CHAPTER 2

Design Consideration of the Variable Speed Controller

2.1 Speed-Torque characteristics of the Induction motor

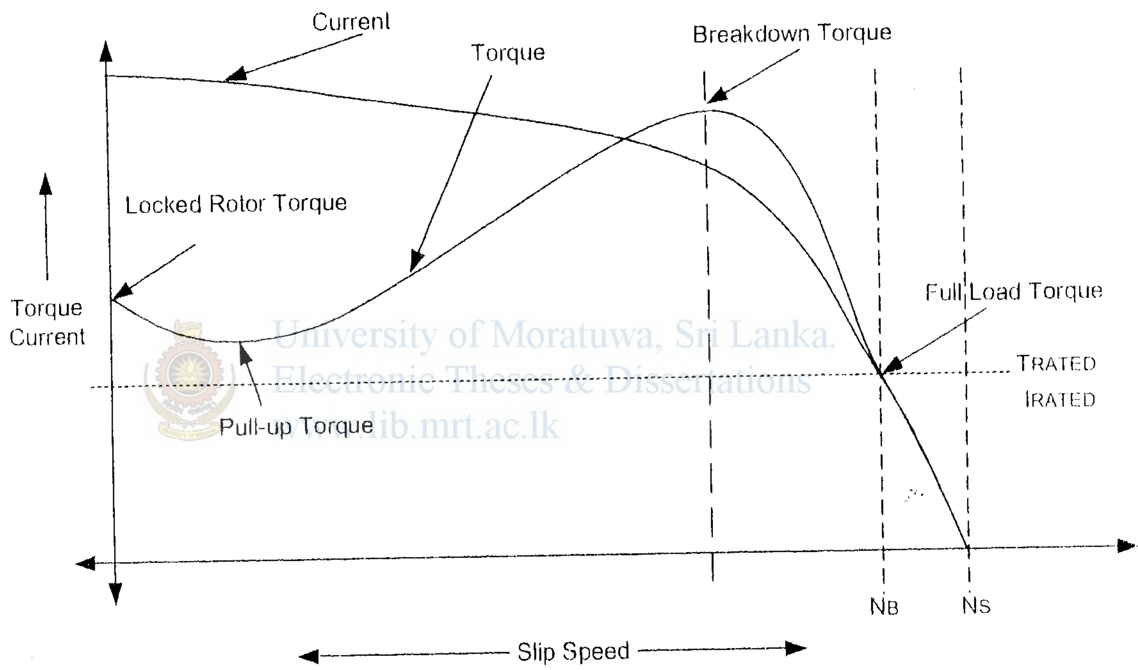

Figure 2.1- Speed-Torque characteristics of the Induction motor

Figure 2.1 shows the typical speed-torque characteristics of an induction motor. The X axis shows speed and slip. The Y axis shows the torque and current. The characteristics are drawn with rated voltage and frequency supplied to the stator. During start-up, the motor typically draws up to seven times the rated current. This high current is a result of stator and rotor flux, the losses in the stator and rotor windings, and losses in the bearings due to friction. This high starting current overcomes these components and produces the momentum to rotate the rotor. At start-up, the motor delivers 1.5 times the rated torque of the motor. This starting torque is also called locked rotor torque (LRT). As the speed increases, the current drawn by the motor reduces slightly .

The current drops significantly when the motor speed approaches ~80% of the rated speed. At base speed, the motor draws the rated current and delivers the rated torque. At base speed, if the load on the motor shaft is increased beyond its rated torque, the speed starts dropping and slip increases. When the motor is running at approximately 80% of the synchronous speed, the load can increase up to 2.5 times the rated torque. This torque is called breakdown torque. If the load on the motor is increased further, it will not be able to take any further load and the motor will stall. In addition, when the load is increased beyond the rated load, the load current increases following the current characteristic path. Due to this higher current flow in the windings, inherent losses in the windings increase as well. This leads to a higher temperature in the motor windings. Motor windings can withstand different temperatures, based on the class of insulation used in the windings and cooling system used in the motor. Some motor manufacturers provide the data on overload capacity and load over duty cycle. If the motor is overloaded for longer than recommended, then the motor may burn out. As seen in the speed-torque characteristics, torque is highly nonlinear as the speed varies. In many applications, the speed needs to be varied, which makes the torque vary. A simple method of speed control called, Variable Voltage Variable Frequency (VVVF or V/f).

2.2 Load characteristics of the Induction motor

Constant Torque, Variable Speed Loads

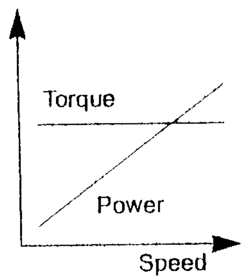

Figure 2.2 - Constant Torque, Variable Speed Loads

The torque required by this type of load is constant regardless of the speed. In contrast, the power is linearly proportional to the speed. Equipments such as screw compressors, conveyors and feeders have this type of characteristic.

Variable Torque, Variable Speed Loads

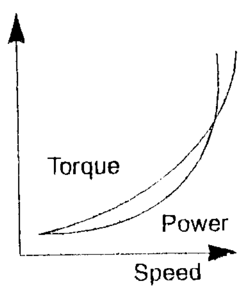

Figure 2.3 - Variable Torque, Variable Speed Loads

This is the most commonly found in the industry and sometimes is known as a quadratic torque load. The torque is proportional to the square of the speed, while the power is proportional to the cube of the speed. This is the typical torque-speed characteristic of a fan or a pump.

Constant Power Loads

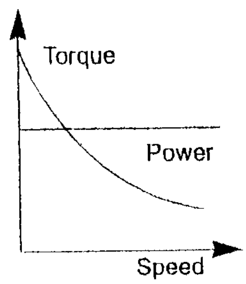

Figure 2.4 – Constant Power Loads

This type of load is rare and sometimes found in the industry. The power remains constant while the torque varies. The torque is inversely proportional to the speed, which theoretically means infinite torque at zero speed and zero torque at infinite speed. In practice, there is always a finite value to the breakaway torque, required. This type of load is characteristic of the traction drives, which require high torque at low speeds for the initial acceleration and then a much reduced torque when at running speed.

Constant Power, Constant Torque Loads

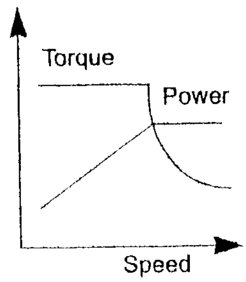

Figure 2.5 - Constant Power, Constant Torque Loads

Constant power , Constant torque load, as speed increases, the torque is constant while the power linearly increasing. When the torque starts to decrease, the power then remains constant.

2.3 V/*f* Control Theory

As the speed-torque characteristics, the induction motor draws the rated current and delivers the rated torque at the base speed. When the load is increased (over-rated load), while running at base speed, the speed drops and the slip increases. As we have seen in the earlier section, the motor can take up to 2.5 times the rated torque with around 20% drop in the speed. Any further increase of load on the shaft can stall the motor.

The torque developed by the motor is direct proportional to the magnetic field produced by the stator. So, the voltage applied to the stator is direct proportional to the product of stator flux and angular velocity. This makes the flux produced by the stator proportional to the ratio of applied voltage and frequency of supply. By varying the frequency, the speed of the motor can be varied. Therefore, by varying the voltage and frequency by the same ratio, flux and hence, the torque can be kept constant throughout the speed range.

Stator Voltage (V) α [Stator Flux(Φ)] x [Angular Velocity (ω)]

$V \alpha \; \Phi \times 2\pi f$

$\Phi \alpha V/f$

This makes constant V/f the most common speed control of an induction motor. Figure 2.6 shows the relation between the voltage and torque versus frequency. Figure 2.6 demonstrates voltage and frequency being increased up to the base speed. At base speed, the voltage and frequency reach the rated values as listed in the nameplate. We can drive the motor beyond base speed by increasing the frequency further. However, the voltage applied cannot be increased beyond the rated voltage. Therefore, only the frequency can be increased, which results in the field weakening and the torque available being reduced. Above base speed, the factors governing torque become complex, since friction and windage losses increase significantly at higher speeds. Hence, the torque curve becomes nonlinear with respect to speed or frequency.

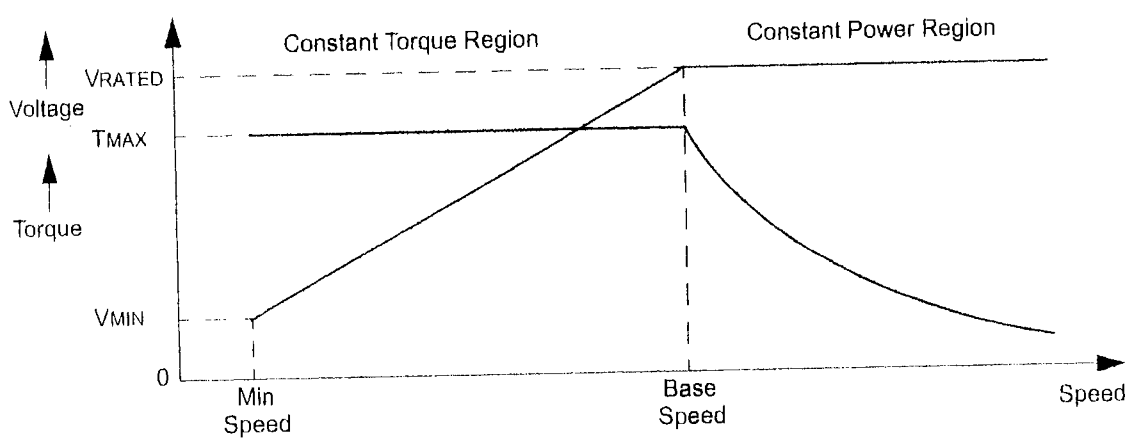

Figure 2.6 - Speed torque characteristics of induction motor