Self-Excited Induction Generators for Wind Turbine Application

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ABSTRACT
The usage of squirrel cage induction machines in wind generation is mostly preferred as a generator of choice. The squirrel cage induction machine is reliable, simple, light weight, cheap and requires very less maintenance. At constant frequency the induction generator is connected to the utility. For constant frequency application, the induction generator runs at small value of slip i.e. practically constant speed. The wind turbine works at maximum efficiency only for a small range of wind speed deviation.

For variable speed application, an induction generator demands an interface to convert the variable frequency output of the generator to the fixed frequency. This system is discussed using self-excited generator because a simple diode bridge requires performing the ac/dc conversion. The successive dc/ac conversion will be performed using various techniques. The use of a thyristor bridge is accessible for large power conversion and has higher reliability and lower cost. The firing angle of the inverter bridge can be controlled for tracking the optimum power curve of the wind turbine. With only thyristors and diodes used in power conversion, the system can be scaled up to a very high power and high voltage applications.

Keywords
Wind energy, variable speed generation system,renewable energy, self excitation.

1. INTRODUCTION
Variety of generator concepts are used and proposed for converting wind energy into electrical energy. In the last ten years the size of the wind turbines is increased and the cost of energy generated by wind turbine goes down. The task is to build large wind turbines and produce cheaper electricity. Thus, there is a need to convert wind energy into electrical energy from wind turbines.

The combination of series [1] and parallel [2] capacitors are used for exciting the induction generator while running at variable speeds. For self-excited mode, the induction generator is excited by three-phase ac capacitors. The slip, frequency, air gap voltage and operating range of the system are altered by the choice of capacitor size and characteristics of the induction generator. In a self-excited mode [3] the operating slip is usually small and the deviation of the frequency is based on operating speed range. The test system has following components:

- a 1/3 HP dc machine for representing wind turbine
- a three-phase, 1/3 HP, induction generator driven by dc machine
- numerous sets of capacitors for providing reactive power to induction generator
- a three-phase diode bridge for rectifying the current given by generator
- a dc reactor for smoothing dc current and for limiting the current peaks on dc bus
- a three-phase thyristor bridge for conversion of power from the dc bus to the utility.

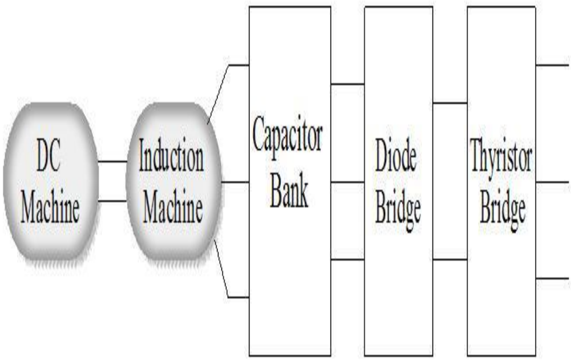

Fig 1: System schematic

The organization of the paper is as follows: Section II describes wind turbine operation. Section III gives the concept of self-excitation of an induction generator. Section IV covers parallel compensation. Section V covers series parallel compensation. The last section covers conclusion.

2. WIND TURBINE
In wind farms, various wind turbines are used with fixed frequency induction generators [4]. Thus the power generated is not upgraded for all conditions ofwind. To operate a wind turbine at different wind speeds, the wind turbine should be operated at its maximum power coefficient (Cp-optimum = 0.3-0.5). For operating around its maximum power coefficient, the wind turbine should operate at a constant tip-speed ratio, which is ratio of the rotor speed to the wind speed. As the wind speed rises, the rotor speed should follow the deviation of the wind speed. The load to the wind turbine is fixed as a cube function of the rotor rpm to operate the wind turbine at maximum efficiency. The aerodynamic power developed by wind turbine is given by:

$$P = 0.5\rho A C_P V^3 (1)$$

Where the aerodynamic power is function of the specific density (ρ) of the air, the swept area of the blades (A) and the wind speed (V). For operating the wind turbine at its optimum efficiency (Cp-optimum), the rotor speed must be varied in the same proportion as the wind-speed variation. If we track wind speed accurately, the power can also be given in terms of the rotor speed.

$$P = K_P rpm^3 (2)$$

The power given by equation [2] is P_{ideal} which is power generated by generator at various rotor rpm. One way of converting a wind turbine from fixed speed operation to variable speed operation is to move thesystem from a utility connected induction generator to a self-excited operation. If the inertia of the rotor of wind turbine is negligible, the rotor speed can follow the variation in speed of wind. So the wind turbine will always operate at Cp-optimum. The wind turbine rotor has large inertia due to blade inertia and other components. The energy captured in variable-speed operation is larger as compared to fixed-speed operation.

For variable-speed operation [2] and comparatively large rotor inertia, there is a buffer between the energy source (wind) and energy sink (utility). For allowing the rotor speed to vary has advantage of using the kinetic energy to be transferred in and out of the rotor inertia. So the aerodynamic power that changes with the input of wind is filtered by the inertia before transmitting to the utility grid which is similar to the use of dc filter capacitor at the dc bus of a dc-dc converter. The dc capacitor filters the voltage ripple to get smooth output voltage. So by variable speed operation the mechanical drives lifetime and other components of the wind turbine can be extended.

3. SELF-EXCITED INDUCTION GENERATOR

By using the steady-state equivalent circuit given in Figure 2 the induction machine is modeled. The frequency dependent reactance is scaled using per unit frequency. Per unit frequency (f_{pu}) is the ratio of operating frequency to the rated frequency (60Hz). The system stable operation is maintained when balance between real and reactive power is keep. The balance of real power depends on power produced in the rotor and the power consumed from the stator winding through power converter. The reactive power balance is set between the ac capacitors and the air-gap flux condition at any operating state.

The equivalent circuit [1] shown in Figure 2 can be presented in terms of its admittance. The admittance of the stator branch has stator leakage inductance, stator resistance, the stator load resistance displaying the power drawn by the diode bridge at the stator, and the excitation capacitor. Stator admittance is found if we have given the capacitor size, load resistance, the stator leakage inductance and stator resistance, the stator admittance is determined. The stator admittance is given as:

$$Y_S = Re(Y_S) + jI_m(Y_S) \qquad (3)$$

The rotor branch is given by

$$Y_r = \frac{\frac{R_r}{S}}{\left(\frac{R_r}{S}\right)^2 + \left(X_{lr} f_{pu}\right)^2} - j\frac{X_{lr} f_{pu}}{\left(\frac{R_r}{S}\right)^2 + \left(X_{lr} f_{pu}\right)^2} \qquad (4)$$

The magnetizing branch is given by:

$$Y_m = -j\frac{1}{X_m} (5)$$

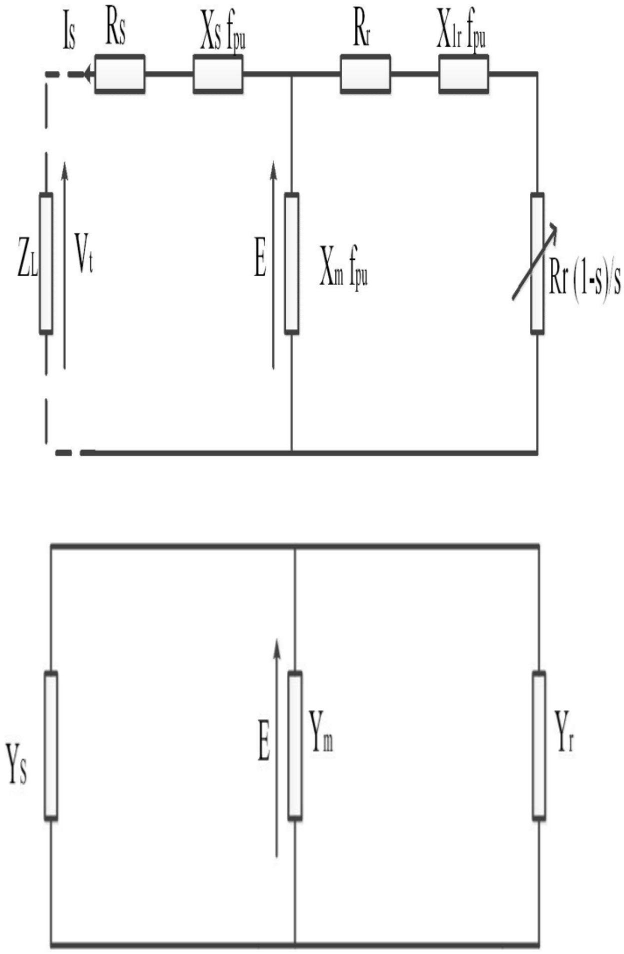

Fig 2: Induction machine equivalent circuit

By equating real part of the stator branch and real part of the rotor branch the balance of real power is determined:

$$Re(Y_s) + \frac{\frac{R_r}{s}}{\left(\frac{R_r}{s}\right)^2 + \left(X_{lr} f_{pu}\right)^2} = 0 (6)$$

The slip is determined from Equation 6. The relationship between imaginary part of the stator branch, rotor branch, and the magnetizing branch is given by Equation 7. It is used to solve X_m.

$$Im(Y_s) + \frac{X_{lr} f_{pu}}{\left(\frac{R_r}{s}\right)^2 + \left(X_{lr} f_{pu}\right)^2} + \frac{1}{X_m f_{pu}} = 0 \ (7)$$

The relationship between magnetizing inductance Lm as function of flux linkage (E/ω) is shown in Figure 3. It shows when value of Lm decreases, the induction generator saturates. From Lm, the air gap voltage can be determined. The stator and rotor current, the terminal voltage, the air gap voltage and input power can be find out.

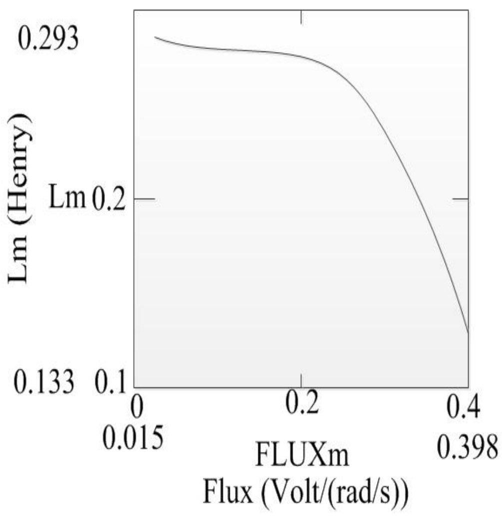

Fig 3: Induction machine magnetizing curve

4. PARALLEL COMPENSATION

The parallel compensation [1] is described in this section. The three-phase ac capacitors are connected in parallel with the load at the terminal of the induction generator. The load is a power converter consisting of the diode bridge and the thyristor bridge. To the generator, the diode bridge presents a unity power factor load. Although the current waveform at the input to the diode bridge is distorted, the presence of the ac capacitors helps to smooth out the current shape. The power output of the generator can be adjusted by controlling the firing angle of the phase-controlled inverter at the utility side. Thus, the utility is seen by the generator as an adjustable energy sink. Figure 4 shows the physical diagram of parallel compensation.

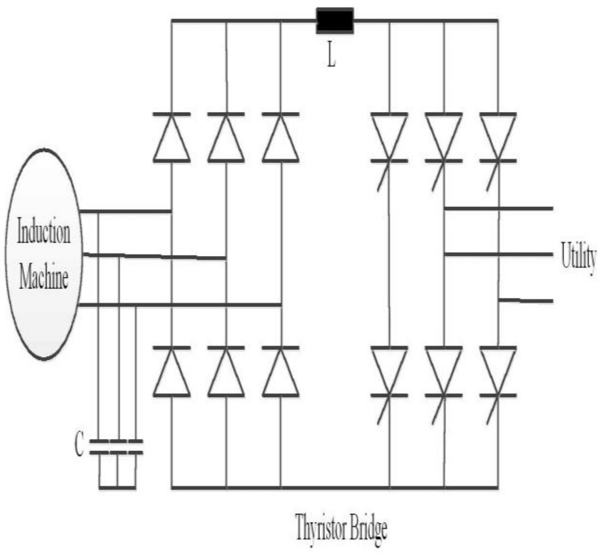

Fig 4: Parallel compensation

5. SERIES-PARALLEL COMPENSATION

The system configuration for series-parallel compensation [2] is shown in Figure 5. In this configuration, both the series capacitor C2 and the parallel capacitor C affect the level of excitation. The series capacitance C2 helps to increase the level of excitation and counteracts the voltage drop acrossthe stator resistance and stator leakage inductance.

The parallel capacitors at the output terminal across the diode bridge filters the harmonics current entering the generator. It is expected that the harmonic losses due to current harmonics are reduced significantly. The torque pulsation which is normally related with current harmonics is considered very small. The effect of torque pulsation on the speed fluctuation is reduced by the fact that the blade inertia is very large as compared to normal load. Thus the rotor speed fluctuation due to harmonics is barely being noticeable.

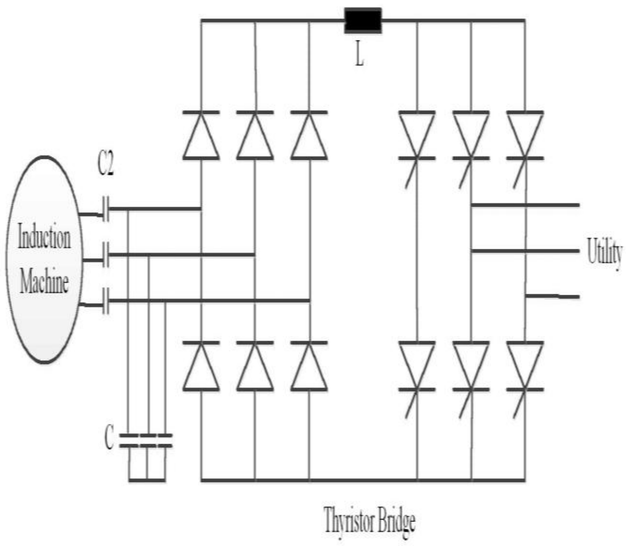

Fig 5: Series-parallel excitation of the induction machine

6. CONCLUSION

The proposed generator is investigated for application in wind power generation. In the first stage of implementation, a proof of concept of the generator was investigated. This paper demonstrates the technical viability of using a self-excited induction generator in variable-speed wind generation. This greatly simplifies the power stages needed to connect to the utility compared with inverter-fed induction generators.

The series-parallel compensation system tracks the maximum power curve of the wind turbine over a wide range of speed, with a pair of capacitor values. The power stage of the power converter consists of diodes and thyristors, thus, this system can be scaled up to a higher voltage and higher power to process very high power in wind power generation.

Its main drawback is the non-sinusoidal output current generated at the grid. However, many schemes have been proposed to improve the power quality at the output of the phase-controlled inverter such as passive filter, active filter, or other topologies.

7. FUTURE SCOPE

Application of self-excited induction generator for energy conversions in remote locations offers many advantages over a synchronous generator. The SEIG is most economical solution for powering customers isolated from the utility grid. The better methods of reactive power/voltage control techniques will make the SEIG more suitable for isolated applications.

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