Asynchronous Generation in Distribution Systems

Introduction

Asynchronous generation is typically applied where the cost or complexity of using synchronous machines cannot be justified and individual generator capacity is usually small in comparison with the distribution supply capacity. Generators are driven by some form of prime mover such as steam turbine, water turbine or wind turbine.

Because of the limited freedom in choosing the point of connection to a distribution feeder, generation can be a challenge to integrate into a system in such a way that system voltage, loading, voltage stability and fault level constraints are met for all possible system conditions.

Feeder power flow directions and magnitudes change with load changes and generator output levels throughout the day. The impact of voltage changes is particularly significant if the generation is connected some distance from the point of supply for the feeder.

Conventional Induction Generator

A common form of asynchronous generator is the squirrel cage induction generator that can be visualized as an induction motor whose shaft is driven by a prime mover. The machine torque-slip curve is shown below in Figure 1. The slip of the machine is initially negative when running as a motor but, as the speed is increased, the slip becomes positive above system synchronous speed and increases as the input power is increased. The machine input power can be increased theoretically to about 2 per unit of rating after which any further increase in slip will result in reduced power. The machine is now operating on the unstable portion of the curve and any further increase in mechanical power simply accelerates the machine to overspeed.

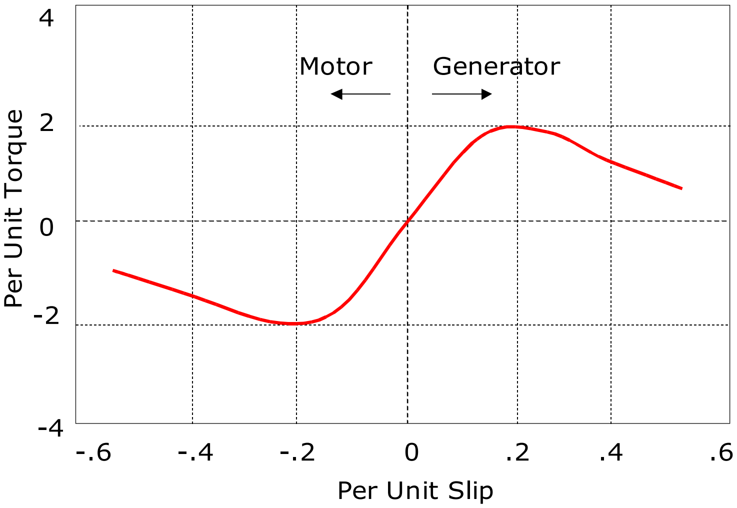

Figure 1: Torque vs Slip

For practical purposes, the positive slip at full load is quite small (.06 to .08) and the machine is operating well inside the stable portion of the curve. Like a synchronous generator, a system fault causing a disturbance on the system will result in a change on the operating point of an induction generator along the curve.

Generators are selected with terminal voltages appropriate to their size. Wind driven machines do not normally exceed 3 MW. If the generator operates at low voltage, it is likely to be connected to a low voltage sub-network via low voltage switchgear, or through a step-up transformer to a high voltage feeder.

One of the major benefits of induction generators is the flexibility of where they can be placed and freedom from the need to control them. The machines can be treated like negative induction motor load for the purposes of visualization. Larger induction generators may be dispatchable but, if used in a cogeneration scheme, the surplus energy available after the process needs are satisfied constrains the electrical output.

Short Circuit Infeed

Connecting generation can increase fault current levels significantly in the vicinity of the generator to the point where existing switchgear is overstressed. The machine fault contribution depends upon the proximity of the fault to the machine. Induction machines contribute the same level of fault current into a fault as a same sized synchronous machine for up to 200ms, after which the current decays rapidly to zero.

The use of a step-down transformer to connect the generator reduces fault levels significantly compared to a direct-connected machine.

Reactive Power Requirements

Induction generators impose special requirements on the distribution system. Because they have no automatic voltage regulation and no reactive power generation capability, induction machines can be considered as large induction motors with a shaft driven by a prime mover. The real-reactive power characteristics of an induction generator are represented by the classical induction motor circle diagram when operating as motor or generator. At no load, the reactive power drawn is about half the full load kVA power rating of the machine. The real power delivered by the generator determines the actual reactive power drawn from the system by the machine.

This is illustrated in Figure 2.

The most critical factor to consider in applying induction generators is the need for the system to supply all the reactive power necessary to provide excitation at all generating levels. This means that the machine can only be applied where there is a source of reactive power and it is of of adequate capacity.

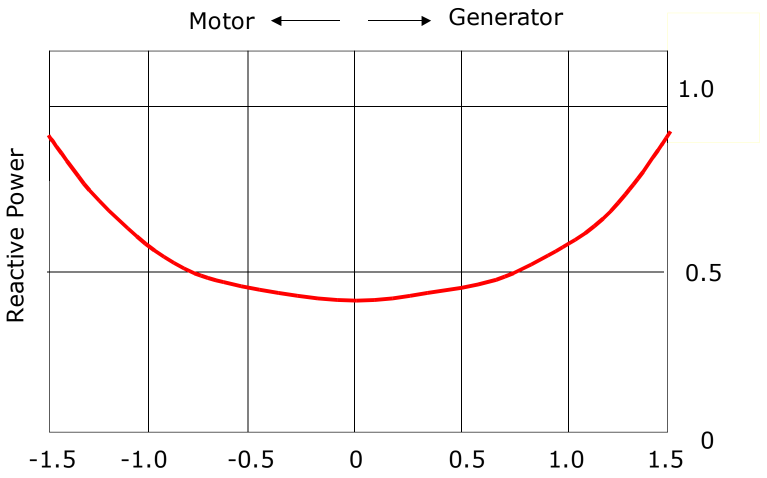

Figure 2: Real vs Reactive Power

If the fault level at the substation supplying the machine with reactive power is not high enough (weak network), the machine will be subject to oscillations in the event of system disturbances, particularly for peak load conditions. It is possible that the reactive power available from the system will be insufficient to prevent a voltage collapse (voltage instability) and a shutdown of part of the system results.

To mitigate the reactive power needs, compensating capacitors are often connected to the machine terminals and switched with the machine. The capacitors move the circle diagram down vertically as shown in Figure 3. It is possible to compensate for the machine peak reactive power needs but this will generate excess reactive power at lighter loads. An option is to use a series of switched capacitors matched to generation at different loading levels, but this means additional cost.

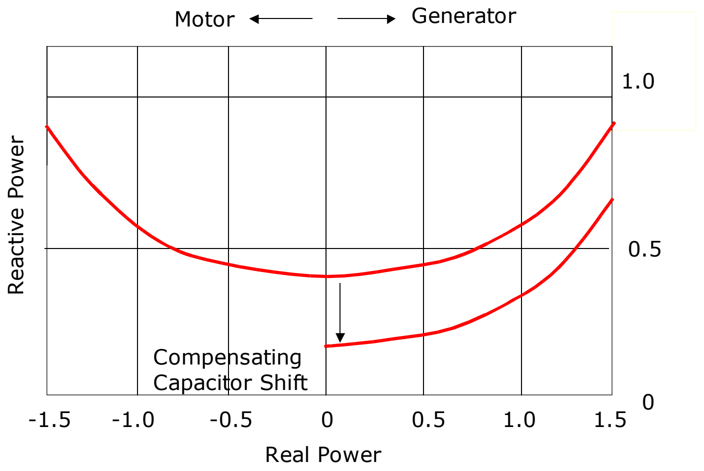

Figure 3: Capacitor Compensation

In addition to reactive power requirements when generating, sufficient supply capacity must be available to ensure that induction machines can be started properly without excessive voltage dips.

Applying certain types of soft starting for induction machines can reduce the total starting current and hence the transient reactive power demand on the system. Figure 4 shows back-to-back switched thyristors which are applied in each phase. The firing circuit controls the firing angle and the magnitude of the inrush current during starting to little more than full load if necessary. The machine magnetizing flux is built up gradually and the mechanical drive input increased until the machine is generating the desired power. Once the machine is at the desired operating level the thyristors are bypassed

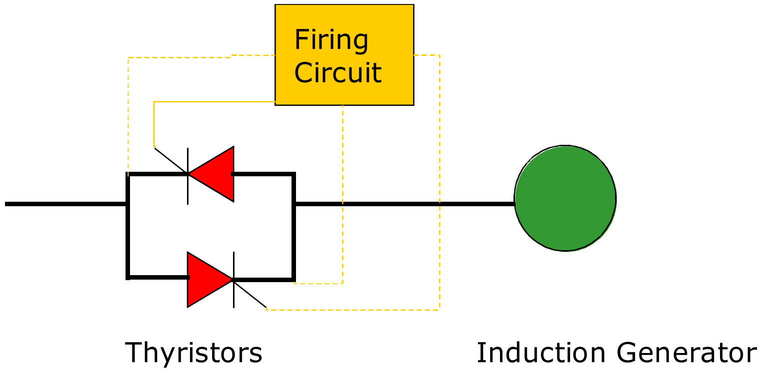

Figure 4: Thyristor Soft Start

Double Fed Induction Generator

The double-fed induction generator is ideally suited for wind generation. It consists of a stator supplied from the system in the usual way and a rotor supplied via an AC-DC-AC converter from the same supply, as shown in Figure 5.

A significant feature is the ability to operate over a limited range of speeds about synchronous to take advantage of prevailing wind speed and thus increase output over a given period. Other advantages are:

- Fault ride-through capability that minimizes machine transients and permits rapid restoration to pre-fault conditions.
- Matching rotor and stator frequencies before closing the stator supply to minimize synchronizing transients.
- Limited fault contribution during system faults.
- Ability to operate over a range of reactive power inputs/outputs.
- Control of voltage or power factor at a selected point.

This last feature provides a means of providing voltage regulating capacity, just as for a synchronous generator, a very useful feature when compared with the conventional induction generator that always requires reactive power support.

The current size of wind generators dictates a generating voltage under a 1000V and requires a step-up transformer for connecting to the high voltage system. Invariably, a tapping range of fixed taps are available to accommodate the operational voltages at different points on the connecting feeder.

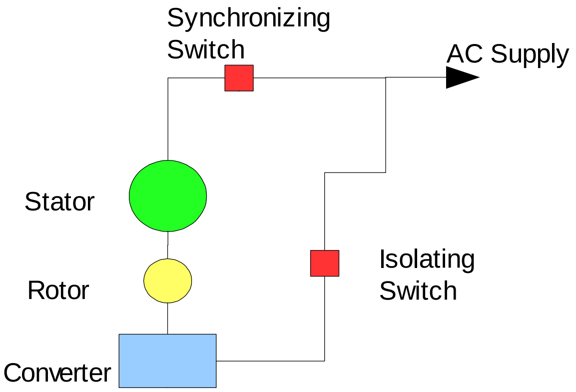

Figure 5: Double Fed Induction Generation

Double fed machine response to external short circuits is complicated because of the rotor converter controls and the imposition of a short circuit (named crowbar) across the rotor for certain fault parameters. The crowbar can be applied for as little as two cycles and, while it is applied, the machine operates like a conventional induction generator. Generally the fault infeed without crowbar decays from between 200% and 50% of rated current for a closeup fault, much like a synchronous machine. With crowbar, the machine behaves like a conventional induction generator and can produce initially up to five times full load current, dependent upon the machine subtransient impedance.