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Role of Reactive Power Source on Performance of Three Phase Self Excited Induction Generator

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***Abstract*—This paper describes the effects of capacitive VAR 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 reactive source on the performance of the machine. The effects of capacitive VAR were investigated using MATLAB/ SIMULINK. Importance of capacitor VAR selection is highlighted through simulated results, as obtained.**

Keywords-Induction Generators, Matlab, Reactive Power, Self-Excitation, Wind Energy.

I. 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 7.0.4/ SIMULINK is used for simulation.

II. SYSTEM DESCRIPTION

System -I

The proposed system consists of a 480V, 60 Hz, 275-kVA, induction generator, driven by wind turbine at a fixed resistive load of 200 kW.

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 (Tm) as a function of wind speed (w_Wind) and turbine speed (w_Turb). The Pm (w_Wind, w_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.

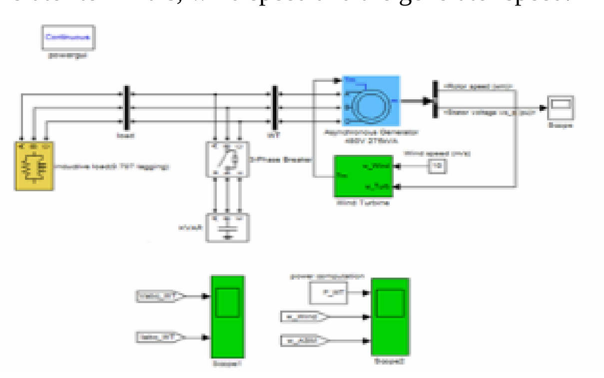

Fig.1Simulink Model

III. 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 fig.1. The simulation time is 50 sec. Machine parameters are given in section-5.

3.1 Case –I: Capacitor bank value = 55 KVAR

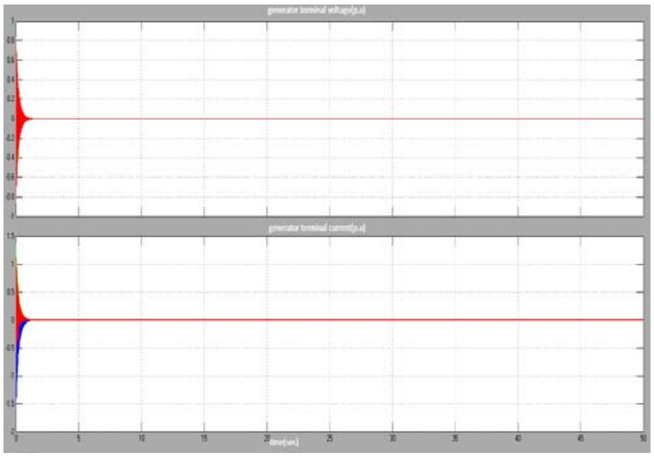

Fig.2 induction generator terminal Voltage V_L, and line Current I_L

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 involtage is due to presence of inductance in the load. The inductance decreases the VAR requirement of the induction generator.

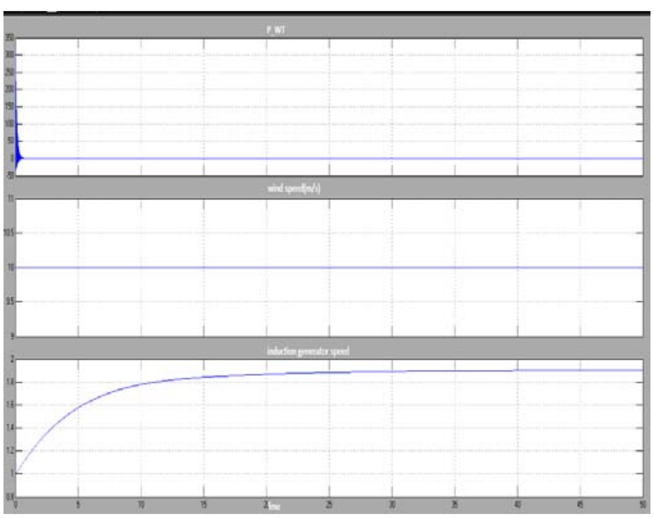

Fig.3 Power in KW, wind speed in m/s and induction generator speed in p.u.

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.

3.2 Case –II: Capacitor bank value = 75 KVAR

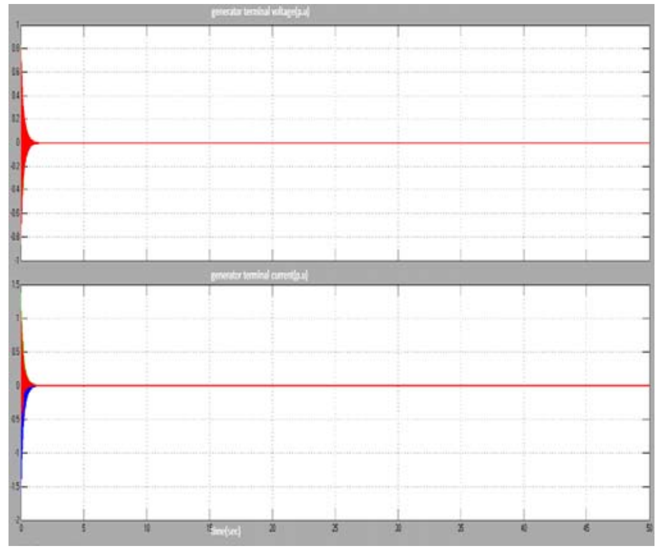

Fig.4 induction generator terminal Voltage V_L, and line Current I_L

When the value of the capacitor bank is changed to 75 KVAR, a slight improvement in the voltage profile is observed. The duration of the dip in the voltage is less andits magnitude is also reduced and becomes zero after 1.7 sec (fig.4). Variation in the output power is shown in the (fig.-5), which is almost the same as that is shown in the 55 KVAR case.

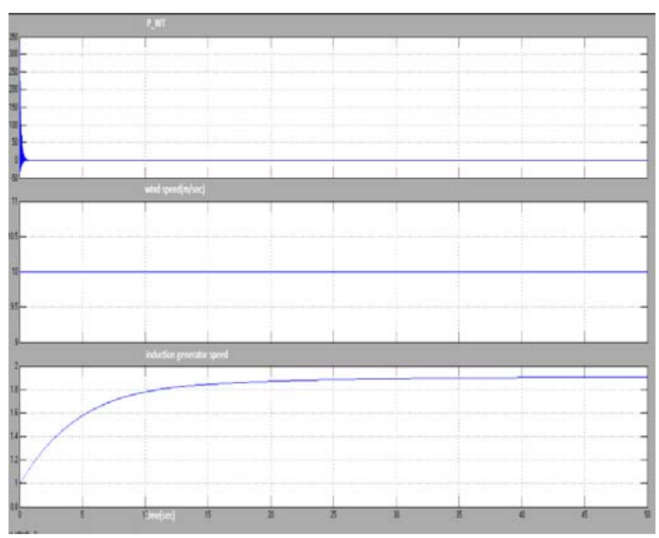

Fig.5Power in KW, wind speed in m/s and induction generator speed in p.u.

3.3 Case –III: Capacitor bank value = 95 KVAR.

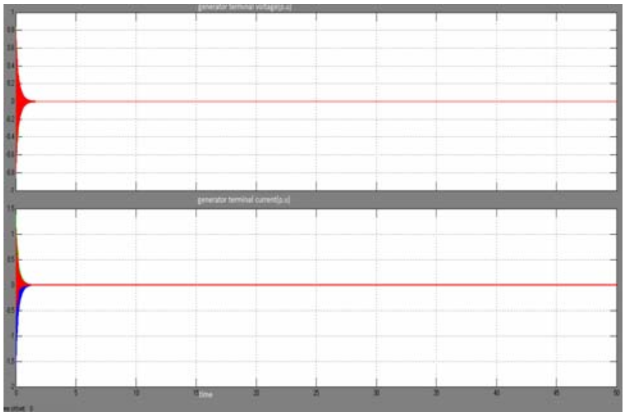

Fig.6 induction generator terminal Voltage V_L, and line Current I_L

When the value of the capacitor bank is changed to 95 KVAR, no further improvement in the voltage profile is observed. The duration of dip in the voltage is less and its magnitude is also reduced and becomes zero after 2 sec (fig.6). Variation in the output power is shown in the (fig.-7), which is almost the same as that is shown in the 75 KVAR case**.**

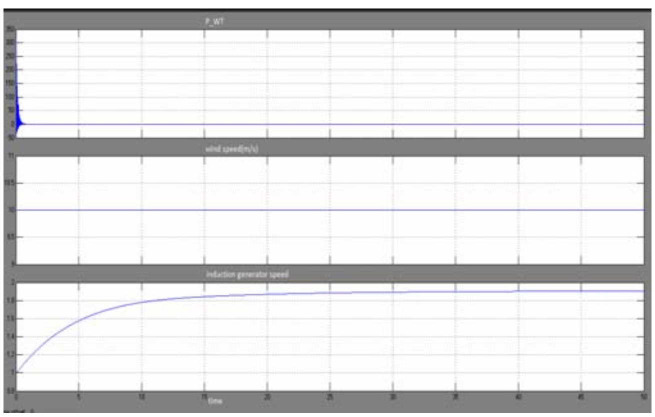

Fig.7 Power in KW, wind speed in m/s and induction generator speed in p.u.

3.4 Case –IV: Capacitor bank value = 115 KVAR.

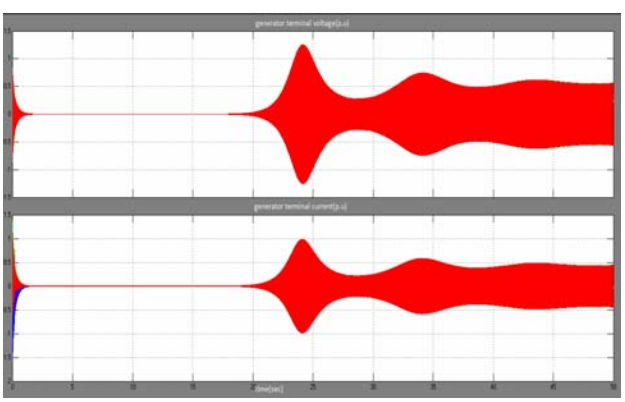

Fig.8 induction generator terminal Voltage V_L, line Current I_L

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.

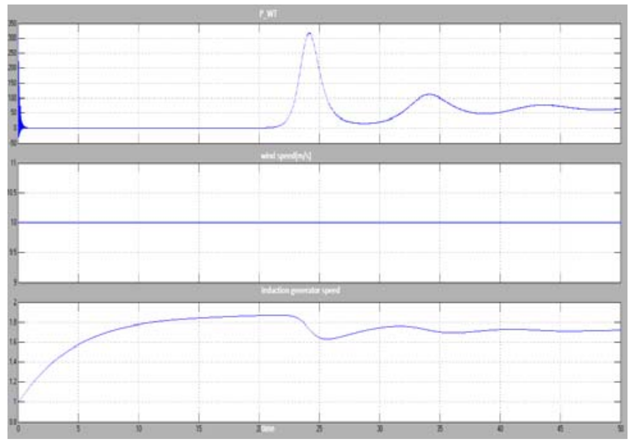

Fig.9 Power in KW, wind speed in m/s and induction generator speed in p.u**.**

3.5 Case –V: Capacitor bank value = 135 KVAR.

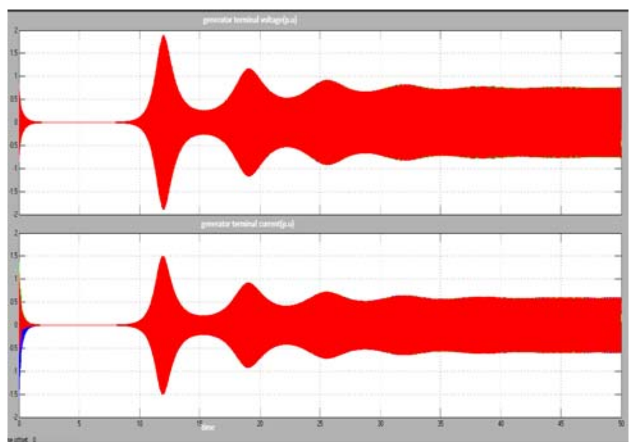

Fig.10 induction generator terminal voltage V_L, and line current I_L

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 voltagestarts 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.

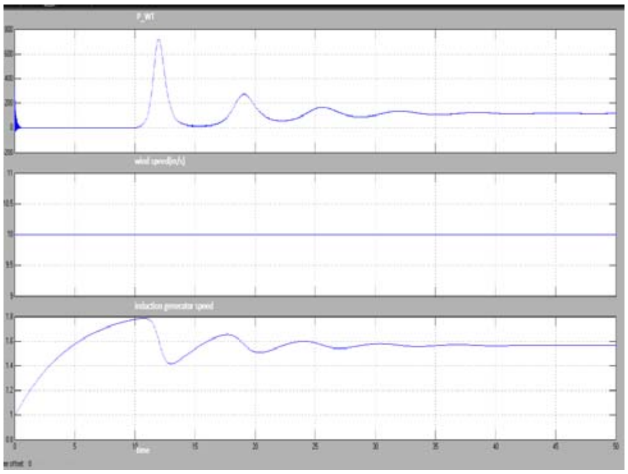

Fig.11 Power in KW, wind speed in m/s and induction generator speed in p.u.

3.6 Case –VI: Capacitor bank value = 155 KVAR.

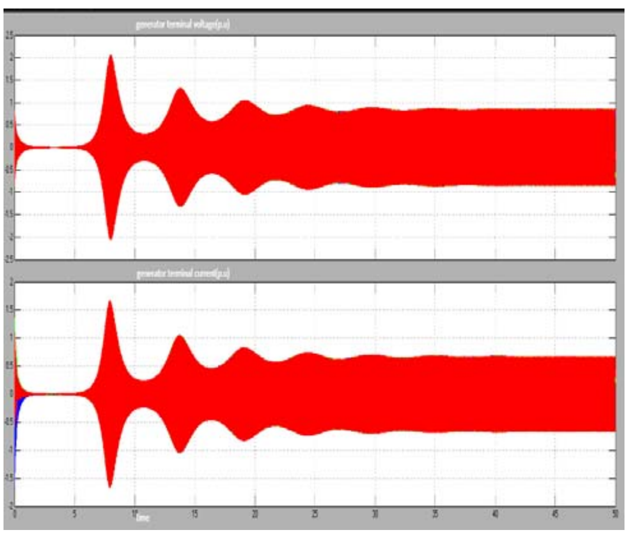

Fig.12 induction generator terminal Voltage V_L, and line Current I_L

Fig.12 and Fig.13 shows the performance of the SEIG used, with a capacitor bank of 155 KVAR. 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.

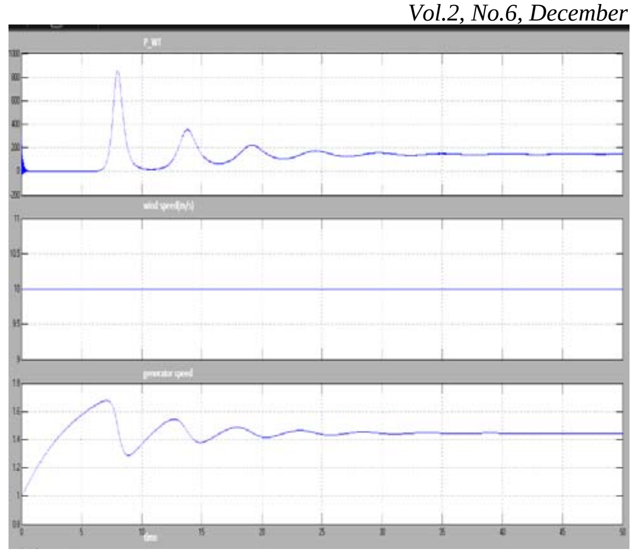

Fig.13 Power in KW, wind speed in m/s and induction generator speed in p.u.

3.7 Case –VII: Capacitor bank value = 175 KVAR.

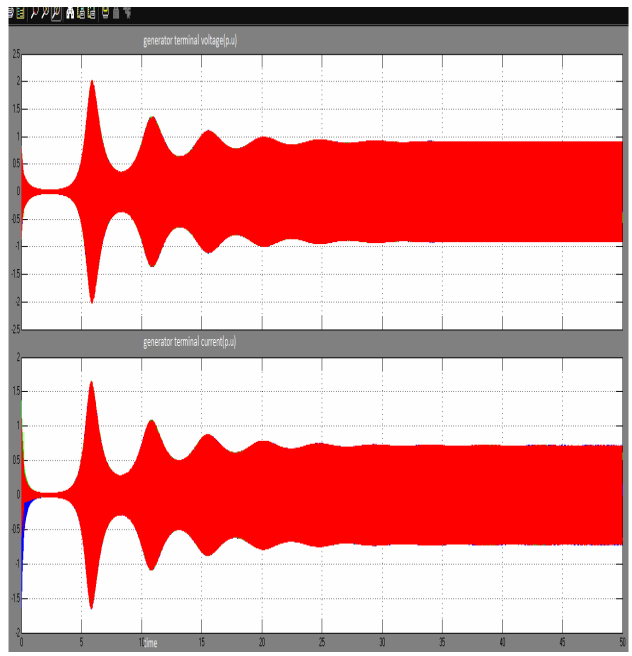

Fig.14 induction generator terminal Voltage V_L, and line Current I_L

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.

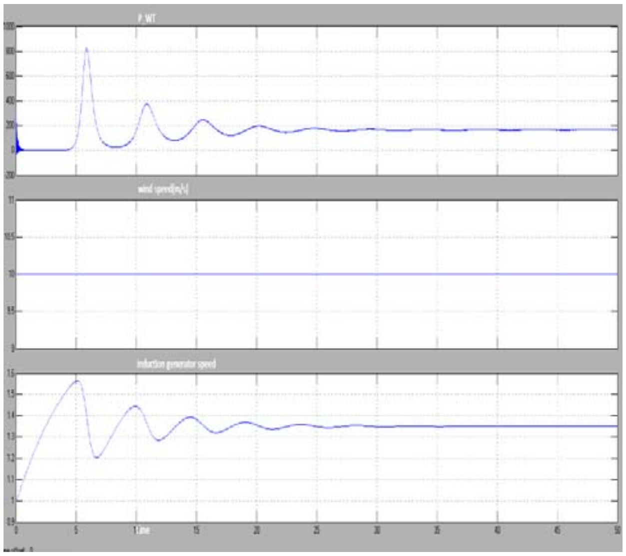

Fig.15 Power in KW, wind speed in m/s and induction generator speed in p.u

3.8 Case –VIII: Capacitor bank value = 295 KVAR

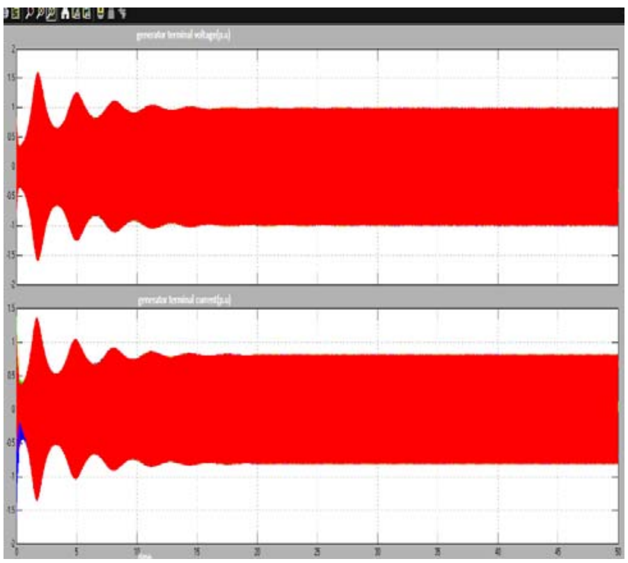

Fig.16 induction generator terminal Voltage V_L, and line Current I_L

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 1.5 p.u. Variation in the power output and generator speed are very less. With this value of capacitance, the parameters under consideration i.e. voltage profile and generator speed are well within operating limits.

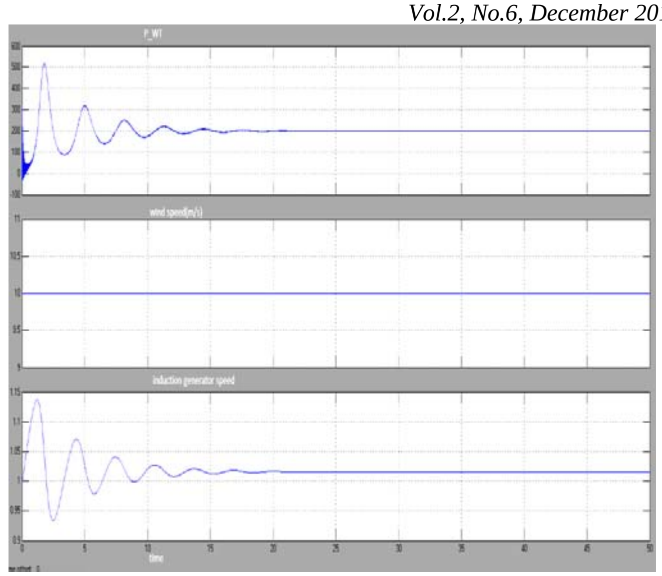

Fig.17 Power in KW, wind speed in m/s and induction generator speed in p.u.

System-II

Another system was developed to see the effect of change in capacitive VAR (reactive power composition) on the harmonics generated by wind turbine.

The system consists 480Volts, 60Hz, 275 KVA induction generators driven by wind turbine feeding a fixed inductive load of 0.7 pf lagging. All other parameters/ components of the system are same as in system-I. In addition to that in this set-up, scope-1 is used to record per unit values of terminal voltage, current and power at generated terminals. Scope-2 records the harmonics at generator terminals. The three Fourier blocks are programmed to record 3^{rd}, 5^{th}, 9^{th} and 12^{th} harmonic at generator terminals.

Above said system was simulated in MATLAB using the SIMPOWER system tool box of simulating to study the effect of variation in capacitive compensation on the above said harmonics i.e. 3^{rd}, 5th, 9th and 12th. Simulating model is shown in the figure-18. Simulation time is 50 seconds and the machine parameters are same used in system-1.

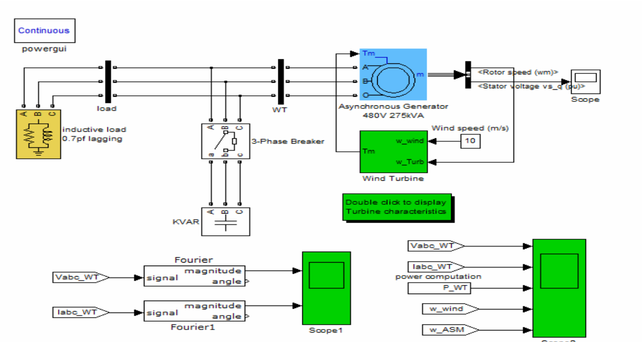

Fig.18 Simulink Model

The Fourier block performs a Fourier analysis of the input signal over a running window of one cycle of the fundamental frequency of the signal. The Fourier block can be programmed to calculate the magnitude and phase of the DC component, the fundamental, or any harmonic component of the input signal. Recall that a signal f (t) can be expressed by a Fourier series of the form

$$f(t) = a_{\downarrow}0/2 + \Sigma_{\downarrow}(n=1)^{\uparrow}\infty \, [a_{\downarrow}n \ \cos [(n(t) + b_{\downarrow}n \ \sin(n(t)]]$$ …. (i)

Where n represents the rank of the harmonics (n = 1 corresponds to the fundamental component). The magnitude and phase of the selected harmonic component are calculated by the following equations:

$$|H_n| = \sqrt{a_n^2 + b_n^2}$$ …. (ii)

$$\angle H_n = \tan^{-1}\left(\frac{b_n}{a_n}\right)$$ …. (iii)

Where,

$$a_{\downarrow}n = \ 2/T \int_{\downarrow}(t-T)^{\uparrow}t \, [f(t)\cos(n(t)dt]$$ …. (iv)

$$b_{\downarrow}n = \ 2/T \int_{\downarrow}(t-T)^{\uparrow}t \, [f(t)\sin(n(t)dt]$$ …. (v)

$$T = \frac{1}{f_1}$$ …. (vi)

f_1 : Fundamental frequency

As this block uses a running average window, one cycle of simulation has to be completed before the outputs give the correct magnitude and angle. The discrete version of this block allows you to specify the initial magnitude and phase of the output signal. For the first cycle of simulation the outputs are held to the values specified by the initial input parameters.

3.9 Case-IX: Capacitor bank value=55 KVAR

3rd ,5th, 9th and 12th harmonics are seen in the output voltage and the variation is shown in the figure 11.

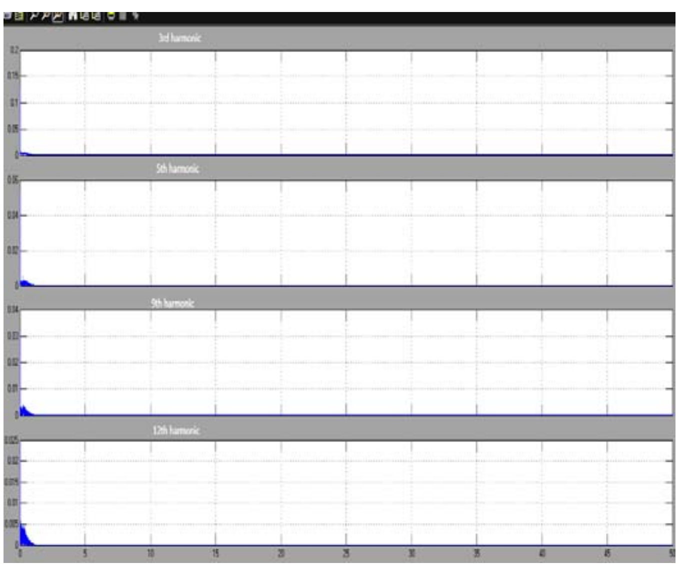

Fig.19

It is observed that the voltage build up is not possible at this value of KVAR; hence the harmonic content is almost zero because voltage across the terminal of induction generator is zero.

3.10 Case-X: Capacitor bank value=75 KVAR

A minute variation is seen in the harmonic content of terminal voltage waveform of induction generator with 75KVAR, which almost same as seen with 55KVAR value.

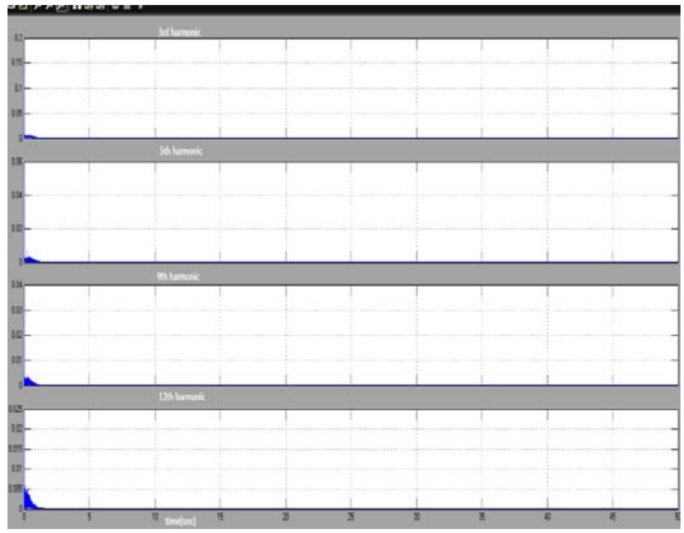

Fig.20

3.11 Case-XI: Capacitor bank value=95 KVAR

3rd ,5th, 9th and 12th harmonics are seen in the output voltage and the variation is shown in the figure 11.it is observed that no noticeable improvement is seen in the harmonic contents. The improvement is not seen because of the inductance of the load, which acts as a sink of reactive power and causes the voltage buildup not to take place

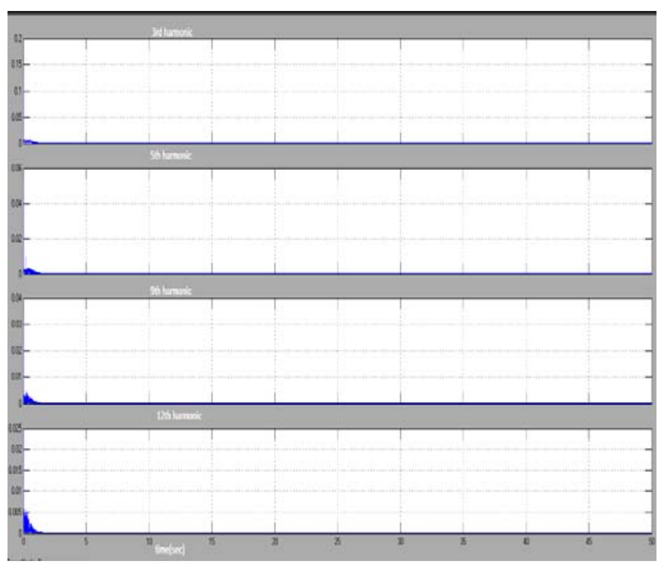

Fig.21

3.12 Case-XII: Capacitor bank value=115 KVAR

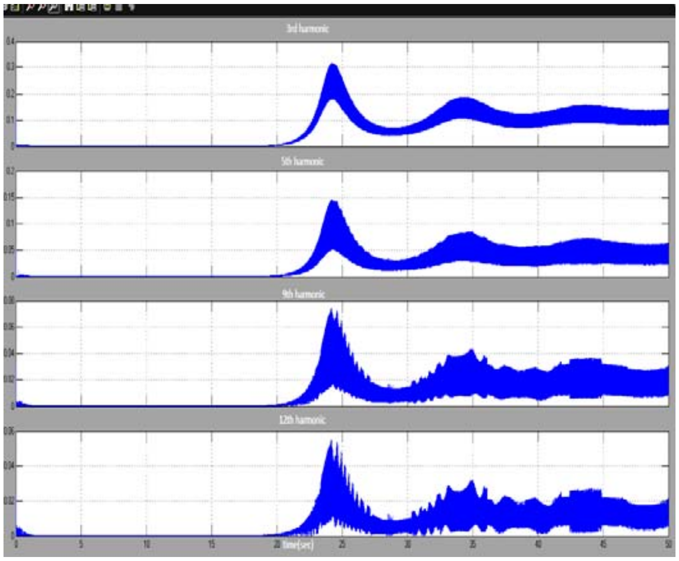

Fig.22

When the capacitor value is changed to 115 KVAR a large increase in all the harmonic components is observed and it is seen that the harmonic components are almost noticeable at this value of KVAR. (Fig.-22)

The 3^{rd} harmonic components attain the maximum value of 0.32 at t=23 seconds, back to 0.05 at t=26seconds and finally settle to a value of 0.15 at t=35 seconds. Itis observed that the values of 5^{th} harmonic components are low initially, but the value rises to 0.15 near time t=23 seconds. Then drop is observed and value reaches 0.08 at t=35 and becomes almost steady at a value 0.07. Similar variations are recorded in 9^{th} harmonic, which attain maximum value of 0.07 at t=24 then drops back to 0.04 at t=27 again rises back to a value of 0.08 at t=33 and after a small dip becomes steady at 0.03. 12^{th} harmonic maximum value is 0.05 again similar kinds of variations are recorded in this also.

3.13 Case-XIII: Capacitor bank value=135 KVAR

When the capacitor value is changed to 135 KVAR an increase in 5^{th}, 9^{th} and 12^{th} harmonics componentswas observed and it is seen that the harmonic components are varying in the similar pattern but reaches the maximum value earlier then when the capacitor value is 115 KVAR.

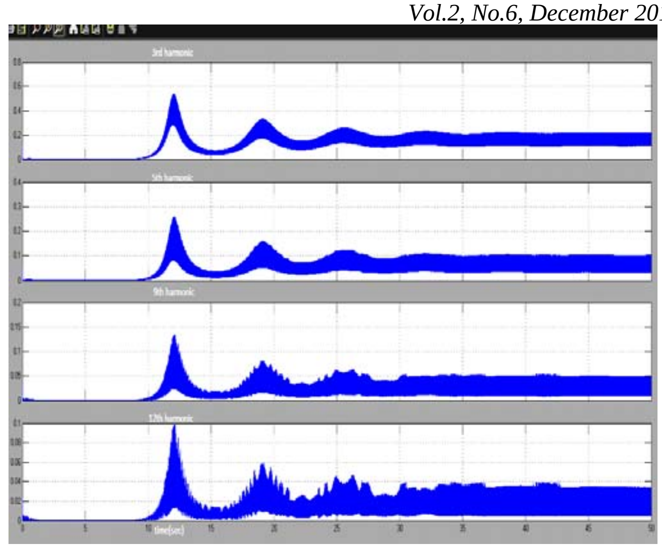

Fig.23

3.14 Case-XIV: Capacitor bank value=155 KVAR

When the capacitor value is changed to 155 KVAR no improvement in 5^{th}, 9^{th} and 12^{th} harmonics components was observed and it is seen that the harmonic components are varying in the similar pattern but reaches the maximum value earlier then when the capacitor value is 135 KVAR.

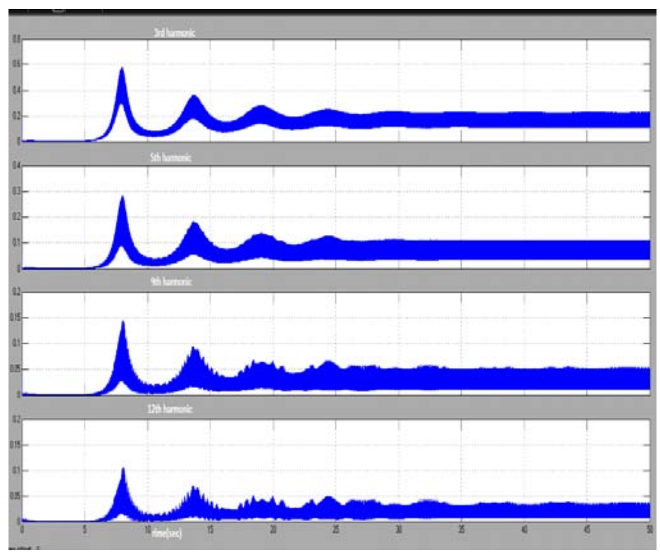

Fig.24

3.15 Case-XV: Capacitor bank value=175 KVAR

When the capacitor value is changed to 175 KVAR a reduction in 5^{th}, 9^{th} and 12^{th} harmonics components was observed and it is seen that the harmonic components are varying in the similar pattern but reaches the maximum value earlier then when the capacitor value is 155 KVAR.

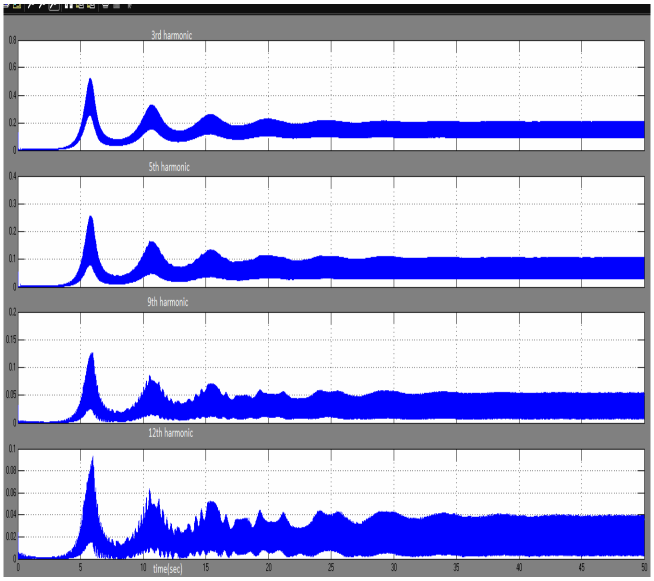

Fig.25

3.15 Case-XVI: Capacitor bank value=295 KVAR

When the capacitor value is changed to 295 KVAR a large decrease in all the harmonic components is observed and it is seen that the harmonic components are almost negligible. (Fig.-13)

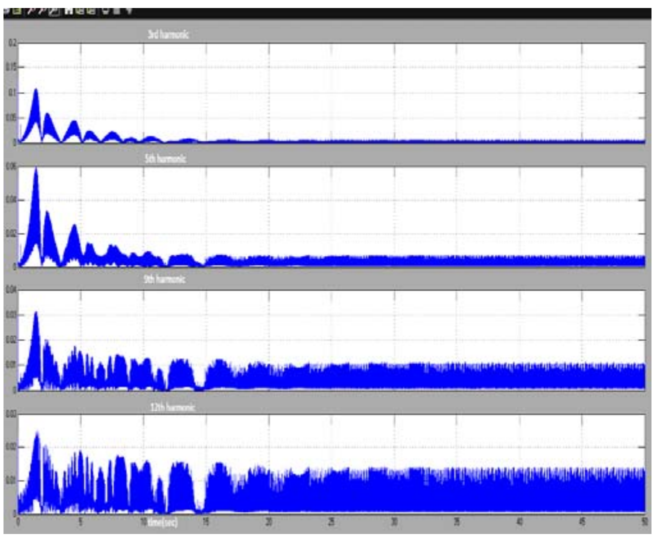

Fig.26

IV. CONSLUSION

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.

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

V. System parameters:

5.1 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

5.2 Three Phase load:

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

5.3 Power factor Correction capacitors:

5. KVAR requirement case 1:	55kVAR
6. KVAR requirement case 2:	75kVAR
7. KVAR requirement case 3:	95kVAR
8. KVAR requirement case 4:	115kVAR
9. KVAR requirement case 5:	135KVAR
10. KVAR requirement case 6:	155KVAR
11. KVAR requirement case 7:	175kVAR
12. KVAR requirement case 8:	295kVAR
13. Configuration:	Delta
14. Nominal voltage:	480V
15. Frequency:	60Hz

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