots of little "things" connected to lots of other little "things" over the Internet. Instead of connecting people to other people, as does the current Internet, the new Internet of Things connects things to things. That sounds simple.

Except, a lot of the so-called smart devices ballyhooed as part of the IoT don't have their own IP addresses, don't connect to the existing Internet, and don't even connect to other devices. Which means the IoT isn't just about connecting things to things; it's also about autonomous operation—things that can operate pretty much on their own, without a lot of human interaction.

5.1.6. Understanding Network Connections

For individual devices to communicate with other devices in the IoT, they must be connected to some sort of network. A network exists when two or more devices are connected together, typically for the purpose of transmitting or sharing data or other communications.

When we’re talking about the IoT, the network connection is typically wireless. That’s a matter of practicality; it would be difficult if not impossible to connect all the billions of smart devices to one another using cables, of whatever sort. It’s a lot easier to connect devices to one another, to central hubs, and to the Internet when those connections are wireless.

5.1.6.1. How Traditional Networks Work

In a traditional network, wireless or wired, individual devices do not connect or communicate directly to each other. That is, the computer in your living room doesn’t communicate directly with the one in your office, nor does your smartphone connect directly to your modem to access the Internet.Instead, each and every device on your network connects directly to a central hub called a *router*. all transmitted data passes through the router en route to another device on the network or to the Internet. (Assuming, that is, that the router itself is connected to the Internet, typically via some sort of modem.) Some call this a *hub-and-spoke* approach, and it’s how things work in most home and office networks today.

Data transferred over the network is broken into smaller pieces, for easier transmittal. When you’re sending a file to another device on a network or over the Internet, that complete file isn’t sent at once. Instead, the file is broken into multiple smaller data packets, which enables large amounts of data to be transferred without clogging the connection. The data packets are then reassembled at the receiving end by the appropriate networked device.To enable this disassembly/transmittal/reassembly process, all networked hardware must work in tandem with a predescribed set of networking transfer protocols. These rules determine how data is transmitted across the network.

The de facto standard network protocol today, used for both Internet and local area network (LAN) connections, is called *TCP/IP* (that’s short for *Transmission Control Protocol/Internet Protocol*). The *IP* part of this protocol provides the standard set of rules and specifications that enables the routing of data packets from one network to another. The *TCP* part of the protocol supports the necessary communication between two devices; it takes network information and translates it into a form that your network can understand. In other words, IP sets the rules and TCP interprets those rules.

Here’s how it works in practice. Let’s say that you want to copy a file from the PC in your home office to the PC located in your basement. When you click the Copy button, TCP establishes a connection between the two computers, and then IP lays down the rules of communication and connects the ports of the two computers. Because TCP has prepared the data for transmittal, IP then takes the file, breaks it into smaller pieces (data packets), and puts a header on each packet to make sure it gets to where it’s going. The TCP packet is also labeled with the kind of data it’s carrying and how large the packet is.

Next, IP converts the packet into a standard format and sends it on its way from the first computer to the second. After the packet is received by the second PC, TCP translates the packet into its original format and combines the multiple packets back into a single file.

5.1.6.2. Understanding IP Addresses

For TCP/IP to work, each device on a network needs to be properly configured with the proper information. In particular, each device needs to be assigned a local *IP address*, which is how the device is known by the network.

An IP address is a numerical label, kind of like a street address but with all numbers. In today's Internet, an IP address is a 32-bit number expressed as a "dot address" with four groups (or *quads*) of numbers separated by periods or dots, like this: **192.106.126.193**

Each of the decimal numbers represents a string of eight binary digits—0s and 1s, as it were. The first part of this address represents the network address, while the latter sections represent the address of the local device (also known as the *host address*).

An IP address is necessary for a network router to know which data goes to which connected device. As you can see in Figure 2.5, TCP/IP broadcasts data to the router, with a particular IP address identified as the recipient of that data. The router reads the IP address and then routes the data to the computer with that address.Every server or device connected to the Internet today is assigned its own IP address. In tomorrow's world of the IoT, every single device, no matter how small, must also be assigned an IP address.

This produces a bit of an issue, as the huge number of devices that need to be connected will easily exceed the available number of IP addresses—at least under the current IPv4 (that's version 4 of the Internet Protocol) address scheme. IPv4 allows for some 4.3 billion unique addresses, a large percentage of which are already assigned to existing devices.

The solution is the rapid adoption of the next-generation Internet Protocol, IPv6. (Yes, that's skipping from version 4 to version 6.) This new protocol expands the pool to a theoretical maximum 340 undecillion—that's 240 trillion trillion trillion—addresses, which should be more than enough to handle all the possible IoT devices. It's fair to say that the full-scale implementation of the IoT would not be possible without IPv6. IPv6 expands the number of available IP addresses by moving from a 32-bit address (in IPv4) to a 128-bit address. It's like changing from a three-digit number to a twelve-digit number—there are simply more possible numerical combinations when you have more characters to work with.

5.1.6.3. Examining Wireless Technologies

In a strictly wired network, devices connect to the router via Ethernet cables. If the network is wireless, the router contains a small radio that transmits and receives the wireless signals from all connected devices. There are several wireless technologies in use today. All transmit and receive (RF) signals at a specific frequency. These are the same types of signals used in AM and FM radio; the big difference is that an AM/FM radio only receives signals, whereas wireless networking devices both send and receive.

5.1.6.4.Understanding RF Technology

How exactly do RF signals work? It all starts with a single radio wave, which is nothing more than a pulse of electromagnetic energy. Radio waves are generated when a transmitter oscillates at a specific frequency. The faster the oscillation, the higher the frequency. An antenna is used to amplify and broadcast the radio signal over long distances.

To receive a radio signal, you need a radio receiver. The receiver is tuned to a specific frequency to receive signals oscillating at that rate. If the receiver is not tuned to that frequency, the radio waves pass by without being received. When we're talking about home networks, the Internet, and the Internet of Things, the radio in each connected device functions as both a transmitter and receiver.RF transmissions are spread over a broad range of frequencies, which are measured in cycles per second. For example, 93.5MHz is a frequency of 93,500,000 cycles per second. (MHz is shorthand for megahertz, or millions of cycles per second; GHz is shorthand for gigahertz, or billions of cycles per second.)

Current wireless networks use two distinct RF frequencies. Earlier equipment works in the 2.4GHz band (frequencies between 2.4GHz and 2.48GHz), while newer equipment can also utilize the 5GHz band (frequencies between 5.15GHz and 5.85GHz).

The 2.4GHz band is free for anyone to use, for any purpose. That's both good and bad—good because it can be used at no cost (without potentially expensive licensing fees), but bad because space within the band is finite, and several other types of devices also use this band.The 2.4GHz frequency range is alternately called the ISM band—for instrumentation, scientific, and medical usage.

Currently, the 2.4GHz band is used by 802.11 Wi-Fi networks, Bluetooth networks, newer cordless telephones, newer models of baby monitors and garage door openers, microwave ovens (!), urban and suburban wireless communications systems (including many emergency radios), and some local government communications in Spain, France, and Japan.

The 5GHz band, on the other hand, is relatively unused—and a lot wider, with more frequencies that can be used. (It stretches from 5.15GHz to 5.85GHz, remember.) Some cordless phones use this band, but not too many, so there's not a lot of competition for frequencies. Like the 2.4GHz band, it's unregulated, which means that it's free for any device to use—which becomes important when we start talking about the IoT.

5.1.6.5. Wi-Fi

Most home, business, and public wireless networks today utilize the Wi-Fi protocol. Wi-Fi (short for *Wireless Fidelity*) is the consumer-friendly name for the IEEE 802.11 wireless networking standard. Most of today's wireless networks are technically Wi-Fi networks and use Wi-Fi–certified products.The IEEE is the Institute of Electrical and Electronics Engineers, and it does things like ratify different technology standards. In the case of Wi-Fi, the technology is now regulated by a subgroup called the Wi-Fi Alliance. Learn more about it at the Wi-Fi Alliance website (www.wi-fi.org).But, here's the thing. There isn't a single Wi-Fi protocol. Instead, there are multiple 802.11 protocols, each designated by a one- or twoletter suffix. Different versions of Wi-Fi offer different levels of performance; the latest version, 802.11ac, operates on the lesser-used 5GHz band (but is backwards compatible with older devices operating on the more-established 2.4GHz band) with enough range to cover a fairly large house.

Wi-Fi networks utilize the hub-and-spoke configuration common to traditional networks. Each Wi-Fi–enabled device connects to the central hub or router and, via the router, is connected to other devices that are also connected to the router. The notebook computer in your living room does not connect directly to the streaming media box in your bedroom; the signals from one device go first to the hub and are then routed to the other device. If you have a dozen wireless devices connected to your Wi-Fi network, that's a dozen devices connected directly to the router.

Each of these devices has to be manually configured to connect to the network, typically employing some sort of wireless security technology. That's a lot of initial set-up necessary; while subsequent connections can be automated, every single Wi-Fi device must be connected by hand, so to speak, on first connection. If you were to have a hundred small IoT devices scattered throughout your living quarters, connecting them all via Wi-Fi would be impractical.

That said, given the ubiquitous nature of Wi-Fi today, it would be convenient for IoT devices to utilize Wi-Fi technology. And, in fact, many current devices do. If you have a smart TV in your living room, for example, it connects to the Internet via Wi-Fi, as do most other current devices.But it's unclear whether Wi-Fi is the best solution for all the connectivity required to implement a global IoT in the future. To that end, other wireless protocols might be better suited to handle the wireless communications between small sensor devices; these devices might then connect to a master device that then connects to the Internet or an appropriate service via Wi-Fi.

5.1.6.6. Bluetooth and Bluetooth Smart

When it comes to close-quarters, device-to-device wireless communications, *Bluetooth* is an interesting option. Bluetooth is similar to Wi-Fi in that it's a wireless technology that operates via RF transmission in the 2.4GHz frequency range. But it's different in that it isn't intended for use in hub-and-spoke networks; instead, it's designed for direct communication between devices—what's called *peer-to-peer networking*—which is how many speculate the IoT will end up working.

Today, Bluetooth is used to connect various devices to one another over short distances, such as your smartphone to your car audio system, or a wireless mouse to your desktop computer. It is not a good technology for transmitting large data packets over long distances; for that, Wi-Fi is still king.Bluetooth radios are extremely small, much smaller than Wi-Fi radios, which makes the technology ideal for miniature IoT sensor devices. They also consume very little power, which also fits into the IoT profile.

When one Bluetooth device senses another Bluetooth device (within about a 30-foot range), they automatically set up a connection between themselves—once the initial manual configuration is complete, of course. This connection is called a *piconet*, which is a kind of mini-network—a *personal area network* (PAN), to be specific.

In a piconet, one Bluetooth device is assigned the role of master, while the other device—and any subsequent devices, up to eight in total—is assigned the role of slave. The master device controls the communication, including any necessary transfer of data between the devices. Each piconet can contain up to eight different devices.

This means that, over short distances, a device such as a smartphone can connect to, synchronize with, and even control the other electronic devices in your home, office, or car—such as your personal computer, printer, television set, home alarm system, or car audio system. All this communication takes place in an ad hoc fashion, without your being aware, totally automatically.

Here's an example of how this works today. You have a smartphone that contains your contacts list. You need to synchronize this contacts list, which includes phone numbers, with your car's built-in dialing system. To do so, all you have to do is carry your smartphone with you when you enter your car. When you're close enough (and your car is powered on), your phone automatically connects to your car's system via Bluetooth, and then automatically synchs the contact data between your phone and the car. If you've added a new contact to your phone, it's also added to your car's system. You can then dial any of your contacts from your car's dashboard—all the communication is synchronized via the Bluetooth connection; no manual intervention necessary on your part.

If that doesn't sound IoT-friendly enough, there's *Bluetooth Smart*, a variation on Bluetooth technology developed especially for the Internet of Things. Bluetooth Smart is a version of Bluetooth that consumes only a fraction of the power of traditional Bluetooth radios. This power efficiency makes Bluetooth wireless connectivity practical for devices that are powered by small coin-cell batteries.

In addition, Bluetooth Smart operation can be tweaked by the hosting app. Instead of being limited to Bluetooth's standard 30-foot range, a Bluetooth Smart device can be optimized to work up to 200 feet away—ideal for in-home sensors where a longer range is necessary. Naturally, extending the range uses more power, so devices that don't need the range can be configured to use less power instead. It's an app-by-app tradeoff, perfect for the IoT.

5.1.6.7.Cellular Networks

Some IoT connections will utilize cellular networks—the same networks you use to connect your mobile phone. For example, the devices in a smart car might communicate with your home network or to the auto dealership by literally dialing in like a cell phone. It's quick and easy and utilizes a somewhat ubiquitous existing technology.

Cellular technology works a little differently than either Wi-Fi or Bluetooth technologies. While cellular signals carrying voice, text, and digital data are transmitted via radio waves, this information is transmitted not to a central hub in a small network of devices (as it is with

Wi-Fi) or even directly from device to device (as it is with Bluetooth), but through a global network of transmitters and receivers.

These networks of transmitting/receiving towers are built on a cellular design. (Hence, the terms “cellular network” and “cellular phone.”) That is, a mobile phone network is divided into thousands of overlapping geographic areas, or *cells*. A typical cellular network can be envisioned as a mesh of hexagonal cells, as shown in Figure 2.6, each with its own *base station* at the center. The cells slightly overlap at the edges to ensure that users always remain within range of a base station. (You don’t want a dropped call when you’re driving between base stations.)The cells in a cellular network vary in size, depending on how many calls are conducted within that geographic area. The smallest cells, which might cover only a few city blocks, are those where there’s the heaviest population density, and thus the largest demand for service. The largest cells are most often in rural areas with a smaller population per square mile.

The base station at the center of each group of cells functions as the hub for those cells—not of the entire network, but of that individual piece of the network. RF signals are transmitted by an individual phone and received by the base station, where they are then re-transmitted from the base station to another mobile phone. Transmitting and receiving are done over two slightly different frequencies.

Base stations are connected to one another via central switching centers which track calls and transfer them from one base station to another as callers move between cells; the handoff is (ideally) seamless and unnoticeable. Each base station is also connected to the main telephone network, and can thus relay mobile calls to landline phones.

Given the capability of transmitting data over long distances, cellular networks may play some part in IoT connectivity. A cellular connection wouldn’t be the best choice for connecting two devices over a short distance (such as inside a car), but could function as the primary connection between a master device and a more distant IoT hub or service.

5.1.6.8.Mesh Networks

As billions of new devices join the IoT, the networks they connect to will become increasingly crowded, leaving those networks—and the Internet in general—unable to handle the increased traffic. This is leading some companies to develop their own specialized networks for IoT connectivity.

One option is to employ a purpose-built, small-scale wireless network that enables devices to connect directly with each other, one after another, kind of like runners passing a baton in a relay race. This type of network, called a *mesh network*, enables the automatic hand-off of wireless signals from one device to another.

A mesh network is the opposite of a traditional centralized network. Where a traditional network connects all devices to a central server or hub, a mesh network can theoretically connect devices from one end of a city to another, one after another, as shown in Figure 2.7.

Each individual device on a mesh network might only have a range of 30 feet to 300 feet, but when they're connected end-to-end, they can cover a wide area.

A mesh network can contain thousands of individual devices all operating in concert. Because there are multiple routes through a mesh network, the failure of any individual device won't bring down the entire network; the signals will find a way using connections to alternate devices.

There are several protocols in development for IoT mesh networks. These protocols are being developed by INSTEON, theZ-Wave Alliance, and theZigBee Alliance. The INSTEON and Z-Wave protocols are proprietary, where ZigBee offers certification to ensure adherence to their standards. At present, networks based on different protocols are not interoperable, although it's possible to connect two mesh networks together using hubs.

5.1.6.9. Proprietary Cellular Networks

Other companies are developing their own purpose-built wireless technologies for IoT connectivity. Like the mesh networks just discussed, these machine-to-machine (M2M) networks are designed specifically for connecting small devices, not people or computers. By offloading M2M communications onto these dedicated networks, the current Internet will maintain bandwidth for effective operations.

Probably the most visible at this stage of the game is a French company called-Sigfox, which is employing its own version of a World War I-era radio technology that submarines used to communicate with each other under water. This technology enables very small bits of data—think Morse code messages—to travel relatively long distances. It operates in the 900MHz frequency range, the same band used by some cordless phones and baby monitors today.

Sigfox is using this technology to build a dedicated low-power, low-bandwidth cellular network optimized for the types of short data transmissions common with IoT devices. The network isn't the fastest around, transmitting small bits of information at just 100 bps, but typical sensor data doesn't need more speed than that. Consider the data collected and sent by a traffic sensor or water meter; this type of device typically sends only a few packets of data on an intermittent basis. Speed isn't important.

What is important is the ability to connect lots of these little devices. Sigfox trades speed for capacity; to that end, its network can support millions of connections.

In addition, by using the 900MHz band instead of the higher frequencies used by today's mobile carriers, Sigfox can space its towers further apart than with typical cellular networks. Even better, it's a low-power solution, so that the power it takes to transmit a given packet of data is a fraction of what is necessary with a traditional cellular radio.

The company is currently building networks in the United Kingdom (UK), Netherlands, Russia, and Spain, with its first United States (US)-based network in San Francisco. At this time, Sigfox is specializing in industrial networking. In Spain, it is employing its network to connect several million home security systems. In France, Sigfox's networks are being used to connect water meters, electronic billboards, and monitoring devices for seniors.

Interestingly, Sigfox's low-power networks are relatively inexpensive to build out. The company's Spanish network cost less than $19 million and took only seven months to complete.

Sigfox isn't the only company investing in proprietary networking technology. For example, Link Labs builds long-range M2M networks for public and private companies; On-Ramp Wireless builds custom networks for oil field operators; and Iotera is building a network to monitor global positioning system (GPS) trackers for pets and children.

Not everyone agrees with Sigfox that a separate network is needed for the IoT. Some view the development of proprietary networks as unnecessary and unproductive, perhaps enough so to hinder the development of the IoT. If competing proprietary or regional networks are developed, network cross-compatibility becomes an issue and we may end up with the same sort of splintered market that plagues today's cellular networks in the United States.

The thinking of some is that today's existing “big three” wireless technologies are sufficient to handle the needs of the IoT. Cellular will be used for wide area networking, Wi-Fi for local area networking, and Bluetooth for personal area networking. For companies developing IoT devices, using one of these existing technologies is relatively easy—potentially a lot easier than working with a newer, less ubiquitous technology.

That said, there's nothing to stop companies from developing their own proprietary connection solutions within larger smart devices or areas. Does it really matter whether the sensor devices in your car communicate via Bluetooth, Sigfox, or some new type of mesh network? At the end of the day, you only care that they *do* communicate with each, and then send their information from your car to your house or dealer or wherever, using technologies that are easy for you to work with.

5.1.7.Understanding the Data

The data collected by a given device is specific to that device's stated use. That is, different devices will collect different types of data.For example, a sensor in a water meter collects data about a home's water usage—how much is used when. A sensor in a home thermostat collects data about when the furnace and air conditioning (A/C) are used, the temperature of the house (and the outside temperature) at different times of the day, and so on. Sensors in your car collect information about the engine temperature, oil level, and so forth. A sensor embedded in a highway collects data about the amount of traffic passing by, and perhaps the ambient air temperature.

The data collected by a given sensor is then transmitted to another device or service that then compares the data to other data and makes decisions based on that comparison. The thermostat data, for example, could be used to determine when to automatically turn up or down the furnace or A/C, based on past usage. It could also be used in conjunction with energy rate data to turn up the A/C when energy rates are highest, or when the power grid becomes overloaded.

You can also get creative with the data you collect. Take the sensor embedded in your local highway. With a little modification, the same device that senses vehicle traffic can also be used to detect the presence of certain chemicals. This data can then be fed into a national homeland security database and used to alert the authorities when certain types of chemicals are detected, thus giving early warning to potential terrorist attacks.

5.1.8. Understanding Intelligent Applications

For data to be useful, it must be capable of being acted upon. This can be done manually, by humans who analyze the data and then make corresponding decisions. But building a people-centric process goes against current technology trends, where every action is triggered by some sort of algorithm. (Think Google.) For the IoT to work, it cannot be labor-intensive; it must be more automated.

The key is to create intelligent apps that are capable of reading data and then acting autonomously on that data, based on certain preset parameters. For example, an app connected to your dishwasher or clothes washer could analyze data collected from the sensor on your water meter and automatically initiate washing when water usage is below a certain level—or delay washing when usage is too high. Another app might collect usage patterns from motion detectors throughout your home, be able to predict when you’re in a given room, and have the lights and heat adjusted to your preferences beforehand.

These intelligent apps will be usage-specific, of course. The apps you use in your house or car will be much different from those used in your hospital, fast food restaurant, or warehouse. But they’re all necessary, or all you have is a bunch of useless data. For the data to become useful, you need the right apps.

5.1.9. Understanding Big Data

The data collected in the IoT becomes even more useful when data from different types of devices are combined in creative ways. It’s a matter of dealing with what the techies call *big data*. This is simply a term for large amounts of data—data sets so large that they can’t be managed with traditional relational database technology. For the IoT to be truly valuable, processes need to be developed that sift through these huge amounts of data to make the connections and correlations that result in intelligent decision-making. It’s all about connecting the data collected by this sensor here and that sensor there, and coming up with a conclusion that wouldn’t have been possible otherwise.

There are actually three challenges involved in processing all the big data gathered via the IoT. First, there’s harvesting the data. Second, there’s storing the data. And third, there’s analyzing the data.

5.1.10. Data Harvesting

Data harvesting (sometimes called *data ingestion*) is a multi-step process that involves data collection by individual devices, and then transmitting that data to some sort of central database. It's all about the devices and the networking—and the database, of course.

5.1.11.Data Storage

Data storage appears simple—deceptively so. All you need is a bunch of servers, probably cloud-based, with enough capacity to hold all the data collected. Sounds simple enough, especially with the continuing drop in the cost of storage. It's really not that simple, of course, even if it is kind of an old school problem. Lots of companies get hung up on the storage part of things and never get around to the more important analysis component.

That's too bad, because there are lots of companies out there that can handle the database storage needs and several different approaches to take.One popular approach is to go with a company offering *database as a service* (DBaaS) functionality, typically in the form of cloud data warehousing. There are lots of options here, including Amazon Redshift, Enterprise Hadoop from Hortonworks, and Cloudera Enterprise. These database management and automation services alleviate the need for companies to install, manage, and operate their own large databases—freeing up valuable resources for the more important data analysis phase.

Similar to DBaaS providers but with even more functionality are the services offered by *managed service providers* (MSPs), such as All Covered and Treasure Data. These companies let you outsource not just data collection and storage but also basic analytics, typically in the form of extracting specified information from the main data. With an MSP doing the heavy lifting, a company can then focus its attention on detailed data analysis—and acting on that analysis.

5.1.12.Data Analysis

It's the third part of the challenge that's the most challenging. Assuming a company can manage or outsource the data harvesting and storage, there now comes the issue of how to extract value from the massive amounts of data collected. In other words, what does a company do with those massive amounts of data it has collected?To work with data of this magnitude requires the development of apps that analyze the collected information for trends, patterns, and pressure points. It's a huge computing challenge, especially if you want results in something approaching real time.When dealing with data on this magnitude, often collected (and thus stored) in an unstructured format, one of the major issues is making sure that you don't inadvertently skip over the important stuff while spending too much time on data that isn't important at all. It's a matter of separating the wheat from the chaff in regards to a particular app or operation. Because of all the coming IoT data that will need to be analyzed, human resources folks predict a huge upsurge in the demand for data analytics experts. It's a good profession to get into.

But just analyzing the data isn't enough. For a company to truly take advantage of and benefit from this huge potential stream of real-time data, a company must develop a culture of data-driven decision-making. That is, companies need to go where the data leads them—not necessarily where old-line management might think they need to go. It's a brave new world, driven by all sorts of new data collected over the Internet of Things. Some companies will thrive on it; others won't.

5.1.13.Profiting from the Internet of Things

It's one thing to look at what the IoT can do for us as consumers. But the business world looks at the IoT from the other side of the table, as a vast opportunity to make money. That's what capitalism is all about after all.

How big an opportunity is the IoT? In Chapter 1, "Smart Connectivity: Welcome to the Internet of Things," we tossed around numbers that ranged from $1.9 trillion to $8.9 trillion by 2020. Even taking the low estimate, that's a lot of money to be made by somebody.

Not surprisingly, lots of big companies—including Cisco, IBM, Intel, Qualcomm, and Samsung—are betting big on building out the infrastructure behind the IoT. These companies see money to be made in selling the necessary hardware, of course, but also in providing additional services once everything is connected.

There are also multitudinous opportunities in individual industries that adopt the IoT. For example, appliance manufacturers can sell higher-priced, network-enabled refrigerators, dishwashers, and laundry equipment, as well as possible add-on services that enable all these appliances to work together. Suppliers to the auto industry will have a new class of parts to sell as auto manufacturers incorporate smarter devices into their cars. Warehouse operators will invest in IoT-enabled tracking and shipping systems that ideally will cut their current labor costs. (And some company will be selling the warehouses all the necessary IoT-enabled machinery and systems, too.)

So who benefits from the IoT? Communications companies, networking companies, tech companies of all stripes—including chip manufacturers, hardware manufacturers, cloud storage services, and app developers. Plus a ton of industry-specific players, of course, with a focus on equipment suppliers. And bet on today's big tech players—Apple, Google, and Microsoft—nosing their way into the IoT market as well.

When it comes to building the Internet of Things, you don't have to do much to prepare. The Ciscos, IBMs, and Intels of the world will be doing that work for you. All they ask is that you generously support their products and services in the years to come.

That said, you need to be aware of the changing infrastructure driven by the development of the IoT. For example, as you add more and more connected devices to your home, your home network might need more capacity. (After all, you don't want Netflix to stutter on your smart TV because your smart refrigerator is taking inventory at the same time.) That might mean upgrading to a newer wireless router or even paying for faster service from your ISP.

And you’ll certainly be prompted (and tempted) to invest in newer “smart” electronics and appliances with enhanced IoT-like functionality. Some of these features might be worth paying for, some not. (And some might be duplicative; do you really need a smart TV, smart Blu-ray player, and smart media player that all offer the exact same Netflix functionality?)

So there’s some decision-making you’ll need to make in terms of what you buy and when. Do you replace your current “dumb” equipment with smart equipment now, or wait until something wears out? Do you invest in the smart versions of things now or figure things will only get smarter in years to come? Do you really want to spend a thousand dollars or more to replace all your light bulbs with smart light-emitting diode (LED) light bulbs, or just get by with cheap incandescents as long as they’re available?

More important is developing the necessary mindset to accept the changes that the IoT is bound to bring. Let’s face it, if the IoT only does half of what everybody’s predicting, the impact on your daily life will be significant.Think about it. Right now you’re accustomed to setting your own thermostat, turning on your own lights, making your own coffee. If the day gets too hot, you turn up the A/C. When it gets dark, you turn up the lights. When you need caffeine, you brew a cup.

With the Internet of Things, however, you won’t have to do any of these things. Your house will always be the perfect temperature, no matter the heat of the day or what room you’re in. Your lights will turn on when you need them and turn off when you leave the room. Your coffee will be ready for you when you wake up in the morning, or when you normally take a mid-day coffee break.

In addition, your lawn will be properly watered and, with the inevitable adoption of the self-driving lawnmower, appropriately groomed. You’ll no longer have to deal with handwritten grocery lists; when you run low on mayonnaise or eggs or beer, your smart refrigerator will know it and submit the list directly to your grocery store for automatic delivery. (Probably by drone. Definitely by drone.) And you won’t need to manually program your digital video recorder (DVR), because your smart TV will know from experience what you like to watch and when, and queue it up for you.

That’s a lot of decisions that you now make that you won’t have to make in the future. Will you be comfortable ceding this much control to devices and apps? Will you trust the IoT to make these decisions for you?

And what will you do with all the time (and brain power) you currently spend making these decisions? One of the big potential benefits of the IoT is that you’ll be rescued from all this old-fashioned manual thinking and labor. If you’re not deciding what to watch tonight or writing out a grocery list or watering your lawn, what will you do instead? There’s more leisure time in store, whether you want it or not.

In addition, some of us garner some small amount of satisfaction from performing these menial tasks. With the IoT doing everything for us, will our self-esteem suffer because we can no longer claim these minor accomplishments?

Perhaps it's a matter of deciding what to automate and what not to. Maybe you want to manually cut the grass or make out your grocery list, IoT be damned. There's something to be said for maintaining some degree of control over your life. The devices, systems, and apps don't have to do everything. As my two-year-old granddaughter insists on saying, "I do it." Perhaps there's a little two-year-old in all of us, and we want to maintain our self-sufficiency in the face of possible automation. Or maybe we're a bunch of lazy slugs who don't want to do anything ourselves. Hard to say until all the options are available

Case study:

5.2 Smart Cars: Connecting on the Road

The Internet of Things (IoT) holds a lot of promise for the automobile industry, and for drivers everywhere. Today's so-called connected cars offer streaming music via the Internet, traffic and weather reports, and even global positioning system (GPS) mapping and directions. But what about a smart car that monitors traffic conditions and automatically reroutes you when necessary? Or one that diagnoses—and even repairs—its own problems if they develop? Or the ultimate smart automobile, a self-driving car that's so advanced you don't have to do much of anything to get from point A to point B other than open the door and strap yourself in. It's obvious that the Internet of Things is going to change the way we get around, and big time. Let's find out more.

Automobiles have been getting progressively smarter over the years. Today's cars contain dozens of computers or computer-like devices, all working together to make sure your car runs as well as it's designed to. These electronic control units control all sorts of in-car functions, including braking and cruise control, and heating/cooling and entertainment systems.

This smarting up of the family wheels is something that's been taking place over the past three or more decades. Go back to 1977, as an example, and you find that the Oldsmobile Toronado had a single computer unit that controlled spark plug timing. In the early 1980s, additional computers were introduced to improve emissions systems, and in the late 1980s, electronic throttle control (ETC) replaced cables and mechanical linkages. And on it goes.

With everything that's computerized in today's cars, it's not far-fetched to consider that the set of wheels sitting in your garage is the smartest smart device in your entire home.

5.2.1.Smart Functionality

Let's talk first about how computers have taken over much of the basic functionality of the average automobile. Many key mechanical systems are now controlled by microprocessors, with the goal of more efficient and safer operation.

Some mechanics look at today’s automated automobiles and see a computer on wheels. Actually, it’s more like 30 or more computers on wheels (close to 100 in luxury cars), all acting in concert to keep your car working in tip-top condition.

What operations are computer-controlled in a typical car? Here’s just a short list:

- Air bag systems
- Anti-lock brakes
- Automatic seat positioning
- Automatic transmission
- Climate control system
- Cruise control
- Entertainment system
- Idle speed
- Keyless entry system
- Security system

These operations are supplemented by a variety of electronic sensors that feed real-time information back to the computer brains. We’re talking air pressure sensors, air temperature sensors, engine temperature sensors, knock sensors oxygen sensors, throttle position sensors, and more. Data from these sensors is used to control spark plugs, fuel injectors, and other key components.

The most advanced computer in cars today is the *engine control unit*, or ECU, such as the one shown in Figure 8.1. The ECU monitors outputs from dozens of different sensors to control the engine’s operation, emissions, and fuel economy. Today’s ECUs are relatively low power, typically using 32-bit architecture, 40MHz CPU, and 1MB or so of RAM. That’s a lot less robust than the 64-bit CPU in your personal computer, but it’s all that’s needed to run the simple code that controls today’s automobiles.

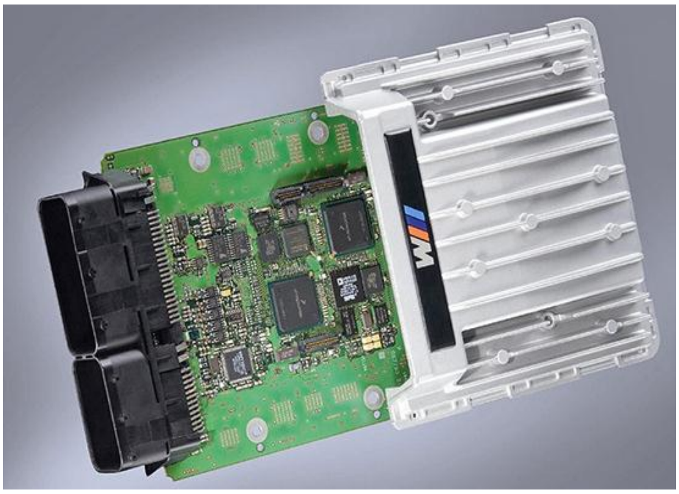


Figure 5.6.*The engine control unit from a BMW.*

5.2.2.Smart Diagnostics

The data collected by a car's electronic sensors is fed to a central communications module, which stores the data for appropriate future use. If sensors detect something is amiss, the communications module alerts the driver, typically via the much-despised Check Engine light. When the driver takes the car in for service, the service technician can then extract a diagnostic code from the car computer to find out what's wrong and then fix it.

As advanced as all this sounds, it really isn't. The onboard computer doesn't actually diagnose anything (and certainly doesn't fix anything itself); it merely stores the error codes reported by other sensors in the car. The service technician doesn't get a screen full of Star Trek-style blueprints and instructions, but rather a list of simple numeric codes—which he then has to look up to see what they mean. It's better than getting no diagnostic help at all, but there's a way to go before these diagnostics can be considered in any way intelligent.

Intelligent or not, many old-line mechanics (and most do-it-yourselfers) decry this rampant computerization of what used to be simple mechanical machines. Long gone are the days where a weekend mechanic could break out the toolbox, get his hands dirty, and pound the typical ailment into submission. Instead, today's service techs need their own banks of computers to diagnose and fix problems related to the many computer-controlled operations in the current batch of state-of-the-art driving machines. You really can't fix your car yourself anymore; you have to take it into an accredited service center.

In the future, however, diagnostics will get easier because the car's electronics will be even smarter. Instead of generating indecipherable error codes, your car's smarter computer will display plain-English explanations of what's wrong. Your car's dumb warning lights will get smarter, too. Instead of displaying a single Low Tire Pressure light (and leaving you to figure out which of the four tires needs air—a time-consuming job), the in-dash display will tell you that the driver's side front tire is five pounds low. That's a simple thing that will make your life immeasurably easier.

Same thing with everybody’s least favorite dashboard alert, the Check Engine light. Nobody knows what it means when this light goes on; it could be nothing, it could be something extremely serious—you just don’t know until you take it into the dealer. Smart systems would do away with this overly generic warning and instead use the in-dash display to tell you precisely what is wrong—and what you should do about it.

Ideally, smart diagnostics systems will identify potential problems before they become real problems—oil levels getting low, belts wearing out, that sort of thing. And then the computer won’t just tell you about the problem, it will use available wireless technologies (Wi-Fi if you’re near a hotspot, cellular if you’re not) to notify the repair center of the problem. The repair center will then order the necessary parts and contact you to schedule an appointment to perform the repairs.Less guesswork, more automation. That’s smart diagnostics in the future.

5.2.3.Smarter Driving

Smart driving systems are slowly but surely finding their way into the average family auto. We’re not talking self-driving cars (although we will in just a few pages), but rather dedicated systems that help drivers perform difficult or sometimes dangerous maneuvers and operations.

The most common smart driving system is the now ubiquitous cruise control. Basic cruise control systems have been around for decades, limiting speed to a preset level. Newer adaptive cruise control systems, however, take this one step further by monitoring the distance to the car in front of you and then adapting the speed as necessary. Used to be you had to slam on the brakes or toggle off the cruise control when you ran into heavy traffic; adaptive cruise control systems do this for you and help you keep in step with the flow of traffic.

On the safety side of things, many cars today come with lane assist systems that monitor your position in your lane and keep you from drifting into the adjacent lane. You may get a warning alert if you start to wander over or, in some luxury models, the car itself may take corrective action.

Parking assist systems are also becoming more common. These systems help with the challenging task (for many) of parallel parking. For example, Volkswagen’s aptly-named Park Assist system automatically detects the nearest empty parking space, measures the space, notes the current position of your car, and then carries out the optimum steering movements to put your car in its place. (You still have to operate the accelerator and the brake during the process.) The process is illustrated in Figure 8.2.

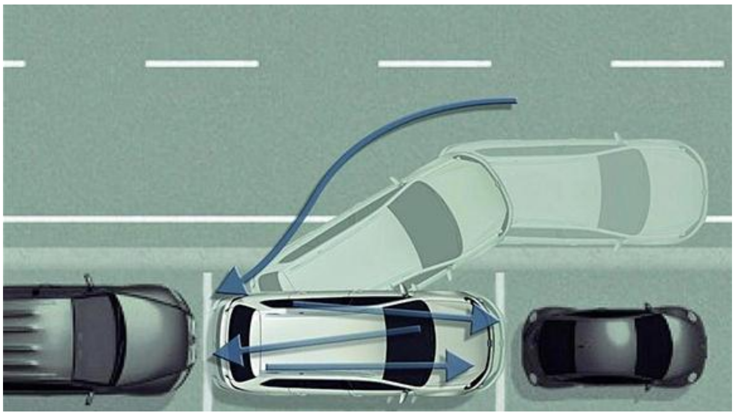


Figure 5.7 *How Volkswagen's Park Assist system automatically parks a car.*

And there's more, especially in higher-end vehicles:

- The Infiniti Q50 utilizes video cameras, radar, and other technology for its lane-keeping, cruise control, and collision avoidance systems.
- The Mercedes S-Class includes systems for autonomous steering, parking, accident avoidance, and driver fatigue detection.
- Some BMWs can read speed limit signs and automatically keep your car under (or at) the proper speed.
- Tesla Motors' AutoPilot mode controls the car's steering, braking, and speed; Teslas also include auto parking.
- Volvo's 2014 models include adaptive cruise control with a steering assist feature that enables your vehicle to follow the car ahead, even if it changes lanes.

Part and parcel with today's smart driving systems are an assortment of in-car cameras, sensors, and warning systems designed to provide a safer driving experience. Backup cameras are becoming standard equipment on even low-end vehicles. Side-mounted "blind spot" cameras are incorporated into lane change avoidance systems. And parking sensors let you know if you're getting too close to the cars around you.

5.2.4.Smart Communications

All the sensors and systems in your car don't operate in a vacuum. These devices communicate and interact with one another—and with the future—with similar devices in other cars.

Today's in-car systems typically operate via wired (not wireless) connections. The dominate communications standard is called CAN, for *controller-area networking*. This standard enables communication speeds up to 500Kbps, which is considerably slower than your home network but fast enough for the simple data transfers between your car’s devices.

In the future, cars will get smarter by communicating with each other. Instead of relying on proximity sensors or radar to identify a nearby vehicle, your car will instead receive a radio signal from that other car. In essence, your car’s computer brain will be communicating with that car’s computer brain. Your car will know what that other car is going to do—where it’s going, by what route, and how fast. By sharing this information in real time, your car can then calculate the appropriate direction and speed to not only avoid contact with that car, but also determine the best route to travel together or apart.

Car-to-car communication systems are part and parcel of the self-driving car, and of creating a safer driving experience. According to the National Highway Traffic Safety Administration (NHTSA), this sort of car-to-car communication could help to prevent more than 80 percent of all traffic accidents. That would be technology well used.

5.2.5.Smart Entertainment

One of the most common applications of technology in the car comes in the form of intelligent entertainment systems. It’s a matter of making it easier to listen to your favorite tunes while driving.

Today’s state-of-the-art in-car entertainment system not only includes an AM/FM/satellite radio (and sometimes a CD player), but also a USB port to which you can connect your smartphone or USB memory stick. The smarter of these systems can control your iPhone (though typically not an Android phone) from the dashboard display and even show album artwork for the current selection.

Even more convenient, many in-car entertainment systems let you connect your smartphone without a cable, via Bluetooth wireless technology. When I start up my Honda CR-V, it automatically recognizes my Samsung smartphone and starts playing the next tune in the phone’s digital queue. I don’t have to do anything other than select the auxiliary input—or, if I don’t like a song, hit the Next button. All the connections happen in the background, and that’s great.

Some cars even come with built-in apps for certain streaming music services, so that you can initiate playback direct from your dashboard (with your smartphone connected, of course). Pandora apps are the most common, although some cars have apps for Spotify, iHeartRadio, and other services, as well.

Apple’s CarPlay technology looks to make in-car music playback even easier. CarPlay utilizes Apple’s Siri voice recognition technology to let you control your entertainment system with a few well-chosen words—which is safer than turning a dial or tapping a touchscreen. (Figure 8.3 shows the CarPlay system at work.) The CarPlay system also enables control of mapping/directions (via the much-maligned Apple Maps app), text messages, phone calls, and the like.

Figure 5.9. *Apple's CarPlay system.*

Apple is working with most major automobile manufacturers to integrate CarPlay into their in-car entertainment systems. Expect to see CarPlay technology in cars from Audi, BMW, Chevrolet, Chrysler, Dodge, Ford, Honda, Hyundai, Mazda, Mercedes, Nissan, Suzuki, Toyota, Volvo, and more within the next few years—with select 2015 models already lined up.Voice command isn't limited to Apple's CarPlay system. Other manufacturers offer similar voice control for making phone calls and answering text and email messages. (Some cars will even read your text messages for you, so you don't have to text and drive—which is becoming increasingly illegal in many jurisdictions.)

Apple isn't alone in wanting to control your car's entertainment system. Google is developing Android Auto, which controls your entertainment system, maps and directions (via Google Maps), and such from your Android phone. (Figure 8.4 shows an Android Auto screen with map and music information.) Like CarPlay, Android Auto can be controlled from your phone, your car's in-dash touchscreen display, or voice commands. Google has partnerships with many of the same automakers as does Apple, so it remains to be seen which of these two competing systems will win the battle for in-car control.

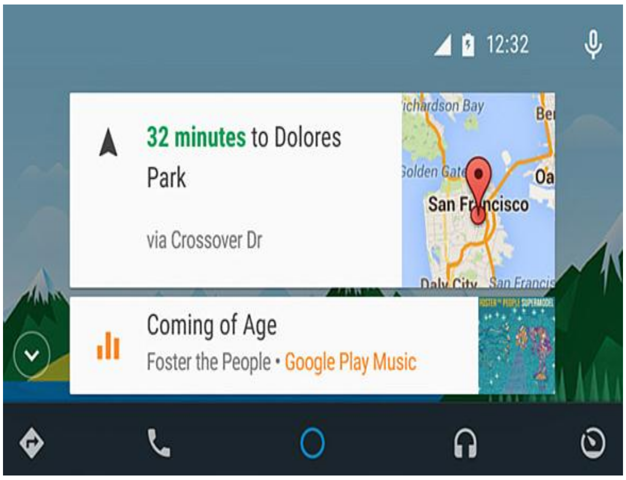


Figure 5.10. *Google's Android Auto system.*

5.2.6.Smart Climate Control

In-car climate control systems are also getting smarter. The day of the single-knob heater/air conditioner (turn it to the right for more heat, to the left for more air) is long gone. Today’s typical system lets you set the precise temperature you want, and then turns itself on and off to keep it there. You also get multiple-zone control, so that the driver and the passenger (and maybe the kids in the back seat) can set their own individual temperature zones. It’s all computer-controlled and works relatively well. (Figure 8.5 shows a typical dual-zone climate control system, part of Ford’s MyFord Touch communications/control system.)

Figure 5.11 *Dual-zone climate control in the MyFord Touch system.*

Climate control will only get smarter in the years ahead. Expect your car to recognize who’s driving (by the particular key fob you carry) and automatically adjust the temperature to your preference. It’ll also adjust your seat and dial into your favorite radio (or Internet radio) station at the desired volume level. It’s all about personalizing the driving experience, based on what you individually like or don’t like.

5.2.7.Hacking a Smart Car

All these smart electronics seem well and good, and no doubt we’ll eventually wonder how we ever drove without them. But they also represent an opportunity for malicious hackers to take control of your car. And that’s something to worry about.

Here’s the scenario. You’re driving in your smart car down the highway at 70 or so miles per hour. With no warning, the steering wheel turns hard to the left and you crash into the car in the next lane. Or maybe your car just slows to a stop. Or shuts down altogether.

The cause of this apparent malfunction? Not your car, but rather someone hacking into your car’s computer systems. It’s not that far-fetched, especially when smart cars start communicating with the outside world via wireless or mobile networks.

In fact, the likelihood of malicious intrusion is higher than most car manufacturers would like to admit. That's because today's car control systems are rather primitive and, unlike your home computer or smartphone, have little to no built-in security. In other words, a car is relatively easy to hack if someone sets their mind to it.

That said, auto manufacturers are aware of the threat and are working to improve their security systems. In fact, Continental, one of the biggest auto parts suppliers, is partnering with IBM and Cisco to add firewalls to their electronic devices. Ford and Toyota are also developing firewalls to protect their cars, with the latter embedding security chips in its in-car computers.It's likely, then, that smart cars will also become more secure cars in the years to come. But the security issue exists and could become problematic for some manufacturers.

Car hacking doesn't have to be malicious. Today, third-party On-Board Diagnostic (OBD) systems let you hack into your car's computer and run your own diagnostics. With the help of these devices, you can see how other drivers are using your car, keep performance at peak efficiency, and even find out just what's behind a pernicious Check Engine Light situation. For more information, go to the OBD-II website at www.obdii.com.

5.3. Cars That Drive Themselves

Now we come to the part of this chapter everybody's been waiting for, the section about self-driving cars. Yes, they're coming—and driving themselves!

5.3.1.How Self-Driving Cars Work

A self-driving car is simply a car that is capable of driving itself, with little or no input from a human driver. It uses sensors, computers, and other smart technologies to sense where it is in relation to other vehicles (and the road), and navigates according to preset coordinates.

A number of different technologies need to be employed for a car to drive completely autonomously. These include:

- 360-degree cameras, to view all sides of the car

- Adaptive cruise control, to regulate speed in traffic

- Emergency brake and steering assistance, to avoid collisions

- GPS, to determine precise location and navigate routes

- Radar and Light Detection and Ranging (LIDAR), to sense the distance between your car and other cars or objects

- Stereo cameras, to outline and identify pedestrians and bicyclists as different objects than other cars

LIDAR is a technology that measures distance by illuminating an object with a laser and then analyzing the reflected light. Radar does much the same thing, but with radio waves.

Of course, a self-driving car must also have a fairly robust computer in charge of the whole shebang. The in-car computer must tie together all these sensors and systems, and determine what actions to take in any given situation. In addition, the in-car computer will also handle all the necessary routing functions, based on GPS and known maps.

I’m particularly fascinated with emergency brake and steering assistance systems, which enable the car to undertake evasive maneuvers by steering itself out of and back into a lane when it detects an obstacle. Figure 8.6 shows one such system, from parts supplier Continental: the Emergency Steer Assist system. As you can see in the figure, the system is alerted to a slower car or obstacle in enough time for the system to take over the breaking and steering systems, slowing the car down and steering it into the next lane—faster and more accurately than most human drivers can respond.

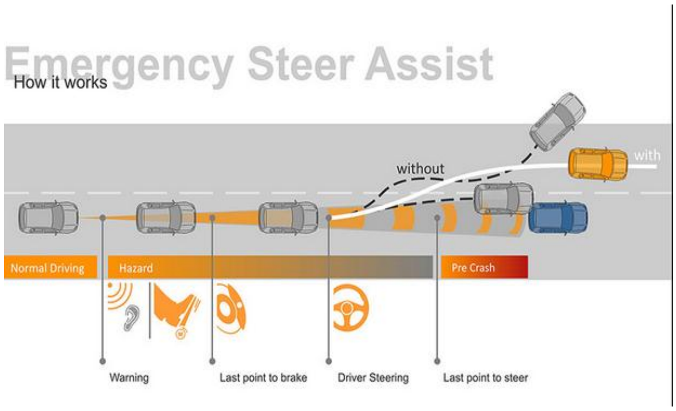


Figure 5.12. *How Continental’s Emergency Steer Assist system works.*

By combining this type of collision avoidance system with adaptive cruise control, a car can drive down the road without hitting anything in its way. The exact route is specified via GPS mapping and navigation, of course. Program in your destination (or just say it; might as well add voice control to the mix) and the car’s computer calculates the best route there. The automatic systems then take over and drive the route.

Many of the automatic systems needed for a self-driving car are in existence today. Not surprisingly, most automobile manufacturers have big plans for their own autonomous vehicles. Here’s what some of the major car companies have in store over the next couple of years:

- Audi plans to market vehicles that can steer, accelerate, and brake, all by themselves.

- Cadillac plans to introduce select models with autonomous lane keeping, speed control, and brake control.

- Mercedes plans to introduce Autobahn Pilot (in the United States, Highway Pilot), a system that enables hands-free highway driving with autonomous overtaking of other vehicles.

- Toyota plans to roll out what it calls near-autonomous vehicles with Automated Highway Assist, Lane Trace Control, and Cooperative/Adaptive Cruise Control.

Looking just a little bit further into the future, Continental, the big auto parts supplier, is working on various autonomous driving technologies in its Advanced Driver Assistance Systems unit. The company plans to have autonomous assistance available for limited freeway driving and for use in construction areas by 2015. By 2017, the company expects to add autonomous low-speed city driving, with technology for driving on two-lane highways and country roads by the end of the decade. Fully autonomous driving is expected to be available by 2025, with premium and luxury cars getting the technology first.

By the way, there actually is one self-driving vehicle commercially available today. It's not a car, however. As you can see in Figure 8.7, the Navia, from Induct Technology, is a cross between a golf cart and an open-air shuttle. It's designed for use in pedestrian zones and travels at a breathtaking 12.5 mph. But it is completely autonomous, which gives us a glimpse of what's coming in more traditional passenger vehicles.

Figure 5.13 *The Navia Electronic Automated Transport, from Induct Technology.*

5.3.2.Levels of Automation

It's unlikely, however, that the self-driving vehicle will arrive in one fell swoop. The robot takeover of our roads is probably going to happen in several evolutionary steps. In fact, the NHTSA has established an official classification system that neatly outlines different levels of automation:• **Level 0**—The driver completely controls the vehicle at all times. (This is what we have today, more or less.)• **Level 1**—Individual vehicle controls, such as automatic braking or electronic stability controls, are automated. We're just now entering this era.• **Level 2**—At least two controls can be automated in unison, such as adaptive cruise control in combination with lane keeping.• **Level 3**—The driver can turn over control of all safety-critical functions in certain conditions. At this stage of the game, the car senses when it's in over its head and lets the driver know he needs to resume control.

- **Level 4**—The car does it all, assuming all safety-critical functions for the entire trip. The driver is not expected to control the vehicle at any time.The ultimate self-driving car, then, is a Level 4 machine. We’re at least ten years away from this ideal.

5.4.Introducing Google’s Self-Driving Car

The most famous self-driving car today isn’t commercially available, but it gets a lot of press. That’s probably because it comes from Google, the big online search company.

Why Google wants to develop self-driving cars is another story, rooted in its drive to create street view photographs of seemingly the entire world for its Google Maps service. (Plus Google is decidedly anti-human in its use of technology; it’d rather make decisions by algorithm than leave it up to human beings.) Officially, Google says that its goal is “improving road safety and transforming mobility for millions of people.” Sounds noble enough.Google started out by retrofitting a variety of stock vehicles—Audi TT’s, Lexus RS450s, and Toyota Priuses—with autonomous driving hardware and software. With that experience under its collective belt, Google then took the next logical step (because everything they do is exceedingly logical) and built its own prototype self-driving car. The company plans to build 200 or so of these robotic driving machines, all set to tool around California for the next year or so.As you can see in Figure, Google’s car (it has no formal name) is not a scion of automotive fashion. It’s kind of cute, actually, especially with the perceived smiley face in the front.

It’s not a toy, however. The Google car is a battery-powered electric vehicle, capable of a maximum speed of 25 mph. It has a stop/start button, but no steering wheel or pedals. There’s room for two inside, but the body is plasticky.Inside Google’s car is a variety of sensors and technologies to detect the vehicle’s surroundings. We’re talking stereo cameras, 360-degree cameras, LIDAR, radar, and sonar devices. All these devices are necessary because they look at things differently; they all have different ranges and fields of view, thus serving a particular purpose in the grand plan.

are mounted around the exterior of the car. They’re used to create overlapping fields of views that can track an object’s distance in real time. These cameras have a 50-degree field of view, but are only accurate up to about 30 meters.

More accurate distance is measured by the car’s LIDAR system, mounted on the top of the car. This system is powered by a Velodyne 64-beam laser that can rotate 360 degrees and take up to 1.3 million readings per second. The LIDAR system is accurate up to 100 meters, which makes it ideal for generating a real-time map of the car’s surroundings.Radar systems are built into the car’s front and back bumpers. These systems are used to warn of impending impacts—and tell the brakes to activate when necessary.Interestingly, the radar systems are paired with sonar systems. That’s because the two technologies are best for different distances. Radar works up to 200 meters away, while sonar is good for distances of 6 meters or less.Up to 1GB of data is generated from these sensors every second. This data is used to build a map of the car’s immediate surroundings. This enables the car to stay in the correct lane and avoid obstacles.

Figure 5.14. *Google's self-driving car, complete with hardware on top.*

For example, stereo cameras—two cameras mounted with a small separation between them—

As the first company doing serious testing on self-driving cars in the wild, it's learning as it goes—which is a good thing. The more we know about how things work, the more effective (and safer) our smart cars can be. So far, Google's smart car has learned a lot about different driving conditions and hazards, including cyclist hand signals, railroad crossings, and what to do when another car is pulled over on the shoulder of the road. But, as any human driver can tell you, there's a lot more to learn.

5.4.1. Pros and Cons of Autonomous Autos

Why is everyone so excited about self-driving cars? Aside from being futuristic neat and all? Well, there are some definite benefits that accrue when you let your sedan or sport utility vehicle (SUV) do the driving—as well as some possible detriments.

5.4.1.1.The Good

Here are the good things made possible by self-driving cars:

- Fewer traffic collisions, due to accident-avoidance systems. Ideally, if all systems are working correctly, we should approach *zero* collisions. That means less money spent on car repairs, medical expenses, and the like.

- Fewer collisions equal fewer injuries and fewer deaths. Today, around 35,000 people die every year in automobile accidents, and 90 percent of these crashes are due to human error. Smart self-driving cars that take the human factor out of the equation should dramatically reduce this accident rate.

- Given the lower accident rate, insurance rates should go down. (Should.)

- Reduced traffic congestion and increased roadway capacity, because autonomous vehicles can drive closer together without hitting each other.

- Reduced drive times, due to the higher speeds enabled by self-driving systems.

- Easier parking, because the car does it for you. In fact, the ultimate self-driving car will drop you off at the door and then go park itself.

- Longer drives without stops due to driver fatigue.

- A less stressful—and more productive—drive for occupants who no longer have to concentrate on driving. Instead, passengers can read, surf the Web, work, or just take a nap during the trip.

- Driver constraints removed. Since the car's doing the driving, it doesn't matter if the occupants are under age, over age, intoxicated, or blind.

- Less need for traffic police and vehicle insurance—assuming all the systems work to obey traffic laws and reduce the number of accidents.

- Reduction in car theft. A self-aware robotic car could just drive away if a bad guy tries to steal it.

- Lower costs for companies (formerly) employing human drivers. Domino's will save a ton on delivery expenses, which they might (or might not) pass on to customers.

Uber, that's who. The crowd sourced transportation network/taxi replacement service intends to eventually replace all of its drivers with self-driving automobiles. Given that Uber's freelance drivers take home 75% of each fare, eliminating those drivers from the equation could be a financial boon to the company—and make it easier for people to find a ride, especially in big cities. On the downside, this would essentially destroy the current taxicab industry and put 10 million people out of work. Is this feasible? More than you think: A Columbia University study suggests that a fleet of just 9,000 autonomous cars could replace every taxi in New York City. The repercussions would be staggering.

5.4.2.The Bad

Of course, not all is milk and honey in the land of autonomous automobiles. There are more than a handful of potential downsides if you and your neighbors all have self-driving cars. These include the following:• **Liability**—When your self-driving car gets in an accident, who's responsible—you or the car? (Or the car's manufacturer? Or systems programmer?) Nobody knows just yet.

- **Reliability**—Let's face it, if the computer in your car is as reliable as the computer on your desktop, we're all in trouble. Can you imagine having to reboot your vehicle in the middle of the drive to work?

- **Privacy**—Your smart car will collect a lot of information about you—where you drive, how fast you drive, and so forth. Who will have access to this data, and what will they do with it?

- **Security**—If a computer's in charge of your car, what do you do if that computer gets hacked? Vehicular cyberattackers could take control of your self-driving car, making it drive to strange places (where you could be robbed), or just stop working altogether. For that matter, less malicious hackers could retrieve your driving data and use it to send you targeted advertising. Just as you get with your PC.

- **Terrorism**—Cyberterrorists could program self-driving cars filled with bombs to initiate deadly attacks. It's not fiction; if you can imagine it, someone will try it.

- **Driver resistance**—Some people like to drive and don't want to cede control to some computer system. Won't self-driving cars take all the fun out of driving?

- **Loss of experience**—When your car does all the driving for you, what do you do when the situation requires you to take over the driving? If you're logging less time behind the wheel, your driving skills may deteriorate.

- **Loss of jobs**—Self-driving cars may be a good thing for employers, but could put a lot of minimum-wage drivers out of work. Say goodbye to the Domino's delivery guy and the taxi drivers in line at the airport. This could reshape the entire service economy.

5.4.3.The Ugly

Then there are the ethical questions. If a self-driving car senses that it's about to hit another vehicle, but swerving out of the way will cause it to crash into a pedestrian, what does it do? Given the choice of injuring a car's occupants in a collision or injuring the occupants of another car, what decision does it make? To what extent does your autonomous vehicle go to protect you—even if it means harming other drivers?

These are difficult choices made no less difficult when they involve algorithms and programming. And maybe you have different views on this subject than does your car's manufacturer.

Ethically, there are several different approaches that could be taken. Your car could be programmed to be

- Democratic, assuming that everyone in a given scenario has equal value.

- Pragmatic, so that certain people are judged more important than others. For example, the car might be programmed to give precedence to children in a school zone or pedestrians in city driving.

- Self-centered, so that you, the occupant of the host vehicle, always comes first.

- Materialistic, so that the least property damage (or legal liability) is inflicted.

While these ethical viewpoints could be programmed into the car by the manufacturer, it’s just as likely that car owners will be allowed to determine which operational actions to take in the event of a pending accident. You, the car owner, could dial in just how much you want to protect yourself versus the occupants of other cars or pedestrians in the event of an accident. This shifts the ethical liability away from the manufacturer and onto you.

But how many people want to think about this sort of thing in advance? Would most people simply accept the manufacturer’s default ethical settings? Would most people even read the obligatory legal disclaimer? (Probably not; do you ever read the Terms of Use that come with all the software you use today?)

This leads us not into ethical dilemmas, but also legal ones. If the car’s manufacturer configures a self-driving car with an assortment of ethical “if then” programming, is the company then responsible for any injuries or deaths caused by the implementation of that programming? Oooh, you see how complicated this is going to be...

5.5 Navigating the Legal Landscape

The liability questions (and maybe the ethical ones, too) will eventually be decided by the courts and our lawmakers. Given the speed that our lawmakers work, however, the technology may get there before the laws can catch up.

The situation is this. If your self-driving gets into an accident (while in autonomous driving mode, that is), who is held legally responsible? Is it you, the car’s owner—even if you weren’t physically driving? Is it the car’s manufacturer? Of the developer of the auto-driving software? Where does the proverbial buck stop?

Does the liability change if you, the driver, have some input as to how the car responds in a given situation? If the manufacturer programs a set of ethical responses (save the car’s occupants first, or always avoid hitting pedestrians, or what not), does that put the legal liability in the lap of the car company?And, before we even get to that point, just how legal is it to pilot a self-driving car on your local roads? Can you use a self-driving car today or not?

In the United States, at least, state vehicle laws typically do not envisage the adaption of self-driving cars. That creates a legal limbo. While existing laws don’t necessarily prohibit autonomous vehicles, they do not explicitly allow them either. In fact, today’s laws implicitly assume that a human being is behind the wheel and responsible for the car’s actions.

With the looming introduction of self-driving cars on a mass scale, those laws will have to start changing. And they are. So far, only a handful of states—California, Florida, Michigan, Nevada, and the District of Columbia—have enacted laws that make the use of self-driving cars explicitly lawful, but many other states have similar legislation in the works. It’s likely that self-driving cars will be explicitly permitted in most jurisdictions within the next several years.These laws, however, do not address the legal liability issues, which are still in flux—and much debated. Motor vehicle departments and lawmakers across the United States are currently discussing this issue and writing draft legislation. Automakers, insurance companies, and other industry groups are offering their own helpful advice. And drivers like you and me will no doubt have our chance to sound off as well.

The point is, for self-driving cars to be successful—in fact, for manufacturers to introduce them for sale at all—the legal issues have to be decided in advance. No automaker with its staff of thousands of legal beagles is going to allow their cars to reach the market not knowing whether it will be legally responsible for whatever may happen out there on the road. Who’s responsible for what and when will be determined and written into law, and the auto insurance industry will adapt coverage, policies, and rates accordingly. While it’s all up in the air now, little will be left to chance by the time the big rollouts occur.

Part A

1. What is smart system?

2. What is the meaning of smart monitoring?

3. Write a note on IPR

4. What is a smart car?

5. Mention four differences between Automatic car and smart car.

Part B

1. Describe smart applications will illustrative examples.

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