CAI335 SOLAR AND WIND ENERGY SYSTEM

UNIT IV NOTES

4.4 Electrical system

4.4.1 Generator

There are four types of wind turbine generators (WTGs) which can be considered for the various wind turbine systems, those are:

1. Direct Current (DC) Generators
2. Alternating Current (AC) Synchronous Generators
3. AC Asynchronous Generators, and
4. Switched Reluctance Generators.

Each of these generators can be run at fixed or variable speed. Due to the dynamic nature of wind power, it is ideal to operate the WTGs at variable speed.
Operating a generator at variable speed reduces the physical stress on the turbine blades and drive, and which improves aerodynamic system efficiency and torque transient behaviours.

1. DC Generator
A DC wind generator system has a wind turbine, a DC generator, an insulated gate bipolar transistor (IGBT) inverter, a transformer, a controller, and a power grid.

For shunt-wound DC generators, the field current increases with operational speed, whereas the balance between the wind turbine drive torque determines the actual speed of the wind turbine.

Electricity is extracted through brushes, which connect the commentator that is used to convert the generated AC power into DC output.

These generators need regular maintenance and are relatively costly because of using commutators and brushes.

Using DC WTGs are unusual in wind turbine applications except in the situations of low power demand.

2. AC Synchronous Generator
AC synchronous wind turbine generators can take constant or DC excitations from either permanent magnets or electromagnets.

This is why they both are called “permanent magnet synchronous generators (PMSGs)” and “electrically excited synchronous generators (EESGs)”.”

When the wind turbine drives the rotor, three-phase power is produced in the stator windings that are connected to the grid via transformers and power converters.

In the case of fixed-speed synchronous generators, the rotor speed needs to be at exactly the synchronous speed. Or else, the synchronism will be lost.

When using fixed-speed synchronous generators, random fluctuations of wind speed and periodic disturbances happen due to tower-shading effects.

Moreover, synchronous WTGs tend to have a low damping effect so that they do not allow drive train transients to be absorbed electrically.

The structure of PM generators is relatively straightforward. The rugged PMs are installed on the rotor to generate a constant magnetic field, and the produced electricity is collected from the stator by using the commutator, slip rings or brushes.

Sometimes the PMs are integrated into a cylindrical cast aluminum rotor to lower the cost. The basic principle of operating PM generators is similar to synchronous generators except that PM generators can be operated asynchronously

Due to the variability of the actual wind speeds, the PMSGs can not produce electricity with a fixed frequency. For this, the generators should be connected to the power grid through rectifying AC-DC-AC by power converters.

It means the generated AC power containing variable frequency and magnitude is first rectified into fixed DC, and then converted back into AC power.

Also, these permanent magnet machines can be useful for direct-drive applications as, in this case, they can get rid of troublesome, gearboxes which cause failures for the majority of wind turbines.

One of the potential variants of synchronous generators is the high-temperature superconducting generator.

The superconductor generators have components such as the stator back iron, stator copper winding, HTS field coils, rotor core, rotor support structure, rotor cooling system, and others.

Superconducting coils may carry nearly 10 times the current than traditional copper wires with moderate resistance and conductor losses.

Also, using superconductors can stop all field circuit power losses. Moreover, the increase in current density allows for high magnetic fields, which will result in a significant reduction in mass and size for wind turbine generators.

Along with higher capacity, synchronous generators may pose several technical challenges, especially for the long-life, low-maintenance wind turbine systems.

One such challenge, for example, is cooling down the system and restoring operation following a technical snag.

3. AC Asynchronous Generators

When the traditional way of power generation uses synchronous generators, modern wind power systems use induction machines, extensively in wind turbine applications.

The induction generators are classified into two types: fixed-speed induction generators (FSIGs) with squirrel cage rotors, and doubly-fed induction generators (DFIGs) with wound rotors.

Generally, induction generators are simple, reliable, inexpensive, and well-designed.

These generators have a high degree of damping and can absorb rotor speed fluctuations and drive train transients.

In the case of fixed-speed induction generators, the stator is connected to the grid through a transformer, and the rotor is connected to the wind turbine through a gearbox.

Until 1998, most wind turbine makers produced fixed-speed induction generators of 1.5 MW and less.

These generators were normally operated at 1500 revolutions per minute (rpm) for the 50 Hz utility grid, along with a three-stage gearbox.

Squirrel cage induction generators (SCIGs) can be used in variable speed wind turbines, as in controlling synchronous machines.

In such cases, the output voltage, however, can not be controlled, and the external supply of reactive power is required.

It means fixed-speed induction generators have restrictions when it comes to operating only within a narrow range of discrete speeds.

Other disadvantages of these generators are about the machine size, low efficiency, noise, and reliability.

These days, more than 85% of the installed wind turbines use DFIGs, and the largest capacity for the commercial wind turbine product has an increased capacity towards 5MW.

The increased capacity offers several advantages, including high energy yield, reduced mechanical stresses, power fluctuations, and controllability of reactive power.

Induction generators are also prone to voltage instability. Additionally, the damping effect may result in power losses in the rotor. There is no direct control over the terminal voltage, nor sustained fault currents.

In these cases, it is possible to regulate the speed and torque of the DFIG by controlling the rotor side converter (RSC).

In sub-synchronous operation, the rotor-side converter works as an inverter and the grid-side converter (GSC) as a rectifier.

On the other hand, in the case of super-synchronous operation, the RSC operates as a rectifier and the GSC as an inverter.

4. Switched Reluctance Wind Turbine Generator

Switched reluctance wind turbine generators have features such as strong rotor and stator. With the rotor's rotations, the reluctance of the magnetic circuit linking the stator and rotor changes. It then, in turn, induces currents in the winding on the armature (stator).

The reluctance rotor is built from laminated steel sheets, and it does not have any electrical field windings or permanent magnets.

For this reason, the reluctance generator is simple, easy to produce, and assemble. Another obvious feature of these generators is their high reliability. It is because they can work in harsh or high-temperature environments.

Due to the fact that the reluctance torque is only a fraction of electrical torque, the rotor of a switched reluctance generator is usually larger than the other with electrical excitations for a given rate of torque.

When reluctance generators are combined with direct drive features, the machines would be quite large and heavy, making them less useful in wind power applications.

4.4.2 Stand alone system

A stand-alone wind power system mainly consists of a wind turbine, a permanent magnet synchronous generator, hybrid energy storage devices based on a vanadium redox flow battery and a supercapacitor, an AC/DC converter, two bidirectional DC/DC converters, a DC/AC converter and a variable load.

4.4.3 Battery

The wind turning a turbine generator changes speeds at almost every instant. Batteries are used to stabilize the inconsistent energy surges to be useful. The system is only an effective means of producing consumable power when the batteries can stabilize the systems energy effectively.

The lithium-ion battery is one of the popular energy wind solutions that engineers and homeowners commonly recommend to provide reliable solar and wind energy storage power systems.

A rotor drives a permanent magnet synchronous generator at variable speed, depending on the wind speed. The output of the generator is rectified and fed to a battery bank. Typically there is a charge controller in the circuit to prevent overcharging of the batteries.

4.4.4 Grid system

Grid-tied wind power systems use a wind turbine to interface wind-generated electricity with existing electric utility power. They are also referred to as 'utility-intertie' or 'utility-interactive' wind power systems. In a grid-tie wind power system, DC electricity is generated by a wind turbine.

In a utility-scale wind plant, each turbine generates electricity which runs to a substation where it then transfers to the grid where it powers our communities.

Off grid systems and On Grid systems

In off grid systems the wind turbine, which is installed on top of a tall tower, collects wind energy and converts it into electricity. The electricity is used to charge batteries, reduce the fuel consumption on a diesel generator, or drive a pump.

On-grid systems connect to the electric grid and supplement the power you receive from your utility company. In contrast, off-grid systems are entirely independent and rely on battery storage. Despite their differences, they offer similar benefits.

4.5 Design of Wind Mill

The three main factors that influence power output are: wind speed, air density, and blade radius. Wind turbines need to be in areas with a lot of wind on a regular basis, which is more important than having occasional high winds.

What is the formula for wind turbine design?

The best overall formula for the power derived from a wind turbine (in Watts) is $P = 0.5\ C_p\ \rho\ \pi\ R^2\ V^3$, where Cp is the coefficient of performance (efficiency factor, in percent), ρ is air density (in kg/m3), R is the blade length (in meters) and V is the wind speed (in meters per second).

Wind turbine design is the process of defining the form and configuration of a wind turbine to extract energy from the wind.[1] An installation consists of the systems needed to capture the wind's energy, point the turbine into the wind, convert mechanical rotation into electrical power, and other systems to start, stop, and control the turbine.

How Fast Does a Big Wind Turbine Turns ? : A 40-m diameter (D) , three bladed wind turbine produces 600 kW at a wind speed of 14 m/s. Air density is the standard 1.225 kg/m^3. Under these conditions,

a) At what rpm does the rotor turn when it operates with a TSR of 4.0?

b) What is the tip speed of the rotor?

c) If the generator needs to turn at 1800 rpm, what gear ratio is needed to match the rotor speed to the generator speed?

d. What is the efficiency of the complete wind turbine (blades, gear box, generator) under these conditions?

Solution:

a) The tip speed ratio of a wind turbine is given by $\lambda = (2\pi RN)/V$ or $(\pi DN/V)$ where λ is the TSR (non dimensional), D is the diameter of the swept area (in meters), N is the rotational speed in revolutions per second and V is the wind speed without rotor interruption in meters/second).

From which we get $\mathbf{N = \lambda.V/\pi D}$

Substituting the given values we get:

Rotor Speed $N = (4x14)/40\pi = 0.446$ RPS or **26.7 RPM**

b) The tip speed of each blade is given by: **Tip speed** = (πDN)m/s

$$= 40.\pi.0.446$$

$$= \mathbf{56\ m/s}$$

The same answer could have been obtained from the other simpler relation also. i.e. Tip speed is given by: λ = Tip Speed (m/s)/(wind speed without rotor interruption in meters/second) or

Tip Speed = λ x Wind speed = 4x14 = **56 m/s**

c) If the generator needs to spin at 1800 rpm, then the gear box in the nacelle must increase the rotor shaft speed by a factor of

Gear ratio = Generator rpm / Rotor rpm = 1800 / 26.7 = **67.4**

d) From (1.3) the power in the wind is given by: $P = \frac{1}{2}\rho AV^3$

Substituting the given values we get:

$$P = \frac{1}{2} .1.225. \pi . \frac{1}{4} .40^2 \times 14^3 = 2112 \text{ kW}$$

So the overall efficiency of the wind turbine, from wind power to final electrical power =600 / 2112 = 0.284 = **28.4%**