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Voltage Stability of Isolated Self Excited Induction Generator (SEIG) for Variable Speed Applications using Matlab/Simulink

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Abstract---Three phase induction generators (SEIG) play a major role in renewable energy like wind energy and hydraulic energy generating systems. In this paper an attempt has been made to give the detailed approach about the analysis and control of SEIG for variable wind speed applications. The main disadvantage of SEIG is poor voltage regulation, here different strategies adopted for voltage regulation are discussed and its scope of research is evolved.

Keywords: Wind, SEIG, Excitation, Capacitor bank, VSI, Universal bridge

I. Introduction

Due to the decrease of resources for fossil fuels dependency on renewable energy is increasing day by day. In these wind energy is drawing more concentration because of it is clean .In WECS induction generators are more predominantly used because their robustness, cheap, reliable. But the problem associated with SEIG is poor voltage regulation. In this different methods are discussed for voltage and frequency control of SEIG. The generators produce AC because DC generators are not reliable and have high maintenance costs because of the collectors, so usually back to back systems are used unless the existence of a constantly running diesel generator. The possible generator types are: permanent magnet generator, induction generator, double fed induction generator and synchronous generator. The principle of operation, equivalent circuit analysis, different voltage control strategies are discussed in the following sections

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II. Principle

If an appropriate capacitor bank is connected across the terminals of an externally driven Induction machine and if the rotor has sufficient residual magnetism an EMF is induced in the machine windings due to the excitation provided by the capacitor. The EMF if sufficient would circulate leading currents in the capacitors. The flux produced due to these currents would assist the residual magnetism. This would increase the machine flux and larger EMF will be induced. This in turn increases the currents and the flux. The induced voltage and the current will continue to rise until the VAR supplied by the capacitor is balanced by the VAR demanded by the machine, a condition which is essentially decided by the saturation of the magnetic circuit. This process is thus cumulative and the induced voltage keeps on rising until saturation is reached. The capacitors may be connected in star or delta but it is economical to connect in delta connection. Due to the varying wind speed and the varying load the out put parameters of the SEIG varies .

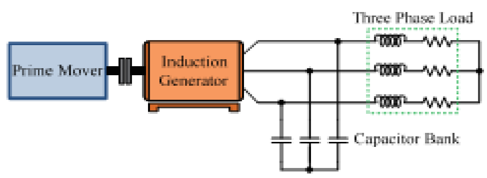
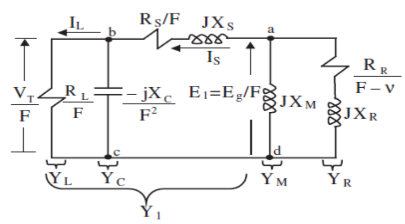


Fig1:basic block diagram of SEIG

a) Equivalent circuit analysis:



Up to now, the model used to analyze self-excited induction generators has been classified into two major categories. One is the per-phase equivalent circuit approach which includes the loop-impedance method adopted by Murthy and Malik and the nodal admittance method proposed by Ouazene and Chan. The other is the dq axis model based on the

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generalized machine theory which was proposed by Elder and Grantham .They attempted to solve a polynomial or a non-linear simultaneous equation in per unit frequency or magnetizing reactance no matter what the model they used. However, it is time consuming to employ an iterative approach to find the solutions of a highly non-linear polynomial.eigen value model is also used to analyze the circuit of SEIG.The previous methods give the upper limits of capacitance but the Eigen value approach gives the upper and the lower limits of capacitance and it give both the steady state and the transient analysis along with the d-q axis model.

The value of magnetizing inductance is given by:

$$X_M = -1/\left\{\frac{X_R}{\left[{R_R}/_{(F-v)}\right]^2 + X_R^2} + \frac{X_{ac}}{R_{ac}^2 + X_{ac}^2}\right\} \quad (1)$$

The value of stator current:

$$I_s = \frac{E_g/F}{\frac{R_S}{F} + jX_S - \frac{jX_C R_L}{F^2 R_L - FX_C}} \quad (2)$$

The value of load current:

$$I_L = \frac{-jX_C R_S}{R_L F - jX_C} \quad (3)$$

The value of rotor current:

$$I_R = \frac{-E_g/F}{\frac{R_R}{F-v} + X_R} \quad (4)$$

The value of terminal voltage:

$$V_T = I_L * R_L \quad (5)$$

The values of output power:

$$P_{in} = \frac{-3R_R F * I_L^2}{F-v} \quad (6)$$

$$P_{out} = 3\, I_L^2\, R_L \quad (7)$$

The appropriate capacitor bank causes this induced voltage to continue to increase until an equilibrium state is attained due to magnetic saturation of the machine. Fig. 2 shows both the magnetizing curve of an unloaded SEIG and the voltage– current characteristic of a capacitor bank plotted on the same set of axes. The intersection of the two curves is the point at which the capacitor bank exactly supplies the reactive power demanded by the generator. As shown in the figure the no-load terminal voltage of the generator may be determined from this point. When a SEIG is loaded, both the magnitude and frequency of the induced e.m.f. are affected by: the prime mover speed, the capacitance of the capacitor bank and the load impedance. To simplify the discussion, we assume that all losses in the generator are ignored (*Pin* = *Pout*), the connected load is purely resistive and the rotor speed is kept constant. In this case, the decrease in the load resistance (increase in *Pout*) will result in a drop in the stator frequency to provide higher torque to match the increment in the power demand.

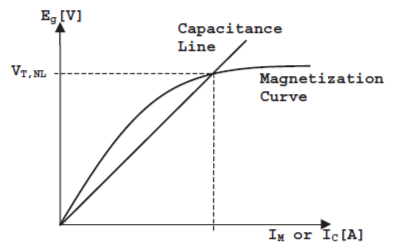

Fig 2 variation of magnetising inductance

III. VOLTAGE CONTROL OF SEIG

The self excited induction generator has a major drawback of poor voltage regulation. The generated voltage depends upon the speed, excitation capacitance, load current and power factor of the load. The voltage control of SEIG con be achieved by controlling the excitation or by using external source for supplying the reactive power, controlling the load or controlling the rotor resistance.

Different control strategies adopted by different researchers is discussed in this section. They can be mainly classified as 1)series capacitors 2)power electronic converters 3)FACTS devices 4) magnetic energy recovery switch 5)using slip rings 6)generalized impedance controller (GIC) 7)induction generator controller(IGC)

A. Series compensation

Series capacitor are the simple and cheap means for voltage control they are connected in series between the SEIG and the load the resultant capacitance values supplies the reactive VARS required for SEIG.the appropriate selection of shunt and series capacitors for any operating speed and load results in maintaining the terminal and load voltage near the rated the value without exceeding the rated current of induction generator.

Simulated Results			
C_{sh}	C_{se}	a	V_{pu}
18.72	18.59	1.0342	1.000241
19.62	20.65	1.0136	0.990486
19.40	21.65	1.0245	0.984433
19.83	18.86	1.0261	0.987254

Table:1 series compensation

B. MERS (magnetic energy recover switch)

MERS consists of a bi directional switch ,DC capacitor and inductor as a filter Two IGBTs are turned on and off in pairs one time each cycle of the ac power source (50-60 Hz) and controlled

synchronously. In a half cycle, two switches (S1 and S3) are turned on, the current flowing is charging and discharging the dc capacitor with the same polarity. In order to get reactive compensation variable reactance of the MERS is obtained by performing a phase shift of the gate signals based on phase of

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line voltages.

C. IGC (induction generator controller)

The excitation capacitors are connected at the terminals of auxiliary (CA) and main winding (CM), which have a fixed value to result in rated terminal voltage at rated load. Consumer load and induction generator controller (IGC) are connected in parallel at generator terminals. The IGC consist of an uncontrolled rectifier, a filtering capacitor (Cf), IGBT based chopper and a series resistive dump load (RD). The uncontrolled rectifier converts the SEIG AC terminal voltage to DC. The output ripples are filtered by filter capacitor. An IGBT is used as a chopper switch. When gate pulse to IGBT is high, the current flows through the dump load and the power is consumed. The pulse width or duty cycle of chopper is decided by the difference of power generation to consumer load.

D. GIC (generalized impedance controller)

It is the combination of VSI and DC link battery. In this only a feed regulate both the SEIG terminal voltage and frequency by using a single-loop control for an electric power generation under source and load perturbations. This has been achieved by operating the SEIG with a generalized impedance controller (GIC) connected at its terminals. The GIC is an operationally modified version of the static synchronous compensator (STATCOM) that is capable of providing bidirectional controlled flow of both active and reactive power.

E. Rotor resistance control

This method also gives promising results for voltage regulation of SEIG.the rotor resistance can be varied by using the slip rings .This is method is mainly employed for slip ring SEIG.

Speed	Rotor resistance	Terminal voltage
C=1.2pu R=1pu a=1pu		
1.145	0.085	1.356
1.175	0.094	1356
1.222	0.125	1.356
1.275	0.154	1.356
1.299	0.164	1.356
1.304	0.174	1.356

Table 2:Rotor resistance control

F. Power electronic converters

Mainly the voltage source converter (VSI) is used for voltage and frequency control. A dc link capacitor is connected across the other side of the VSI ,by varying the switching pulses of the inverter the reactive power flow can be varied. For switching different techniques like PWM(or)SVM or matrix converter are used. Here the theme is to maintain the constant DC across DC link.

G. SEIG feeding DC motor through universal bridge for varying wind speed

The main winding terminal is connected with consumer load of resistive and reactive nature and induction generator controller in parallel. A diode universal bridge converts the AC voltage into equivalent DC voltage. The output DC is connected with dump load resistance and filter capacitor in parallel. The voltage amplitude is computed. The voltage amplitude is compared with the reference and processed through sample based controller. The obtained output is compared with reference wave through a relational operator to obtain a modulated pulse of suitable duration (width). This pulse is given to the pulse generator of universal bridge.

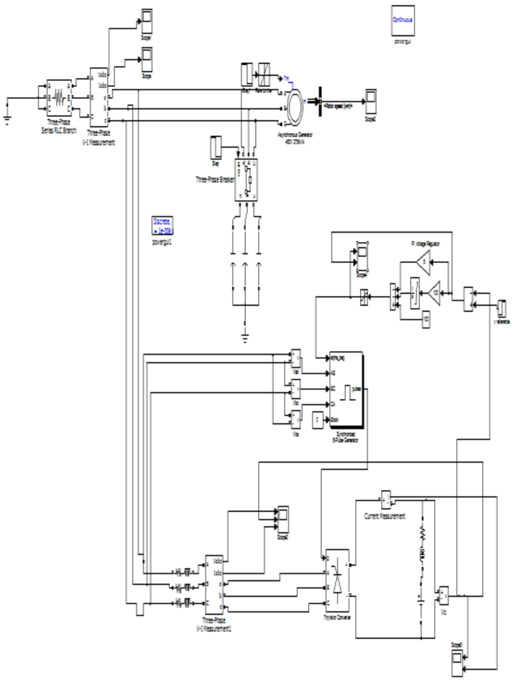

Fig 3.simulink model of SEIG feeding Dc `drive with controller

The above simulink diagram has induction machine across which an appropriate capacitor bank is connected which forms an SEIG fed from a variable torque wind turbine. Here the out put is give to a dc load (motor)through

a universal bridge. The output fed to throw motor is maintained constant by controlling the pulses to bridge.

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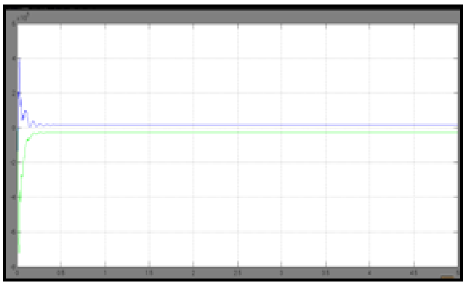

Fig 4:Active and reactive power flow of SEIG

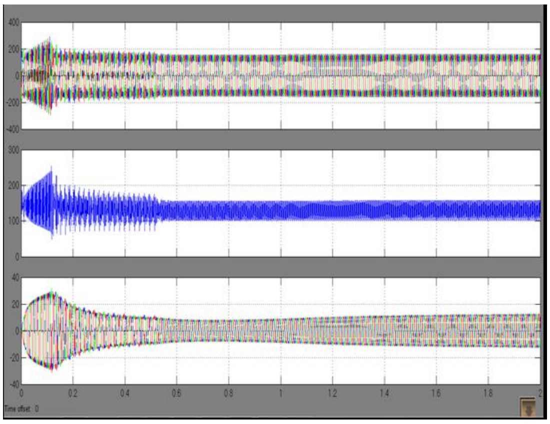

Fig 5: Output voltage, DC load voltage and current of SEIG

From the results its is observed that the constant dc id fed to the load. The SEIG take some for the voltage build up to take place. The controller is capable of maintaining the out put voltage. Some harmonics are presenting the wave form during the voltage build up.

H. *SEIG feeding a induction motor through VSI under varying wind speed*

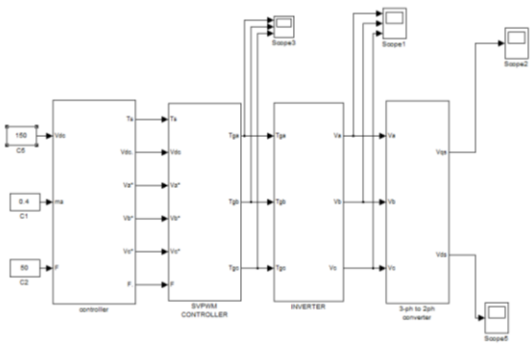

Fig 6: simulink diagram of VSI feeding IM

The above simulink diagram shows a space vector modulate voltage source inverter ,it is connected in between the universal bridge and the induction motor .the switching sequence of the VSI is based on SVM technique .based on the variation on the terminal voltage the SVM controller generates the pulses to maintain constant voltage and frequency

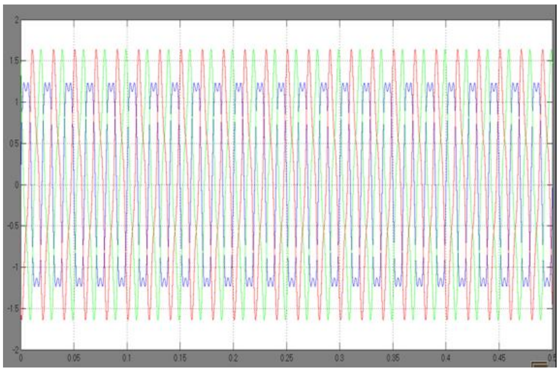

Fig 7: output voltage of VSI(p.u)

The above results says that the output voltage of VSI is constant for varying torque to the SEIG

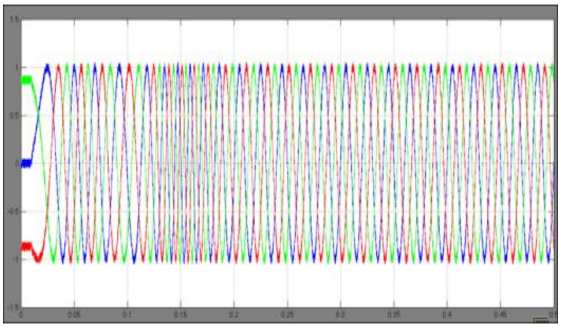

Fig 8: output current of VSI

IV. Conclusion

In this different techniques for control of load voltage of SEIG are discussed series compensation concludes that appropriates selection of capacitors maintains constant voltage .the IGC controls the load on the SEIG .the GIC controls both active and reactive power ,the rotor resistance control provides control in discrete steps .the MERS controls the excitation to the SEIG .finally the power electronic converters gives wide and accurate results for both load voltage and frequency control of SEIG .the above results with DC and AC motors justifies it. In additional the control of AC and DC loads is possible at a time. This paper concludes that even though series compensation is cheap and MERS is simple the use of power electronic converters gives wide range of operation ,applications and control.

Specifications of the Machine

10 h.p (7.5kW), 3-phase, 4 poles, 50 Hz, 480volts, 3.8A Delta connection,

Base Voltage / Rated Voltage = 415V

Base Current / Rated Current = 2.2A

Rs = 1.0 ohm

Rr = 0.77 ohm

Xls = Xlr = 1.0 ohm

J = 0.1384 kg-m2

C=284mf

Rl=1000 ohms

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