Performance Analysis of Self-Excited Induction Generator Supplying DC Load

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Abstract *- This paper gives out the implementation of wind energy system which is becoming one of the solutions for energy crisis since it is safe, inexhaustible, environmentally friendly and is capable of supplying significant amount of power. The proposed system employs an induction generator driven by a DC motor that has been connected to a dc load through a three-phase diode bridge rectifier along with a control system. The squirrel cage induction generator with capacitor excitation known as Self-Excited Induction Generator (SEIG) has been employed which is suitable for generating low power and can be used mainly for small scale wind generators. In this paper, steady state and dynamic analysis of SEIG has been carried out using d-q reference frame. The rectified output has been given to a buck converter and connected to a dc load. To maintain the required output voltage at the output terminals, PI controller has been employed which determines the duty cycle of the converter. The system's simplicity in analyzing and maintaining of output are the major advantages. The system proposed in this paper has been simulated using MATLAB/SIMULINK.*

Keywords *-* DC load, DC motor, Induction generator, MATLAB, Power converter.

I. INTRODUCTION

The electric power generation using inexhaustible energy sources are receiving considerable attention due to their nature friendly advantages. We have a lot of applications using solar energy. In this paper, wind energy source has been given a keen interest and the implication of wind energy has been done. Unlike synchronous machine, induction machine can be operated in various speed and thus used in a wide variety of applications like in wind power generation. Induction machine operating above the synchronous speed can act as a generator. We have two types of induction machine which are squirrel cage and wound type. Wound type induction machines have complication and maintenance problems associated with brushes and slip rings. Also, the reactive power consumption and poor voltage regulation under varying speed are the major drawbacks of the wound type induction generators. To overcome these drawbacks, squirrel cage induction generator in stand-alone mode known as Self-Excited Induction Generator (SEIG) has been employed in this paper. Also, in the present-day scenario most of the loads use dc source and thus a dc load has been used in this paper [1]-[4].

In this paper, analysis of self-excited induction generator has been done using d-q reference frame. Normally we have two fundamental circuit models employed for examining the characteristics of a SEIG. One is the per-phase equivalent circuit which includes the loop impedance method and the nodal admittance method. This method is suitable for studying only the machine's steady-state characteristics. But it is necessary to know both the steady and transient state performance of the generator. Thus, the other method, d-q axis model based on the generalized machine theory has been employed to analyses the machine's transient state as well as steady state. The excitation capacitor used for operating induction generator at the start is also very important and has been calculated theoretically [5]-[12].

The output voltage of SEIG can be given directly to an ac load, but to achieve various output voltages or to regulate the voltage, designing a drive system is of importance. Also, for supplying power to the ac load many power electronic topologies have been proposed but for dc load we have only few articles and thus in this paper dc load has been given a great interest and power electronic topology for dc load has been employed [13], [14]. The regulated output from an uncontrollable diode bridge rectifier has been given to a buck converter and to the dc load. For the better voltage regulation, at the output PI controller has been used since it is comparatively simple to other controllers to design. The working has been simulated using MATLAB. In this paper, description of the system employed, its performance analysis in steady-state and dynamic-state are explained in the following.

II. PROPOSED SYSTEM

In this paper, the proposed system as shown in Fig.1. mainly comprises of the induction generator that has been operated in self-excited mode with the DC motor to drive SEIG to operate it in wide range of speeds. Capacitor banks are used for reactive power requirement of the generator mainly at the start. Normally to convert renewable source to an electrical energy, one quadrant operation is sufficient and thus an uncontrolled DBR has been connected at the terminals. DBR has a displacement factor of 1 and so it can reduce the burden on the excitation capacitor banks [13]-[14]. Even controlled rectifier with different control approaches have been proposed in various articles but these rectifiers need additional circuit for firing the switching devices along with a controller for closed loop operation. Thus, to reduce the complexity DBR has been chosen [15]-[18]. Further to obtain required output for dc load, simple control strategy of dc-dc converter has been proposed.

The output from DBR gives out a higher dc voltage. Since we have considered dc load which are normally used in residentials and other domestic purposes which probably needs low voltage and since induction generators are used for lower power applications, we have proposed a buck converter and a control strategy using a PI controller has been proposed in this paper.

III. ANALYSIS OF THE SYSTEM PROPOSED

A. Analysis of SEIG

To analysis SEIG in both the steady state and dynamic state, state model using d-q as reference frame has been used. In electrical machine analysis, a three-axes to two axes transformation is applied to produce simpler expressions that make complex system simple to analyze and to find easy solutions. The three axes represent the real three phase supply system. However, the two axes are fictitious axes that represent two fictitious phases, displaced by 900, to each other. It is assumed that the three axes and the two axes are in a stationary reference frame which can be rephrased as a transformation between abc and stationary dq0 axes. The conventional per-phase equivalent circuit representation of an induction machine is convenient to use for steady state analysis. However, the d-q representation is used to model the SEIG under dynamic conditions. The basic equations are given as,

The capacitor voltage,

$$vcq = 1/C \int iqs\, dt + vcq0$$
$$vcd = 1/C \int ids\, dt + vcd0$$

The rotor flux linkage,

$$\lambda qr = Lm\, iqs + Lr\, iqr + \lambda qr0$$
$$\lambda dr = Lm\, ids + Lr\, idr + \lambda dr0$$

The matrix equation for the d-q model of a self-excited induction generator from Fig.2., in the stationary stator reference frame is given as:

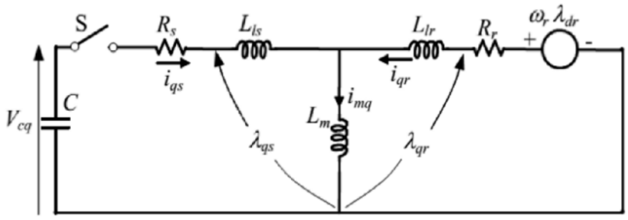


Fig.2.Equivalent circuit of SEIG using d-q reference frame.

$$\begin{bmatrix} R_s + pL_s + {}^1/_{pC} & 0 & pL_m & 0 \\ 0 & R_s + pL_s + {}^1/_{pC} & 0 & pL_m \\ pL_m & -\omega_r L_m & R_r + pL_r & -\omega_r L_r \\ \omega_r L_m & pL_m & \omega_r L_r & R_r + pL_r \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} + \begin{bmatrix} v_{cq0} \\ v_{cd0} \\ K_{qr} \\ K_{dr} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$[Z][I_v] + [V_v] = [0]$$

(1)

where, Z is the impedance matrix, Iv is the stator and rotor current vectors and Vv is the voltage vector due to initial condition.

Basically, an induction machine can be modelled using RLC circuit elements. Self-excitation in an induction generator is the growth of current and the associated increase in the voltage across the capacitor without an external excitation system. Transients that grow in magnitude can only happen if there is an external energy source that is able to supply all the power losses associated with the increasing current. The SEIG is able to have a growing transient because of the external mechanical energy source that is driving the induction generator. The transient process of terminal voltage growth continues until the iron parts gets saturate. The self-excitation process to initiate, a capacitor bank of suitable size must be connected across the terminals of induction motor, the core of which retains some residual flux. For a particular speed and given load, excitation capacitor should sufficient enough to provide VAR to produce rated voltage. An uncontrolled self-excited induction generator shows considerable variation in its terminal voltage, and output frequency under varying load. Thus, it is of importance to find the minimum capacitance that is required for excitation.

B. Analysis of the Converter

The main target in power electronics is to convert electrical energy from one form to another and to reach the load with highest efficiency. Power electronics also targets to reduce the size of the device to convert these energies with reduced cost and high availability. In this project, the rectified output from DBR is given to buck (dc to dc) converter shown in Fig.3.

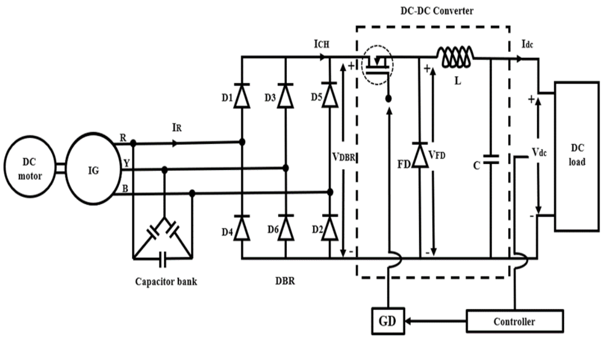


Fig.1.Schematic diagram of the proposed DC motor driven SEIG supplying dc load.

IG: induction generator; DBR: diode bridge rectifier and GD: gate driver circuit

With this to control the output voltage, PI controller had been used. A proportional-integral (PI) is a control loop feedback mechanism widely used in industrial control system. The disturbances can influence the behavior of the converter and its stability which is controlled by PI. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable. The feedback signal may be the output voltage, the inductor current, or both. The feedback control either analog or digital. PI is the linear control method. The rectified output has been given as input to the buck converter which uses a controlled switch to elicit unidirectional power flow from input to output. The inductor and the capacitor are used to store and transfer the energy from input to output. The voltage and current waveform get smoothen by filter.

1) Steady-State Continuous Conduction Mode Analysis: The duration of the ON state as from Fig.4. is $D \times T$S where D is the duty cycle, set by the control circuit, expressed as a ratio of the switch ON time to the time of one complete switching cycle, Ts. The duration of the OFF state as from Fig.5. is (1–D)×TS. During the OFF state, the magnitude of the voltage applied across the inductor is constant maintaining our same polarity convention, this applied voltage is negative (or opposite in polarity from the applied voltage during the ON time). Hence, the inductor current decreases during the OFF time. Also, since the applied voltage is essentially constant, the inductor current decreases linearly.

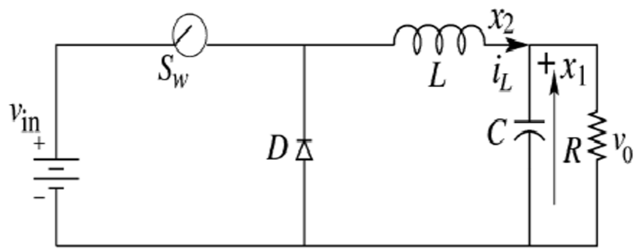


Fig.3.Buck converter.

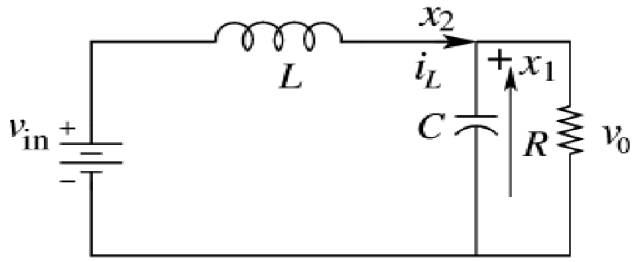


Fig.4.Buck converter-ON state.

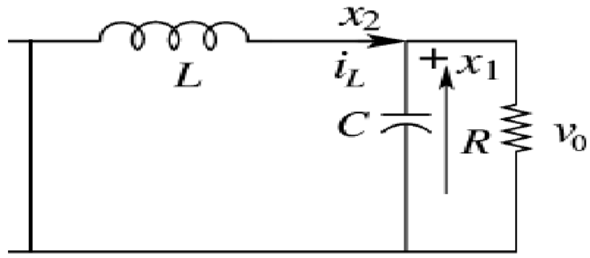


Fig.5.Buck converter-OFF state.

For choosing the value of inductor key factor need to be concern is that the peak to peak ripple current ΔIL of inductor should not cross the permissible value. There is a thumb rule that the peak to peak inductor ripple current ΔIL should be around 30% to 40% of average inductor current $Iavg$ or the output current.

$$L = \frac{(V_{in} - V_o)V_o}{V_{in} f_s \Delta I_L} \quad (2)$$

When selecting the value of inductor there is another parameter need to be considered, that is the saturation current $Isat$ of the inductor, which should never be exceeded in the operation. Operating the inductor above $Isat$ would cause a significant inductance loss and a steep increase of the inductor current during the charging phase.

The main function of capacitor is to maintain constant output voltage. It makes the output voltage ripple free. As ideal capacitor is almost practically impossible to construct there always an ESR incorporated with it and this ESR affects the output voltage. The best practice is to use low-ESR capacitors to minimize the ripple on the output voltage. For a certain peak-to-peak output voltage ripple ($\Delta V_{o,ripple}$), the required maximum ESR of the output capacitor can be calculated by using the following equation

$$ESR=\frac{\Delta V_{o,ripple}}{\Delta I_L} \tag{3}$$

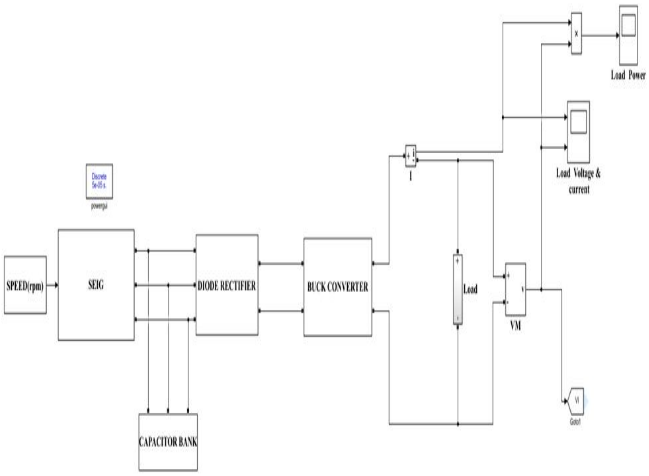
The following equation has been used for calculating the value of capacitor

$$C=\frac{\Delta I_L \Delta T}{\Delta V_{o,ripple}-(\Delta I_L\ ESR)} \tag{4}$$

Because of this ESR in the capacitor the loss of power takes place and due to this the capacitor gets heated up. This temperature rise negatively affects the lifetime and reliability of the capacitor. Since excessive temperature negatively affects the reliability and the lifetime of a capacitor, an output capacitor with an adequate current rating should be selected. In order to achieve better output voltage regulation, low-ESR capacitors are required. Ceramic capacitors generally have very low ESR.

IV. SIMULATION RESULTS

The simulation of the proposed system has been done using MATLAB/SIMULINK. MATLAB (matrix laboratory) is a fourth-generation high-level programming language and interactive environmental for numerical computation, visualization and programming. MATLAB was developed by Math Works. Since Dc motor has been used as a prime mover and the main parameter from this is the speed, for simulation a constant block has been used. The library values of 1725rpm, 60Hz has been used in the asynchronous machine model that is available is MATLAB. A three-phase diode bridge rectifier model along with dc-dc converter model has been connected at the output of the generator and given to a lamp load. The overall Simulink model of the proposed system has been shown in Fig.6. The output voltage of SEIG at two different speeds has been shown in Fig.7 and Fig.8.



The output of SEIG has been rectified which gives out voltage and current as shown in Fig.9. and then given to a buck converter whose semi-converter switch receives the pulse from a PI controller to which the output voltage of buck converter is fed back for giving out the required voltage.

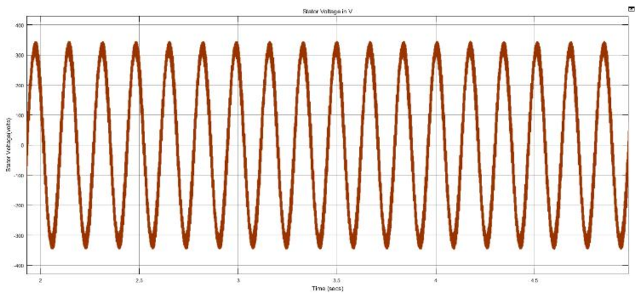


Fig.7.Stator output voltage of SEIG at 1725rpm with excitation capacitance of 100µF/phase.

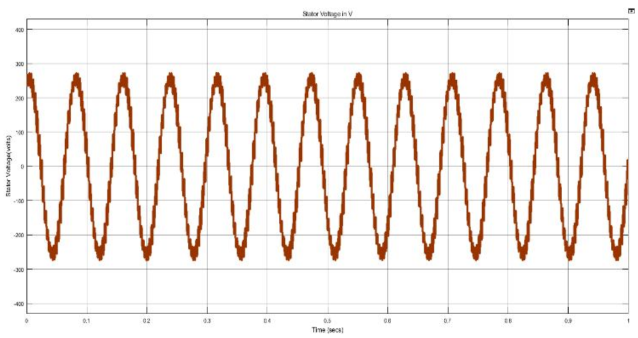
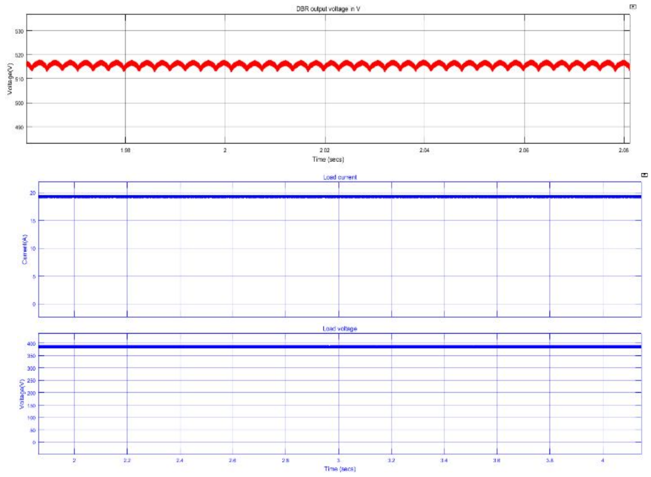
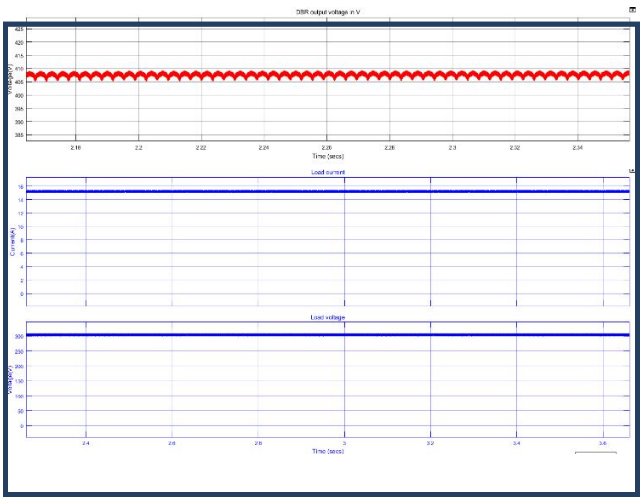


Fig.8.Stator output voltage of SEIG at 1500rpm with excitation capacitance of 100µF/phase.



(a) 1725rpm



(b) 1500rpm

Fig.9.Outputs corresponding to DBR voltage, load current and voltage.

Table i

performance of seig at different rotor speeds

Rotor speed(rpm)	Stator voltage(V)	Stator output power(kw)
1120	152	1.49
1300	205	2.63
1410	240	3.64
1500	270	4.66
1725	345	7.45

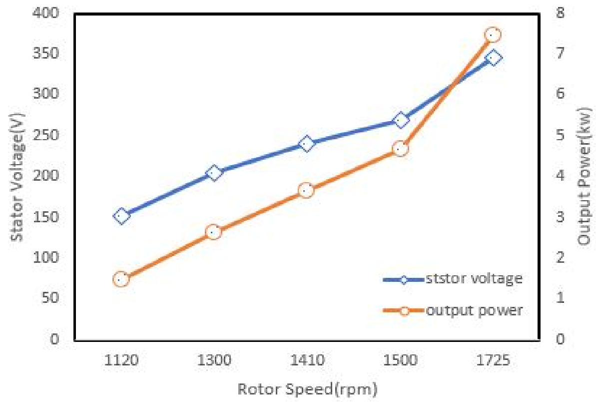


Fig.8. Performance of SEIG representing the stator voltage and power at different rotor speeds. C=100μF/phase.

V. CONCLUSION

The modelling of SEIG with d-q reference frame has been done and analysed. Also, buck converter with PI controller has been designed. The simulation of the whole system and the respective waveforms were obtained. This system with SEIG is more advantageous than synchronous generator and it has been further used for demonstration of the power generation from wind turbine which has been replaced by a DC motor in this paper.

In future, the model will be extended with mppt technique using pic controller or fuzzy logic controller.

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