EFFECT OF CAPACITIVE EXCITATION ON VOLTAGE STABILITY OF THREE PHASE SELF EXCITED INDUCTION GENERATOR

SACHIN KUMAR, SOVIT KUMAR PRADHAN & ALOK YADAV
Department of Electrical Engineering, Indian Institute of Technology, Banaras Hindu University, Varanasi, India

ABSTRACT

Self Excited Induction Generators (SEIG) require Controllable Capacitive VARs to magnetise the machines and compensate the demagnetising effect of loads. This paper describes the effects of capacitive excitation on the performance of a three phase self-excited induction generator. Generally, Static VAR power devices are employed to achieve the required performance in a self-excited induction generator. Literature survey reveals that very little work has been done to investigate the ‘effects of capacitor bank selection’ on the voltage profile of generator. In this paper, an attempt is made to analyze the effects of capacitive excitation on the performance of the machine. The effects of capacitive excitation were investigated using MATLAB/ SIMULINK. Importance of excitation capacitance selection is highlighted through simulated results, as obtained.

KEYWORDS: Induction Generators, Matlab, Reactive Power, Self-Excitation, Wind Energy

INTRODUCTION

It is well known that when capacitors are connected across the stator terminals of an induction machine, driven by an external prime mover, voltage develops at its terminals [1]. The induced emf and current in the stator windings will continue to rise until steady state is attained, which is influenced by the magnetic saturation of the machine. At this operating point, the voltage and current will continue to oscillate at a given peak value and frequency. In order for self-excitation to occur, for a particular capacitance value, there is a corresponding minimum speed [2-4].

Self-excited induction generators (SEIG’s) are good candidates for wind powered electric generation applications, especially in remote areas, because they do not need external power supply to produce the magnetic field. Permanent magnet generators can also be used for wind energy applications but they suffer from the uncontrollable magnetic field, which decays over a period, due to weakening of the magnets, and the generated voltage tends to fall steeply with load. The self-excited induction generator (SEIG) has a self-protection mechanism because the voltage collapses when there is a short circuit at its terminals. Further, the SEIGs have other advantages such as low cost, reduced maintenance, rugged and simple construction, brush-less rotor (squirrel cage) etc.

In this paper, we shall study the effects of variation in the value of capacitor bank used for compensation, on the voltage profile of SEIG. Efforts are made to find out the most suitable value of capacitance for SEIG, supplying constant inductive load and operating at constant wind speed. Power system toolbox of MATLAB 7.8.4(R2009a)/ SIMULINK is used for simulation.

SYSTEM DESCRIPTION

The proposed system consists of a 480V, 60 Hz, 275-kVA, induction generator, driven by wind turbine at a fixed inductive load of 0.7pf lagging. A three-phase delta connected capacitor bank is connected to the terminals of the induction generator. The value of this capacitor bank is to be changed to study the effects of capacitance variation on voltage profile.
and harmonics. The wind speed is kept constant, for this study, at 10 m/s. The Wind Turbine block uses a 2-D Lookup Table to compute the turbine torque output \( T_m \) as a function of wind speed \( w_{\text{Wind}} \) and turbine speed \( w_{\text{Turb}} \). The \( P_m(w_{\text{Wind}}, w_{\text{Turb}}) \) characteristic gets automatically loaded into the workspace (psbwindgen_char array), when we open this setup. The turbine characteristic can be displayed by double clicking the block located below the Wind Turbine block. The asynchronous machine operates in generator mode i.e. its speed is slightly above the synchronous speed. According to turbine characteristics, for a 10 m/s wind speed, the turbine output power is 0.75 p.u. (206 kW). Scope 1 is used to record the p.u. values of terminal voltage and current of the induction generator and Scope-2 records the power at the generator terminals, wind speed and the generator speed.

![Simulink Model](image)

**Figure 1: Simulink Model**

**SIMULATION RESULTS AND DISCUSSIONS**

The above mentioned system is simulated in MATLAB, using the Simpower system toolbox of SIMULINK, to study the effects of variation in capacitive compensation/VAR on the voltage profile. The SIMULINK model of the system is shown in figure.1. The simulation time is 50 sec. Machine parameters are given in section-5

**Case –I: Capacitor Bank Value = 95 KVAR**

![Graph](image)

**Figure 2: Induction Generator Terminal Voltage \( V_{1L} \), and Line Current \( I_{0L} \)**

Large variation in the voltage profile is recorded when the value of the capacitor bank at the terminal of induction generator is 55 KVAR (fig.-2). At the starting i.e. during the instant (0 sec to 1.5 sec), the voltage drops to very low value of 0 p.u. and after 1.5 seconds the voltage remains at zero level and settles down at this level. This variation in voltage is
due to presence of inductance in the load. The inductance decreases the VAR requirement of the induction generator. The power output is reduced to zero during the large dip in the voltage (fig.-3). The wind speed is shown constant at 10 m/s. The generator speed reaches up to 1.9 p.u. after variation from 1.0 p.u. at 0 sec and 1.8 p.u. at 20 sec.

Figure 3: Power in KW, Wind Speed in m/s and Induction Generator Speed in p.u.

Case –IV: Capacitor Bank Value = 115 KVAR

When the value of the capacitor bank is changed to 115 KVAR, a significant improvement in voltage profile is observed. At the starting i.e. during the period of 0 sec to 2 sec, the voltage drops to a very low value of 0 p.u. and remains at the same level up to 17 sec. After 17 sec, the voltage starts building up and reaches the maximum value of 1.5 p.u at 24 sec. After 24 sec, it settles down at a value of 0.8 p.u. as seen in fig.8. Variation in the output power is shown in the fig.-9. The variation is from 250 kW to 0 kW and remains 0 kW up to 23 sec. After 23 sec, the power starts rising and reaches a maximum value of 330 kW and finally settles down at a value of 50 kW as show in fig.7. The wind speed is constant at 10 m/s. The generator speed variation is also reduced at time 25 sec and is limited to a value of 1.7 p.u.

Figure 4: Induction Generator Terminal Voltage $V_L$, Line Current $I_L$

Case –V: Capacitor Bank Value = 135 KVAR

When the value of the capacitor bank is changed to 135 KVAR, further improvement in voltage profile is observed. At the starting i.e. during the instant (0 sec to 2.5 sec) the voltage drops to a very low value of 0 p.u. and after 2.5 sec and till 8 sec remains at zero level. After 8 sec, the voltage starts building up and reaches the maximum value of 2.0 p.u.
at 12 sec. After 12 sec, it settles down to a value of 0.9 p.u as seen in fig.10. Variation in the output power is shown in the fig.-11. The variation is from 300 kW to 0 kW and remains 0 kW up to time 10sec.After 10 sec, the power starts rising and reaches a maximum value of 700 kW and finally settle down to a value of 100 kW as show in fig.11. The wind speed is constant at 10 m/s. The generator speed variations are also reduced at time 12 sec and are limited to a value of 1.5 p.u.

Figure 7: Power in KW, Wind Speed in m/s and Induction Generator Speed in p.u.

Case –VI: Capacitor Bank Value = 155 KVAR

Fig.12 and Fig.13 shows the performance of the SEIG used, with a capacitor bank of 155KVAR. An increase in the voltage level is observed, when the capacitor bank value is changed to 155 KVAR. The voltage rises to 2.1 p.u. and then drops back to 1.0 p.u. The decrease in the generator speed is also observed. The speed is reduced to a value of 1.4 p.u.

Figure 9: Power in KW, Wind Speed in m/s and Induction Generator Speed in p.u.

Case –VII: Capacitor Bank Value = 175 KVAR

Fig.14 and Fig.15 shows the performance of the SEIG used, with a capacitor bank of 175 KVAR. A further increase in the voltage is observed, when the capacitor bank value is changed to 175 KVAR, as compared to 155 KVAR. The decrease in the generator speed is also observed. The speed is also slightly reduced to a value of 1.35 p.u.

Figure 11: Power in KW, Wind Speed in m/s and Induction Generator Speed in p.u
Case –VIII: Capacitor Bank Value = 195 KVAR

![Figure 12: Induction Generator Terminal Voltage $V_L$ and Line Current $I_L$](image)

Fig.16 and Fig.17 shows the performance of the SEIG used, with a capacitor bank of 195 KVAR. A further increase in the voltage is observed, when the capacitor bank value is changed to 195 KVAR, as compared to 175 KVAR. The decrease in the generator speed is also observed. The speed is also slightly reduced to a value of 1.28 p.u.

![Figure 13: Power in KW, Wind Speed in m/s and Induction Generator Speed in p.u](image)

Case –XI: Capacitor Bank Value = 235 KVAR.

![Figure 14: Induction Generator Terminal Voltage $V_L$ and line Current $I_L$](image)

Fig.18 and Fig.19 shows the performance of the SEIG used, with a capacitor bank of 235 KVAR. A further increase in the voltage is observed, when the capacitor bank value is changed to 235 KVAR, as compared to 195 KVAR. The decrease in the generator speed is also observed. The speed is also slightly reduced to a value of 1.15 p.u.

![Figure 15: Power in KW, Wind Speed in m/s and Induction Generator Speed in p.u](image)

Case –X: Capacitor Bank Value = 255 KVAR

![Figure 16: Induction Generator Terminal Voltage $V_L$ and Line Current $I_L$](image)
Fig. 20 and Fig. 21 shows the performance of the SEIG used, with a capacitor bank of 255 KVAR. A further increase in the voltage is observed, when the capacitor bank value is changed to 255 KVAR, as compared to 235 KVAR. The decrease in the generator speed is also observed. The speed is also slightly reduced to a value of 1.1 p.u.

![Figure 17: Power in KW, Wind Speed in m/s and Induction Generator Speed in p.u](image)

**Case –XI: Capacitor Bank Value = 275 KVAR**

Fig. 22 and Fig. 23 shows the performance of the SEIG used, with a capacitor bank of 275 KVAR. A further increase in the voltage is observed, when the capacitor bank value is changed to 275 KVAR, as compared to 255 KVAR. The decrease in the generator speed is also observed. The speed is also slightly reduced to a value of 1.048 p.u.

![Figure 18: Induction Generator Terminal Voltage V_L, and Line Current I_L](image)

![Figure 19: Power in KW, Wind Speed in m/s and Induction Generator Speed in p.u](image)

**Case –XII: Capacitor Bank Value = 295 KVAR**

The capacitor bank value when fixed at 295 KVAR, the characteristic shows that the voltage profile becomes smooth and there is a very small variation at the start. The terminal voltage is 1.0 p.u. Variation in the power output and generator speed is very less. With this value of capacitance, the parameters under consideration i.e. voltage profile and generator speed are well within operating limits.
Effect of Capacitive Excitation on Voltage Stability of Three Phase Self Excited Induction Generator

Figure 21: Power in KW, Wind Speed in m/s and Induction Generator Speed in p.u

Case –XIII: Capacitor Bank Value = 315 KVAR

Fig 26 and Fig. 27 shows the performance of SEIG with a capacitor bank rated as 315 KVAR. An increase in the voltage is observed when the capacitor bank value is changed to 315 KVAR. The voltage rises to 1.25 p.u. and then drops back to 0.9 p.u. the decrease in the generator speed is also observed. The speed is reduced to a value of 0.9 p.u.

Figure 22: Induction Generator Terminal Voltage $V_{1L}$, and Line Current $I_{1L}$

Figure 23: Power in KW, Wind Speed in m/s and Induction Generator Speed in p.u

CONCLUSIONS

The experiment attempted to investigate the effects of three-phase capacitor bank/reactive power source, on the performance of SEIG’s under general resistive-inductive load. Simulation results, as observed, indicate the importance of such practice. For the specific machine (used for simulation), reactive power source with 295 KVAR gives smooth voltage profile and satisfactory operating results.

Thisemphasizes the need of appropriatetechnique to select the optimum rating of capacitor bank and the in turn improvement in the performance of the machine.

REFERENCES


APPENDICES

Three Phase Induction Generator

1. Rotor type: Squirrel Cage
2. Reference frame: Rotor
3. Nominal power: 275 KVA
4. Voltage (line-to-line): 480 V
5. Frequency: 60Hz
6. Stator resistance (pu): 0.016
7. Stator inductance (pu): 0.06
8. Rotor resistance (pu): 0.015
9. Rotor inductance (pu): 0.06
10. Mutual inductance (pu): 3.5
11. Inertial constant: 2
12. Fraction factor: 0
13. Pair of poles: 2

**Three Phase Load**

1. Load PF: 0.707 Pf lagging
2. Voltage (line-to-line): 480 V
3. Frequency: 60Hz
4. Configuration: Y grounded

**Power Factor Correction Capacitors**

5. KVAR requirement case 3: 95kVAR
6. KVAR requirement case 4: 115kVAR
7. KVAR requirement case 5: 135kVAR
8. KVAR requirement case 6: 155kVAR
9. KVAR requirement case 7: 175kVAR
10. KVAR requirement case 8: 195kVAR
11. KVAR requirement case 9: 235kVAR
12. KVAR requirement case 10: 255kVAR
13. KVAR requirement case 11: 275kVAR
14. KVAR requirement case 12: 295kVAR
15. KVAR requirement case 13: 315kVAR
16. Configuration: Delta
17. Nominal voltage: 480V
18. Frequency: 60Hz