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Comparison of Different Compensation Devices in Wind Turbine Driven Induction Generator

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ABSTRACT: Developments in wind turbine technology are facilitating the increase of power generation capacity from renewable energy resources. The utilization of the squirrel-cage induction generator for wind power generation has some advantages over that of conventional synchronous generators. In this paper an induction generator model driven by wind turbine and connected to the grid is simulated in SIMULINK / MATLAB. Static VAR Compensator (SVC) and capacitor bank improves the response of grid connected wind farm. The simulation results confirm that the competitive dynamic response of the system using capacitor bank and SVC.

KEYWORDS: Wind Turbine Induction Generator, Capacitor Bank, Static VAR Compensator(SVC), Reactive Power compensation.

I.INTRODUCTION

High penetration of wind energy into the current grid is prevented by many reasons, especially the high capital and maintenance cost of the system [1]. To some extent this problem is mitigated by utilizing squirrel cage induction generator (SCIG). The use of SCIG in wind energy generation is widely accepted as a simple and cheap option, as it is reliable and requires very little maintenance due to its brushless rotor. Hence, it offers significant cost advantage over other type of generators [2].In wind farms, fault on the transmission line can lead to wind generator over-speed and cause instability of the network voltage [3].

When, fault occurs, the terminal voltage of the IG drops. Therefore, the electrical torque abruptly decrease to zero due to the terminal IG voltage and the rotor speed starts to increase. After the clearance of the fault, the reactive power consumption increases resulting in reduced voltage of IG. Thus the IG voltage does not recover immediately after fault. Therefore generator becomes unstable. To minimize reactive power exchange between grid and wind generator, dynamic compensation of reactive power can be done [4].Capacitor bank and SVC can be used for reactive power compensation of power systems to provide voltage support and stability improvement [5]. The effect of capacitor bank and SVC in improving the stability performance of Wind turbine induction generator is analyzed in this paper.

II.SYSTEM MODELLING

OVERALL SYSTEM

The model of the system considered for this paper is given in Fig. 1. The induction generator is driven by wind power and is connected to the grid system through distribution transformer. In this model, the wind turbines are an uncontrolled turbine and its power depend on the effective head (H) and debit (Q). The mechanical power output of the turbine (P_m) is given by equation (1)

$$Pm = gHQ\eta_T \qquad (1)$$

Where:

g is gravity constant

η_T is turbine efficiency

The mechanical torque (T_m) is used to drive the induction generator is presented by equation: (2)

$$T_m = \frac{P_M}{w_m} \text{Where} \qquad (2)$$

ω_m is the rotor angle speed

In wind power generations, the head viable charge can be balanced physically utilizing the opening entryway .The power that is produced by the induction generator that is traded to Low Voltage (LV) side distribution system. In the system considered, the capacity power of wind power generation is less than the capacity power of distribution transformer, so they empower supply the power simultaneously. The simplified equivalent of grid system on medium voltage (MV) side of distribution transformer is assumed one generator with its impedance.

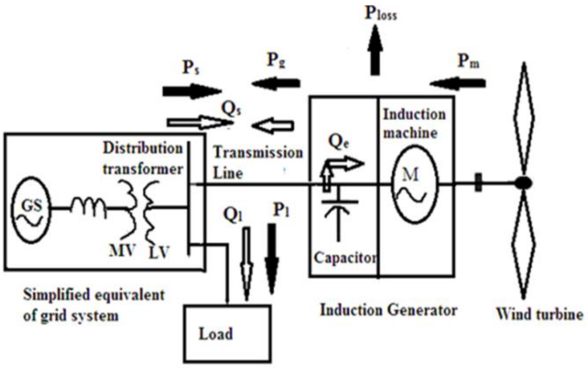

Fig. 1. Block diagram representation of the model.

POWER BALANCE

As shown in Fig. 1, the induction generator absorbs the mechanical power (P_m) from the turbine and produces the supplied active power (P_g) to the load (P_l) and also produces heat loss. The induction generator absorbs the reactive power (Q_g) from the excitation capacitor (Q_e) or/and from grid system. The reactive power when the capacity of the excitation capacitor is more than reactive power that is required by induction generator. The load absorbs the active and reactive power (P_l, Q_l) from the grid system and/or the induction generator. Whereas the grid system can export or import the active and reactive power (P_s, Q_s). The active and reactive power balances in the induction generator is given by equation (3) & (4).

$$\textstyle\sum. P_{\text{produce}} = \sum. P_{\text{absorbe}} \qquad (3)$$

$$\textstyle\sum. Q_{\text{produce}} = \sum. Q_{\text{absorbe}} \qquad (4)$$

INDUCTION GENERATOR MODELING

The induction generator model has been derived from an induction machine and reactive load generations. The active load generations can be undertaken by excitation capacitor or grid systems. The mathematical modelling of squirrel-cage induction machine in d-q frame is given by following equations from (5) to (20).

Electrical System

$$v_{qs} = R_s i_{qs} + \frac{d\lambda qs}{dt} + w\lambda ds \qquad (5)$$

$$v_{ds} = R_{si_{ds}} + \frac{d\lambda q_s}{dt_,} - w\lambda qs \qquad (6)$$

$$0 = R'_r i'_{qr} + \frac{d\lambda'_{dr}}{dt_,} - (w - w_m)\lambda'_{qr} \qquad (7)$$

$$0 = R'_r i'_{qr} + \frac{d\lambda'_{dr}}{dt} - (w - w_m)\lambda'_{qr} \qquad (8)$$

And

$$\lambda_{qs} = L_s iq_s + L_m i'_{qr} \qquad (9)$$

$$\lambda_{qs} = L_s i_{ds} + L_m i'_{dr} \qquad (10)$$

$$\lambda'_{qr} = L'_r i'_{qr} + L_m i_{qs} \qquad (11)$$

$$\lambda'_{dr} = L'_r i'_{dr} + L_m i_{ds} \qquad (12)$$

Where:

$$L_s = L_{ls} + L_m \qquad (13)$$

$$L'_r = L'_{lr} + L_m \qquad (14)$$

Where:

vds, vdr, v_{qs}, v_{qr} are the stator and rotor voltages in the d-q frame

ids, i'dr, iqs, i'qr are the stator and rotor currents in the d-q frame

λds, λ'dr, λqs, λ'qr are the stator and rotor fluxes in the d-q frame

Rs, R'r are the stator and rotor resistances

Lls, L'lr are the stator and rotor leakage inductances

Lm is the magnetizing inductance

ω is the arbitrary reference frame

Electromagnetic Torque- The electromagnetic torque is given by equation (15)

$$T_e = \frac{3}{2} P\{\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\} \qquad (15)$$

Where:

T_e denotes Electromagnetic torque and number of pole pair is denoted by P.

EXCITATION SYSTEM

$$i_{qs} = i_{ql} + wq_{dc} + \frac{dq_{qc}}{dt} \qquad (16)$$

$$i_{ds} = i_{dl} - wq_{qc} + \frac{dq_{dc}}{dt} \qquad (17)$$

And

$$q_{qc} = cv_{qs} \qquad (18)$$

$$q_{dc} = cv_{ds} \qquad (19)$$

Where:

I_{dl}, I_{ql} are the d line currents in the d-q frame

q_{dc}, q_{qc} are the electric charge in the d-q frame

C is the capacity of capacitor excitation

MECHANICAL SYSTEM

$$\frac{dW_m}{dt} = \frac{1}{2H}\{T_e - FW_m - T_m\} \qquad (20)$$

Where:

ω_m is the rotor angle speed

In equation (20), the machine acts as a generator if T_m is negative.

III. CONTROL STRATEGY

A. RESPONSE OF INDUCTION GENERATOR USING CAPACITOR BANK

The unbalance in grid voltage has been found to make significant impact on the generator and system performance. The self excitation mode operation uses excitation capacitor to create the reactive power. Shunt capacitor connected at the generator terminals maintains the terminal voltage near to nominal voltage and improves the power factor.

B. RESPONSE OF INDUCTION GENERATOR USING SVC

A static var compensator (SVC) is an electrical device for providing fast acting reactive power compensation on high-voltage electricity transmission networks. static var compensator (SVC) is a shunt device of the flexible a.c. transmission systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. The SVC controls voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage decreases, the SVC produces reactive power. When system voltage increases, it absorbs reactive power. Typically SVC comprises of bank of individually switched capacitors in conjunction with thyristor controlled reactor. By means of phase-angle modulation switched by thyristor, the reactor may be variably switched into the circuit, and so provides a continuously variable VAR injection (or absorption) to the electrical network. Other arrangements like thyristor-switched reactor and thyristor-switched capacitor are also possible. In transmission application, SVC is used to regulate grid voltage. If the reactive load of power system is capacitive (leading), the SVC will use thyristor controlled reactor to consume VAR from the system, decreasing the system voltage. Under Inductive (lagging) conditions, switches of the capacitor banks are automatically switched in and provide a higher system voltage. The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank switch is operated by three thyristor switches (thyristor switched capacitor or TSC). Reactors are either switched on-off (thyristor switched reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR). By connecting a thyristor controlled reactor, which is continuously variable, along with a capacitor bank that will result in continuously variable leading or lagging power. Fig. 2 shows a single-line diagram of a static var compensator and a simplified block diagram of its control system.

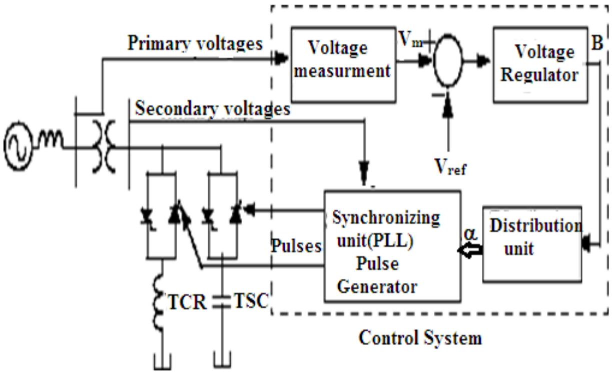

Fig. 2. Single-line diagram of an SVC and its control system block

The control system consists of a

- Measurement system, that measures the positive-sequence voltage to be controlled.
- Voltage regulator that uses the voltage error (difference between the measured voltage V_m and the reference voltage V_{ref}) to determine the SVC susceptance B.
- Distribution unit that determines the TSCs (and eventually TSRs) that must be switched on and off, and computes the firing angle α of TCRs.

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IV.SIMULATION AND RESULTS

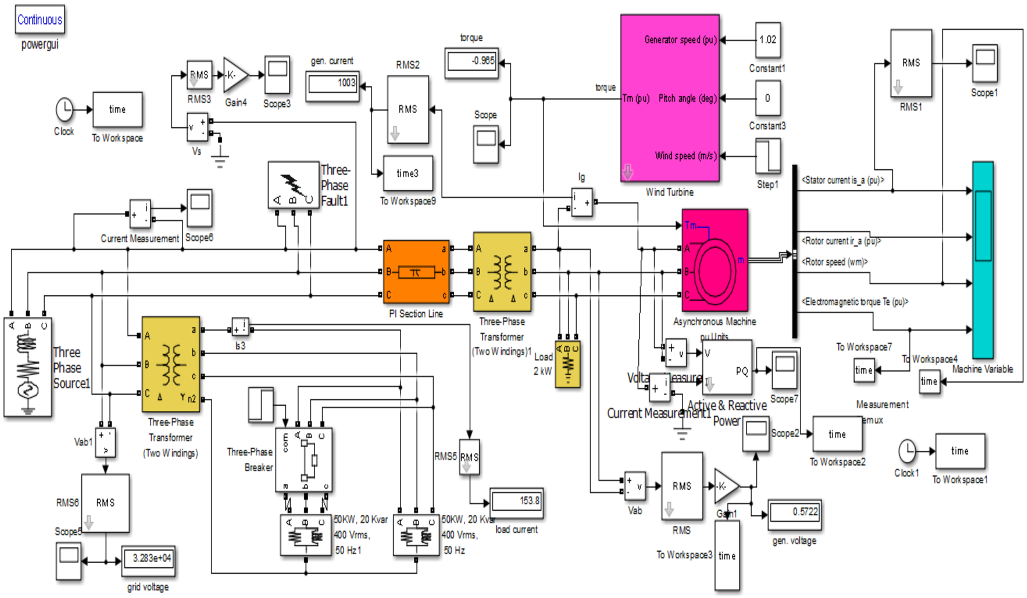

Fig. 3. Basic simulink model (case 1)

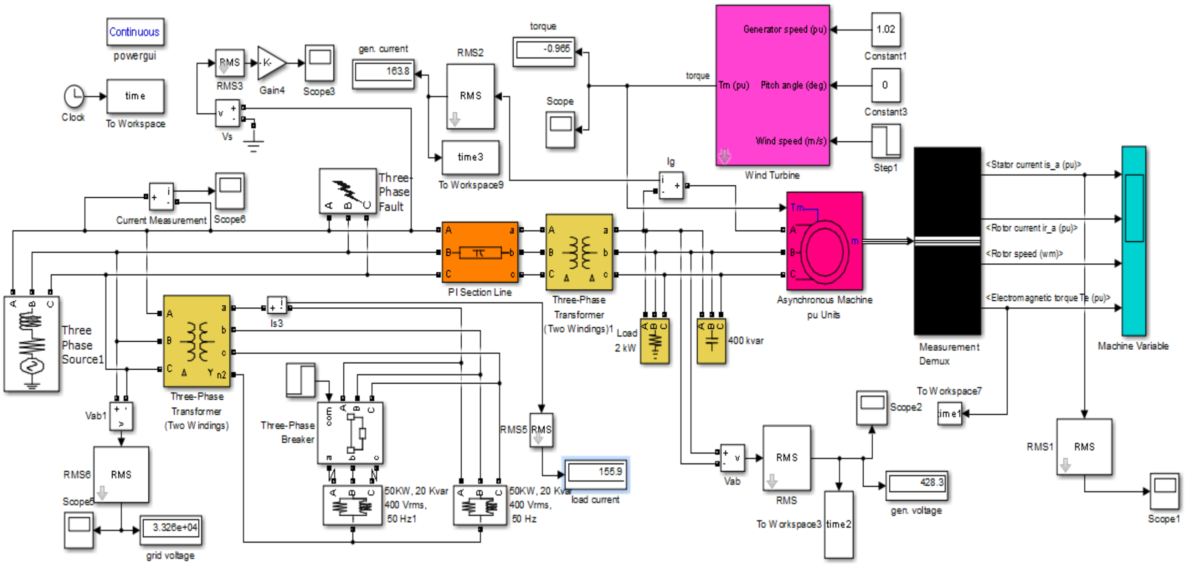

Fig. 4. Simulink model with a capacitor bank (case 2)

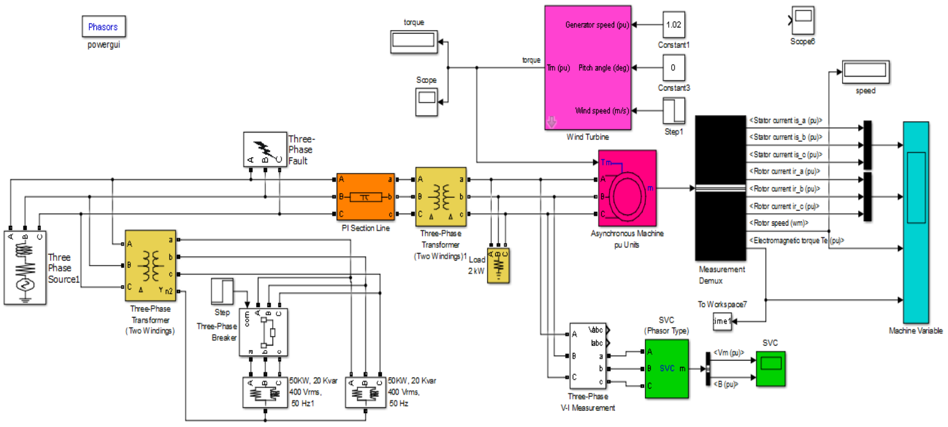

Fig. 5. Simulink model with a SVC (case 3)

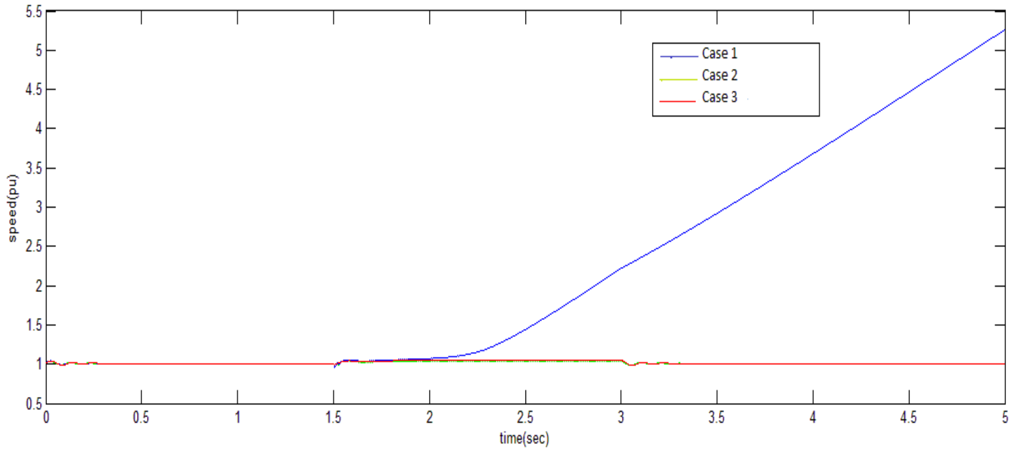

Fig. 6. Result showing variation of Rotor speed with time

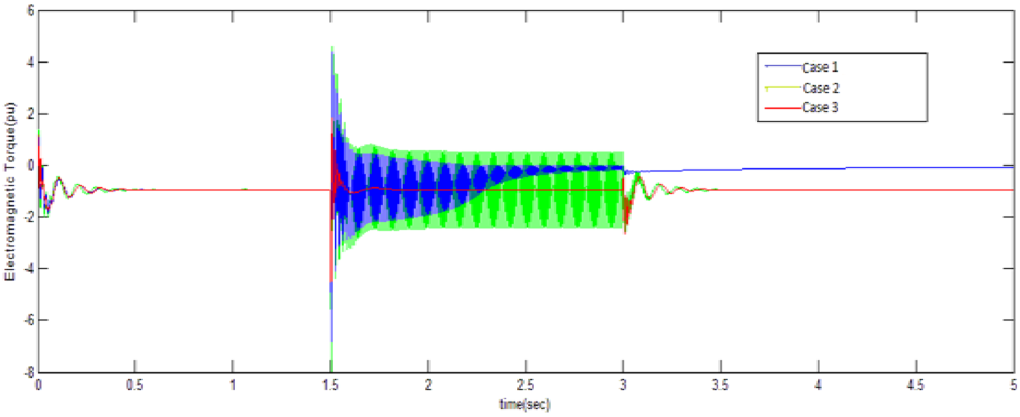

Fig. 7. Result showing varitaion of Electromagnetic Torque with time

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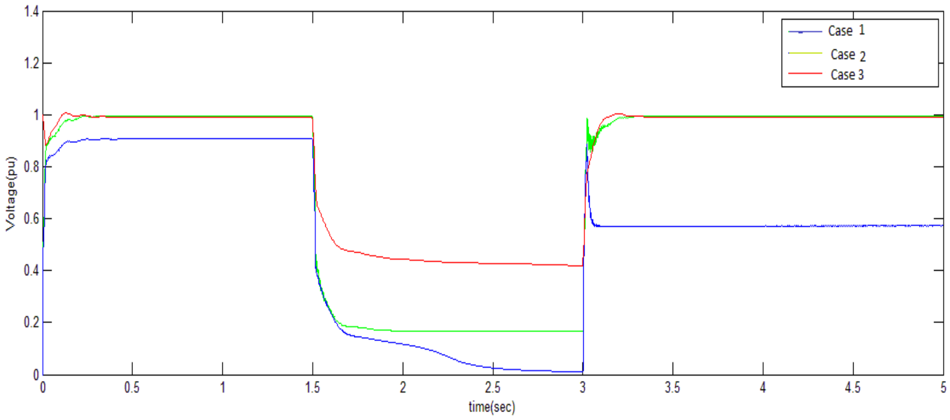

Fig. 8. Result showing variation of Voltages with time

In order to analysis of the grid connected induction generator under fault conditions, three different cases are analyzed. Fig. 6-8 shows the simulation results of the system model with capacitor bank and SVC, where the effect of grid fault on rotor speed, electromagnetic torque and system voltage has been shown w.r.t time. The description of each case is provided in the following.

Case 1- Basic model of the system
Case 2- Model of the system with capacitor bank
Case 3- Model of the system with svc

Case 1

The increasing of mechanical power input raises the machine currents, rotor speed and electromagnetic torque w.r.t. to time. In this simulation the grid fault has been assumed to occur during a period 1.5 sec to 3.0 sec. The rotor speed increases during the grid fault and becomes approximately double. The electromagnetic torque will also increase. During the grid fault condition, the voltage of the system decreases to a very low value due to the voltage dip, speed of the rotor increases as such reactive power requirement of IG increases. After clearance of the fault the machine variables do not regain their value. The existing system is not capable of providing the necessary reactive power required for maintaining the generator voltage to nominal value.

Case 2

In this case we use a capacitor bank. When grid fault occur there is a change in rotor speed and electromagnetic torque. The voltage of the system decreases to a very low value due to the voltage dip. By the use of capacitor bank there is an improvement in the system from the above case. During the grid fault there is a drop in voltage from 1 P.u. to 0.17 P.u. the reactive power requirement of the IG increases. By the use of capacitor bank there is decrease in voltage drop. But the existing system is not capable of providing the necessary reactive power required for maintaining the generator voltage to nominal value, due to this generator tends to go out of synchronism.

Case 3

To prevent the induction generator from going out of synchronism, the necessary reactive power required to build up the voltage is provided by using SVC. For controlling the reactive power during fault condition SVC is connected across the generator terminals. The simulation results shows the effect of grid fault on the rotor speed and electromagnetic torque .during the grid fault there is a drop in voltage from 1P.u. to 0.46P.u. and there is a slight increase in rotor speed from 1 P.u. to 1.045 P.u. The reactive power requirement of generator increases during the fault period. After time 3.0 sec, when fault is cleared, the rotor regains its normal value and voltage becomes constant to its normal value that is 1. From the above results show that the necessary reactive power required for voltage build up of IG can be provided by SVC so that the generated voltage can recover rapidly, and rotor speed can normalize.

IV. CONCLUSION

`The performance characteristics of 110 KW induction generators under unbalanced grid voltage have been studied in this paper. The performance of SCIG is studied under normal and grid fault conditions in grid.

The adjustment of the mechanical input power and the load caused the system to build the new power balances through the change of the machine and system variables. The balancing power action is taken by the induction generator when the mechanical input power is adjusted, whereas the balancing power action is incorporated by the grid system when the load power is modified. The unbalance in grid voltage has been found to make significant impact on the generator as well as system performance. The result shows that if fault clearance time is less, then the IG can restore its normal operation as before the occurrence of fault where as if fault clearance time is more, then speed becomes excessive and IG can no longer remains under control. Thus, it is clear from the results that shunt capacitor connected at the generator terminals maintains the terminal voltage near to nominal voltage and improves the power factor and hence overall efficiency of the system. The results with SVC show that the dynamic response of the grid connected induction generator under fault condition gets improved in comparison to capacitor bank. SVC can maintain the generated voltage to normal value and can ensure continuous running of the system.

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