2.4 POWER FLOW CONTROL IN ELECTRIC DRIVE-TRAIN TOPOLOGIES

1. HYDRODYNAMIC TRANSMISSION

Hydrodynamic transmissions use fluid to transmit power in the form of torque and speed and are widely used in passenger cars. They consist of torque converter and an automatic gearbox. The torque converter consists of at least three rotary elements known as the impeller (pump), the turbine, and the reactor, as shown in Figure 1.1. The impeller is connected to the engine shaft and the turbine is connected to the output shaft of the converter, which in turn is coupled to the input shaft of the multispeed gearbox. The reactor is coupled to external housing to provide a reaction on the fluid circulating in the converter. The function of the reactor is to enable the turbine to develop an output torque higher than the input torque of the converter, thus Producing torque multiplication. The reactor is usually mounted on a free wheel (one-way clutch) so that when the starting period has been completed and the turbine speed is approaching that of the pump, the reactor is in free rotation.

At this point, the converter operates as a fluid coupled with a ratio of output torque to input torque that is equal to 1.0. The major advantages of hydrodynamic transmission may be summarized as follows:

- When properly matched, the engine will not stall.
- It provides flexible coupling between the engine and the driven wheels.
- Together with a suitably selected multispeed gearbox, it provides torque–speed characteristics that approach the ideal.

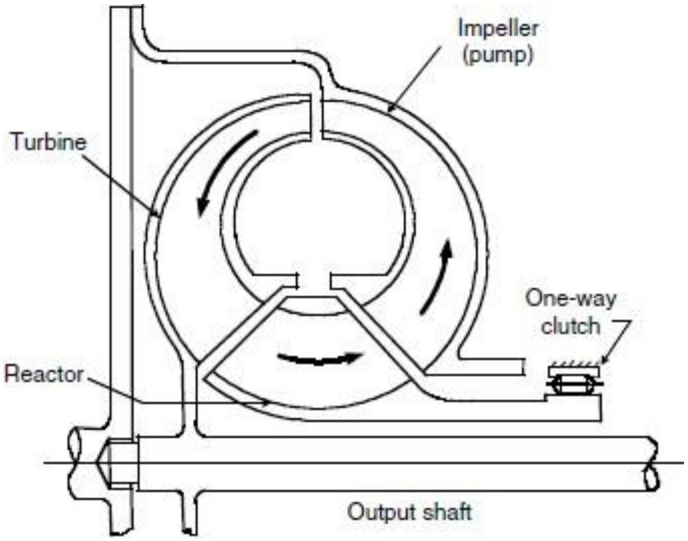

Figure1.1. Schematic view of a torque converter

The major disadvantages of hydrodynamic transmission are its low efficiency in a stop–go driving pattern and its complex construction. The performance characteristics of a torque converter are described in terms of the following four parameters:

1. Speed ratio:

$$C_{sr}=\frac{output\_speed}{input\_speed},$$ ………………….eq1

Which is the reciprocal of the gear ratio mentioned before.

2. Torque ratio:

$$C_{tr}=\frac{output\_torque}{input\_torque}.$$ …………..eq2

3. Efficiency:

$$\eta_c=\frac{output\_speed\times output\_torque}{input\_speed\times input\_torque}=C_{sr}C_{tr}.$$ …………eq3

4. Capacity factor (size factor):

$$K_{tc}=\frac{speed}{\sqrt{torque}}.$$ …………eq4

The capacity factor, *Kc*, is an indicator of the ability of the converter to absorber transmit torque, which is proportional to the square of the rotary speed. Typical performance characteristics of the torque converter are shown in Figure 1.5.3.2.2, in which torque ratio, efficiency, and input capacity factor — that is the ratio of input speed to the square root of input torque — are plotted against speed ratio. The torque ratio has the maximum value at stall condition, where the output speed is zero. The torque ratio decreases as the speed ratio increases (gear ratio decreases) and the converter eventually acts as a hydraulic coupling with a torque ratio of 1.0. At this point, a small difference between the input and output speed exists because of the slip between the impeller (pump) and the turbine. The efficiency of the torque converter is zero at stall condition and increases with increasing speed ratio (decrease in the gear ratio). It reaches the maximum when the converter acts as a fluid coupling (torque ratio equal to 1.0). To determine the actual operating condition of the torque converter, the engine operating point has to be specified because the engine drives the torque converter. To characterize the engine operating condition for the purpose of determining the combined performance of the engine and the converter, an engine capacity factor, *Ke*, is introduced and defined as

$$K_e=\frac{n_e}{\sqrt{T_e}},$$ ……..eq5

Where *ne* and *Te* are engine speed and torque, respectively.

The variation of the capacity factor with speed for a typical engine is shown in Figure. To achieve proper matching, the engine and the torque converter shouldhave a similar range in the capacity factor.

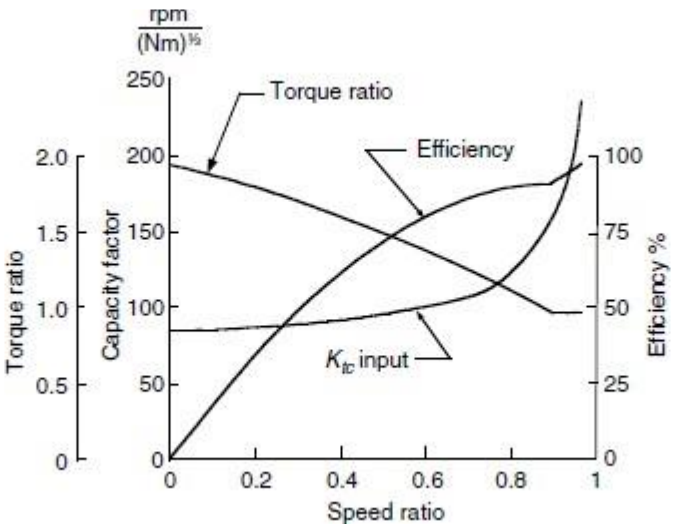

Figure 1.2: Performance characteristics of a torque converter

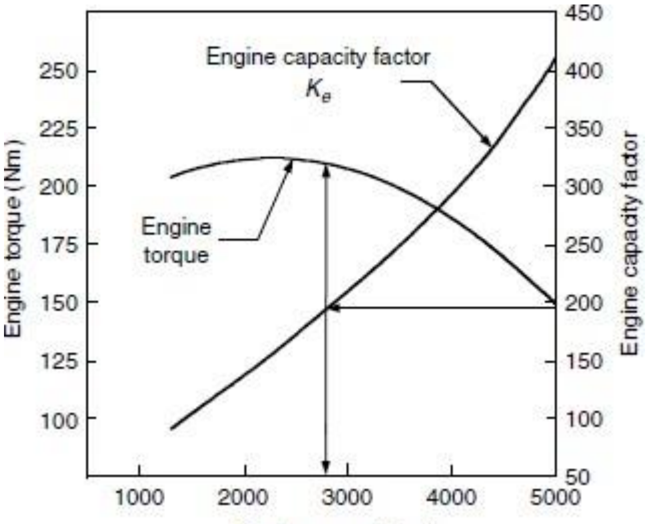

Figure 1.3: Capacity factor of a typical engine

The engine shaft is usually connected to the input shaft of the torque converter, as mentioned above. That is,

$$K_e = K_c.$$ ……….eq6

The matching procedure begins with specifying the engine speed and engine torque. Knowing the engine operating point, one can determine the engine capacity factor, *Ke*(see Figure 1.5.3.2.5). Since *Ke_ Kc*, the input capacity factor of the torque converter corresponding to the specific engine operating point is then known. As shown in Figure 1.5.3.2.4, for a particular value of the input capacity factor of the torque converter, *Ktc*, the converter speed ratio, *Csr*, and torque ratio, *Ctr*, can be determined from the torque converter performance characteristics. The output torque and output speed of the converter are then given by

$$T_{tc} = T_e C_{tr}$$ …………………….eq7

and

$$n_{tc} = n_e C_{sr},$$ …………….eq8

Where *Ttc*and*ntc*are the output torque and output speed of the converter, respectively. Since the torque converter has a limited torque ratio range (usually less than 2), a multispeed gearbox isusually connected to it. The gearbox comprises several planetary gear sets and is automatically shifted. With the gear,

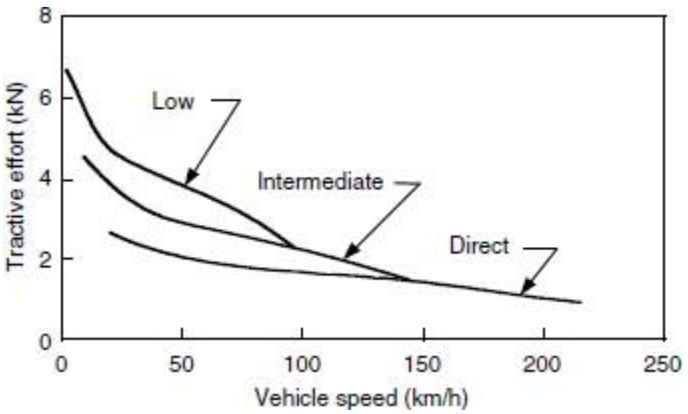

Figure 1.4.: Tractive effort–speed characteristics of a passenger car with automatic transmission

Ratios of the gearbox, the tractive effort and speed of the vehicle can be calculated by

$$F_t = \frac{T_e C_{tr} i_g i_0 \eta_t}{r}$$ **………**eq9 and

$$V = \frac{\pi n_e C_{sr} r}{30 i_g i_0} (\mathrm{m/s}) = 0.377 \frac{n_e C_{sr} r}{i_t} (\mathrm{km/h}).$$ ………….eq10

Above fig shows the variation of the tractive effort with speed for a passenger car equipped with a torque converter and a three-speed gearbox.