International Journal of Electrical and Electronics Engineering (IJEEE)
ISSN 2278-9944
Vol. 2, Issue 1, Feb 2013, 31-40

A SURVEY OF SELF-EXCITED INDUCTION GENERATOR RESEARCH

LALIT GOYAL[1], OM PRAKASH MAHELA[2] & SUNIL GOYAL[3]

[1, 2]Junior Engineer, Rajasthan Rajya Vidhyut Prasaran Nigam Ltd., Jaipur, India

[3]Assistant Professor, Department of Electrical Engineering, Apex Institute of Engineering & Technology, Jaipur, India

ABSTRACT

The increasing use of renewable energy sources such as wind energy, bio-gas energy, solar energy, and hydro potential have become essential to adopt a low cost generating system, which are capable of operating in the remote areas, and in conjuction with the variety of prime movers. With wind turbines and mini/micro hydro generators as an alternative energy source, the induction generators are being considered as an alternative choice to well developed sysnchronous generators because of their lower unit cost, inherent ruggedness, operational and maintenance simplicity, absence of separate DC source, self-protection against overloads and short circuits etc. The research is underway to investigate the various issues related to the use of induction generator as potential alternative to the synchronous generator to utilize the small hydro and wind energy to accomplish the future energy requirement, and feed the power to remote locations and far flung areas, where extension of grid is not economically feasible. This paper presents an exhaustive survey of literature of research on self-excited induction generator (SEIG) over the past 30 years so that further work can be carried out for better results.

KEYWORDS: Mini-Hydro, Parallel Operation of SEIG, Renewable Energy Sources, Self-Excited Induction Generator, Steady-State Analysis, Transient Analysis, Wind Energy

INTRODUCTION

The increasing concern for the environment and resources has motivated the world towards rationalizing the use of conventional energy sources and has given emphasis on renewable energy sources such as wind, mini/micro-hydro, solar, geothermal, industrial waste etc. [1]. Since small hydro and wind energy sources are available in plenty, their utilization was felt quite promising to accomplish the future energy requirements. Harnessing mini/micro hydro and wind energy for electric power generation is an area of research interest and at present, the emphasis is being given to the cost-effective utilization of these energy resources for quality and reliable power supply [2]. With their limitations, a renewable energy power plant is installed locally and equipped with a small-size generator, up to only a few MW rating [3]. Traditionally, synchronous generators have been used for power generation but induction generators are increasingly being used these days because of their relative advantageous feature over conventional synchronous generators [4].

The self-excited induction generator (SEIG) has attracted considerable attention due to its applicability as a stand-alone generator using different conventional and non-conventional energy resources with its advantage over the conventional synchronous generator. Due to the research of renewable energy resources and isolated power systems, the SEIG become one of the most important renewable sources in developing countries [5]. It has its inherent advantages such as brushless construction with squirrel-cage rotor, reduced size, absence of DC power supply for excitation, reduced maintenance cost, and better transient performances. Major drawbacks of SEIG are reactive power consumption, its relatively poor voltage and frequency regulation under varying prime mover speed, excitation capacitor and load characteristics [6]. A detailed study of the performance of the SEIG operated in stand-alone and grid connected mode during steady-state and various transient conditions is important for the optimum utilization of its advantageous features. This paper presents a survey of research presented by the researcher recently on self-excited induction generator.

CLASSIFICATION OF INDUCTION GENERATORS

The induction generators are simpler than synchronous generators. They are easier to operate, control, and maintain, do not have any synchronization problem and are economical. Depending upon the rotor construction induction generators are two types [7]: (i) the wound rotor induction generator and (ii) the squirrel cage induction generator. On the basis of the prime movers used and their locations, generating schemes can be broadly classified in to two types [8]-[9]: (i) the constant-speed constant-frequency, (ii) the variable-speed constant-frequency, and (iii) the variable-speed variable-frequency.

Constant-Speed Constant Frequency

T.S. Jayadev in [9] described that in this scheme, the prime mover speed is held constant by continuously adjusting the blade pitch and/or generator characteristics. An induction generator can operate on an infinite bus bar at a slip of 1% to 5% above the synchronous speed [10].

Variable-Speed Constant Frequency

Dezza *et al.* [11] presented that variable-speed operation of wind electric system yields higher output for both low and high wind speeds. This results in higher annual energy yields per rated installed capacity. Both horizontal and vertical axis wind turbines exhibit this gain under variable-speed operation. The popular schemes to obtain constant frequency output from variable speed are: (i) AC-DC-AC Link and (ii) Double output induction generator.

The double output induction generator (DOIG) is described in literature [12]-[14]. It consists of a three-phase wound rotor induction machine that is mechanically coupled to either a wind or hydro turbine, whose stator terminals are connected to a constant voltage constant frequency utility grid. One of the outstanding advantages of DOIG in wind energy conversion systems is that it is the only scheme in which the generated power is more than the rating of the machine. However, due to operational disadvantages, the DOIG scheme could not be used extensively.

Variable-Speed Variable Frequency

For variable speed corresponding to the changing derived speed, SEIG can be conveniently used for resistive heating loads, which are essentially frequency insensitive. The application of this scheme for stand-alone wind power is presented in literature [15]-[16].

THREE PHASE SELF-EXCITED INDUCTION GENERATOR MODEL

When an induction machine operates as a Self-excited induction generator (SEIG), there is no external power grid that defines voltage and frequency on the stator terminals. Thus, both of them are unknown variables whose values change independently, being affected by rotor speed, capacitance of excitation capacitors and loading conditions. Saturation level of the magnetic circuit is also variable, which means that magnetizing inductance cannot be considered constant [17]. Several different variants of SEIG's equivalent circuit can be found in literature [18]-[20]. For the modeling of the self excited induction generator the main flux path saturation is accounted for while the saturation in the leakage flux path of magnetic core of the machine, the iron and rotational losses are neglected [21]-[22].

Steady-State Circuit Model

Most of the steady state models of SEIG developed by different researchers are based on per phase equivalent circuit. These models use the following two basic methods: (i) Loop impedance method and (ii) Nodal admittance method. The steady state model based on nodal admittance method and used in [17] is presented here in Fig. 1. This model makes assumptions that the load is RL, machine core loss component is neglected and the machine parameters (except for magnetizing reactance) remain constant.

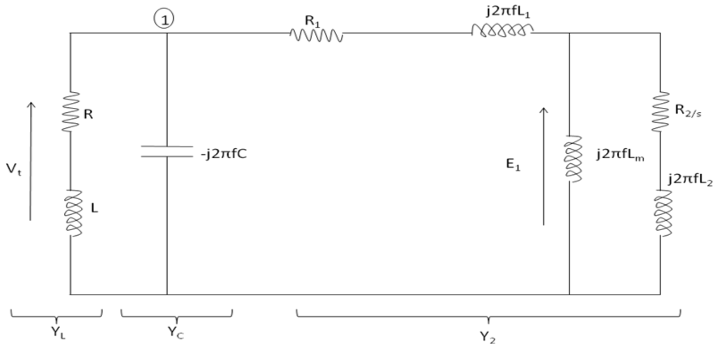

Figure 1: Equivalent Circuit of Self-Excited Induction Generator

T.F. Chan in [23] presented a steady state model of SEIG in which all the circuit parameters are assumed to be constant and unaffected by saturation. Machine parameter except capacitance and frequency all are known values. Mahendra Lalwani *et al.* [24] proposed a steady state model of single phase self-excited induction generator with one winding for obtaining constant output voltage. D. Joshi *et al.* [25] presented conventional equivalent circuit model for steady state analysis of SEIG using artificial neural network. K.S. Sandhu *et al.* [26] proposed a model for steady state operation of self-excited induction generator with varying wind speeds. Jordan Radosavljevic *et al.* [27] proposed induction generator model with its positive and negative sequence circuits for steady-state analysis of parallel operated self-excited induction generators supplying an unbalanced load. Eduard Mujadi *et al.* [28] presented a model of asynchronous machine in terms of admittance using the steady state equivalent circuit.

Mathematical Model

For the machine to self-excite on load, the impedance line corresponding to the parallel combination of the load impedance and excitation capacitance should intersect the magnetization characteristic well in to the saturation region [29]. For the self-excitation of the machine on no load, the excitation capacitance must be larger than some minimum value, this minimum value decreases with decreasing speed [30]. For the circuit shown in Fig. 1, by using Kirchhoff's current law, the sum of currents at node (1) should be equal to zero, therefore

$$\mathbf{VY} = \mathbf{0} \tag{1}$$

Where **Y** is the net admittance given by

$$\mathbf{Y} = \mathbf{Y_L} + \mathbf{Y_c} + \mathbf{Y_2} \tag{2}$$

The terminal voltage cannot be equal to zero, therefore

$$\mathbf{Y} = \mathbf{0} \tag{3}$$

By equating the real and imaginary terms in equation (3) respectively to zero, we have

$$\mathrm{Real}(\mathbf{Y_L} + \mathbf{Y_c} + \mathbf{Y_2}) = \mathbf{0}$$

$$\mathrm{Real}(\mathbf{Y_L} + \mathbf{Y_c} + \mathbf{Y_2}) = \mathbf{0}$$

M.H. Haque in [31] proposed a mathematical model of SEIG for determination of critical speed capacitance requirements in which core losses are modeled by adding resistor in parallel with magnetizing inductance. H.H. Hanafy *et al.* [32] presented a mathematical model of self-excited short-shunt induction generator driven by unregulated turbine under no load and on load conditions for voltage and frequency control. Analysis was done to choose appropriate set of values of both shunt and series capacitances to control the magnitude and frequency of the load voltage. M.H. Haque in [33] presented a simple method of evaluating the steady state characteristics of a three-phase SEIG with *P-Q* load model. First the problem of generator is formulated through its equivalent circuit using the basic circuit laws.

The formulated problem is then solved using a numerical based routine. The proposed method is then tested on a 1.5-KW machine. Bhaskara Palle *et al.* [34] proposed dynamic mathematical model to describe the transient behavior of a system of self-excited induction generators operating in parallel and supplying a common load. Sasikumar *et al.* [35] presented a simple mathematical model to compute the steady-state performance of six-phase self-excited induction generators. A mathematical model is formed directly from the equivalent circuit of six-phase self-excited induction generator by nodal admittance method. Genetic algorithm is applied to solve the proposed model. The model of induction machine with *D-Q* axes equivalent circuit has been reported in literature [36]-[39].

PERFORMANCE ANALYSIS OF SELF-EXCITED INDUCTION GENERATOR

The performance analysis of self-excited induction generator may be discussed by categorizing in to four important headings viz: (i) steady-state analysis, (ii) the transient analysis, (iii) the voltage control aspects, and (iv) the parallel operation of SEIG.

Steady- State Analysis

In an isolated power system, both the terminal voltage and frequency are unknown and have to be computed for a given speed, capacitance and load impedance. Therefore the steady-state analysis of self-excited induction generator is of great interest, both from the design and operational points of view.

Harish Kumar *et al.* [40] presented the steady state performance of SEIG with genetic algorithm, pattern search and quasi-newton optimization techniques. At given load, speed and terminal voltage two unknowns i.e., p.u. capacitive reactance and frequency are determined. The steady state equivalent circuit is used to compute the performance of SEIG after determining the unknowns.

The effects of various system parameters are presented. Wang *et al.* [41] have presented an eigenvalue-based approach to predict both minimum and maximum values of capacitance required for self-excitation of SEIG. Muthy *et al.* [42] presented a general steady-state analysis of a three-phase self-excited induction generator feeding a three-phase unbalanced load or single-phase load. Symmetrical component theory is used to obtain relevant performance equations through sequence quantities.

The feasibility of using three-phase machines for unbalanced operations has been critically examined for stand-alone power generation. B. Singh *et al.* [43] predicted the steady-state performance of the two-winding single-phase SEIG and verified with experimental results for three different schemes, namely; fixed-shunt capacitor excitation, fixed and variable capacitor excitation, shunt- and series-capacitor excitation.

Rajakaruna *et al.* [44] have used an iterative technique which uses an approximate equivalent circuit and a mathematical model for B-H curve and the solution is reduced to a nonlinear equation.

Transient Analysis

The transient studies of induction generators are related to voltage buildup due to self-excitation and load perturbations. The D-Q model can be used to investigate the SEIG transient performance under balanced condition. The literature [45]-[48] have presented transient/dynamic analysis of self-excited induction generator.

Hamouda *et al.* [49] presented a transient model of a stand-alone self-excited induction generator. This model is based on direct phase quantities and is suitable to study the performance of the generator under any condition. It includes a general load as well as general excitation capacitor model. Shridhar *et al.* [50] presented the transient performance of short-shunt SEIG. It is seen that it can sustain severe switching transients, has good overload capacity, and can re-excite over no load after loss of excitation.

It is also observed that except for the most unusual circumstances, the short-shunt SEIG supplies adequate fault current to enable over-current protective device operation. Wang *et al.* [51] presented transient performance of a stand-alone self-excited induction generator under unbalanced excitation capacitors. An approach based on three-phase induction machine model is employed to derive dynamic equations of an isolated SEIG under unbalanced conditions. The neutral points of both Y-connected excitation capacitor bank and Y-connected stator windings of the SEIG are connected together through a neutral line.

Wang *et al.* [52] have presented a comparative study of long-shunt and short-shunt configurations on dynamic performance of an isolated SEIG feeding an induction motor load. Results show that the long shunt configurations may lead to unwanted oscillations while the short shunt provides the better voltage regulation. In [53], the permanent and dynamic behaviours of self-excited induction generator in balanced mode are discussed. The effects of varying the resistive load, the excitation’s capacitors and the drive speed on the stator output voltage are also presented.

Voltage-Control Aspects

The induction machine has no field windings; therefore the current to magnetize the machine must be supplied by the system to which it is connected. The need of reactive power support and poor voltage regulation are the two major drawbacks of induction generators. Induction generators require the supply of reactive power [54]. Depending upon the arrangement to supply the reactive power, two modes of operation are possible for an induction generator i.e. regeneration and self-excitation. In first mode, the induction generator takes its excitation in terms of lagging magnetizing current from the power source of known voltage and frequency i.e. grid, to produce its rotating air gap field for required regeneration. In second mode, the VAR generating unit has to be connected across the terminals of induction machine, which are generally realized in the form of capacitor banks [55].

Malik *et al.* [56] have shown that the minimum capacitance requirement of SEIG is inversely proportional to the square of speed and maximum saturated magnetizing reactance. Swati Devabhaktuni *et al.* [57] presented a method for computing the minimum value of capacitance to initiate self-excitation in the SEIG. The method is based on the steady state equivalent circuit, but features the separate consideration of the load and excitation capacitance branches, which enables the frequency to be determined by solving a single 4^{th} order polynomial.

Elsharkawi *et al.* [58] presented a fixed and switched capacitors scheme consisting of two discrete groups of fixed and switched capacitors, which furnish enough reactive power for an induction generator throughout its desired operating region of speed. The number of switched capacitors is kept to a minimum to simplify the switching circuit, and yet provides adequate and varying reactive power compensation.

Parallel Operation of SEIG

The self-excited induction generators usually operate in parallel where natural resources are available in abundance to utilize full potential of the natural resources. Parallel operation of induction generators has the advantage of elimination of the need for synchronization and of the associated problems with hunting etc. The references [59]-[61] are available on parallel operation of such units.

Chakraborty *et al.* [62] have analyzed the effects of parameter variations on the performance of parallel-connected SEIG operating in stand-alone mode. The investigation outlines the parameter influence on the performance of individual generators as well as on the system as a whole. Effects of parameter deviations on the voltage regulation have been examined in this paper. Rotor resistance is found to have the largest influence on current and power sharing of individual machines and also on terminal frequency. Yun *et al.* [63] presented a new methodology to analyze the parallel operation of single-phase self-excited induction generators in a distribution system. The model is then employed by analyzing starting currents and short circuit currents contributions from the SEIGs. The method of analysis in [60] is based on a simplified equivalent circuit, and as a result the developed expressions lack accuracy in certain situations, and also fail to meet the requirements to study many aspects of parallel connected generators. Bahrani *et al.* [64] studied the voltage-control behavior of multi-induction generators operating in parallel with one three-phase bank of excitation capacitors connected to a common bus and load. It has been reported that voltage regulation under varying load conditions is improved by controlling either the capacitance or speed of one or more generators. Under controlled terminal voltage operation, it is noticed that the capacitive reactive power and speed demand increases with increased load. Under the similar conditions of controlled terminal voltage, the system frequency also depends on load power and terminal voltage.

CONCLUSIONS

Applications of self-excited induction generator for energy conversions in remote locations offer many advantages over a synchronous generator. The SEIG is most economical solution for powering customers isolated from the utility grid. This article have presented a comprehensive literature survey on important aspects of SEIG such as the process of self-excitation, modeling, steady-state and transient analysis, reactive power/voltage control, and parallel operation useful for the researchers. The better methods of reactive power/voltage control techniques will make the SEIG more suitable for isolated applications.

REFERENCES

1. N. Ammasagounden, and M. Subbiah, Microprocessor based voltage controller for wind-driven self-excited induction generators, *IEEE Transaction Industrial Electronics*, Vol. 37, No. 6, December 1990, pp. 531-537.
2. G. Boyle, *Renewable Energy: Power for Sustainable Future*,(Oxford University Press, 2000).
3. N. Jenkins, R. Allan, P. Crossley, D. Kirschen, and G. Strbac, *Embedded generation* (The Institute of Electrical Engineers, 2000).
4. G. Raina, and O.P. Malik, Wind energy conversion using a self-excited induction generator, *IEEE Transaction on Power Apparatus and Systems*, Vol. 102, No. 12, 1983, pp. 3933-3936.
5. Elder J.M., Boys J.T., and Woodward J.L., Self-excited induction machines as a small low cost generator, *Proceeding IEE*, Vol. 131, Part C, No. 2, pp. 33-41, 1984.
6. S.M. Alghuwainmen, Steady-state analysis of self-excited induction generator including transformer saturation, *IEEE Transactions on Energy Conversion*, Vol. 14, No. 3, September 1999.

7. McPherson G., and Laramore R.D., *An Introduction to Electrical Machines and Transformers.* (New York, Wiley, 1981).
8. L. Quazene and G. G. McPherson Jr., Analysis of an isolated induction generator, *IEEE Transactions on Power Application System,* Vol. 102, No. PAS-8, August 1983, pp. 2793-2798.
9. T.S.Jayadev, Windmills stage a comeback, *IEEE Spectrum,* Vol. 13, No. 11, November 1976, pp. 45-49.
10. R.C. Bansal, Three-phase self-excited induction generators: an overview, *IEEE Transactions on Energy Conversion,* Vol. 20, No. 2, June 2005, pp. 292-299.
11. F.C. Dezza, A.D. Geriando, and R. Perini, Performance comparison among different converters fed by self-excited wind driven induction generators, *Proceeding 7th International Conference on Electric Machine Drives,* pp. 438-443, 1995.
12. M.S. Vicatos, and J.A. Teqopoulos, Steady state analysis of a doubly-fed induction generator under synchronous operation, *IEEE Transaction Energy Conversions,* Vol. 4, No. 3, September 1989, pp. 495-501.
13. M.G. Loannides, Determination of frequencies in autonomous double output asynchronous generator, *IEEE Transactions Energy Conversions,* Vol. 7, No. 4, December 1992, pp. 287-297.
14. Z. Slameh, and S.Wang, Microprocessor control of double output induction generator, Part-I: inverter firing circuit, *IEEE Transaction Energy Conversions,* Vol. 4, No. 2, June 1989, pp. 172-176.
15. R.C. bansal, T.S. Bhatti, and D.P. Kothari, A bibliographical survey on induction generator for application of nonconventional energy systems, *IEEE Transactions on Energy Conversions,* Vol. 18, No. 3, September 2003, pp. 433-439.
16. R.C. bansal, T.S. Bhatti, and D.P. Kothari, Induction generator for isolated hybrid power system applications: A review, *Proceeding 24th National Conference on Renewable Energy Conversion,* Bombay, pp. 462-467, 2000.
17. Swati Devabhaktuni, and S.V. Jayaram kumar, Performance analysis of self-excited induction generator driven at variable wind speeds, *International Journal of Engineering and Advanced Technology,* Vol.1, Issue.2, December 2011, pp. 81-86.
18. S.M. Alghuwainmen, Steady-state analysis of self excited induction generator including transformer saturation, *IEEE Transactions on Energy Conversion,* Vol.14, No.3, September 1999.
19. T.F. Chan, L.L. Lai, Steady-state analysis and performance of a single-phase self regulated self-excited induction generator, *IEEE Proc. Generation, Transmission and Distribution,* March 2002.
20. Shakuntla Boora, Analysis of self-excited induction generator under balanced or unbalanced conditions, *ACEEE International Journal on Electrical Power Engineering,* Vol. 01, No. 03, December 2010, pp. 59-63.
21. A.K. Tandon, S.S. Murthy, and G.J. Berg, Steady-state analysis of capacitor self excited induction generators, *IEEE Transactions on Power Application and System*, PAS-103, No. 3, 1984, pp. 612-618.
22. A.I. Aloah, M.A. Alkanhal, Analysis of three phase self-excited induction generator under static and dynamic loads, *IEEE Proceedings,* 1991.
23. T.F. Chan, Self-excited induction generators driven by regulated and unregulated wind turbines, *IEEE Transactions on Energy Conversion,* Vol. 11, No. 2, June 1996.
24. Mahendra Lalwani, and Mool Singh, Analysis of single phase self-excited induction generator with one winding for obtaining constant output voltage, *International Journal of Electrical Engineering (International Research Publication House),* Vol. 4, No. 2, 2011, pp. 173-181.
25. D. Joshi, K.S. Sandhu, and M.K. Soni, Performance analysis of self-excited induction generator using artificial neural network, *Iranian Journal of Electrical and Computer Engineering,* Vol. 5, No. 1, 2006, pp. 57-62.

26. K.S. Sandhu, and S.P. Jain, Steady state operation of self-excited induction generator with varying wind speeds, *International Journal of Circuits, Systems and Signal Processing,* Vol. 2, Issue 1, 2008, pp. 26-33.
27. Jordan Radosavljevic, Dardan Klimenta, and Miroljub Jevtic, Steady-state analysis of parallel operated self-excited induction generators supplying an unbalanced load, *Journal of Electrical Engineering,* Vol. 63, No. 4, 2012, pp. 213-223.
28. Eduard Mujadi, Jesus Sallan, Mariano Sanz, and Charles P. Butterfield, Investigation of self excited induction generators for wind turbine application, *IEEE Industry Application Conference 34 IAS Annual Meeting,* Arizona USA, 3-7 October 1999.
29. Malik N.H., and Mazi A.A., Capacitance requirements for isolated self excited induction generators, *IEEE Transactions on Energy Conversion,* Vol. EC-2, No. 1, 1987, pp. 62-69.
30. T.F. Chan, Capacitance requirements of self-excited induction generators, *IEEE transaction on Energy Conversion,* Vol. 8, No. 2, June 1992, pp. 304-310.
31. M.H. Haque, A novel method of evaluating performance characteristics of a self-excited induction generator, *IEEE Transaction Energy Conversion*, Vol. 24, No. 2, 2009, pp. 358-365.
32. H.H. Hanafy, A.M. Geraha, M.M. Abd-Elaziz, and A.F. Zobaa, Voltage and frequency control of self-excited short-shunt induction generator, *Journal of Engineering and Computer Sciences, Qassim University,* Vol. 1, No. 2, July 2008, pp. 95-108.
33. M.H. Haque, Analysis of a self-excited induction generator with P-Q load model, *IEEE PES Letter.*
34. Bhaskara Palle, and M. Godoy Simoes, Dynamic simulation and analysis of parallel self-excited induction generators for island wind farm systems, *IEEE Transactions on Industry Applications,* Vol. 41, No. 4, July-August 2005, pp. 1099-1106.
35. S.Sasikumar, and S.Singaravelu, Modelling and analysis of six-phase self-excited induction generator for wind energy conversion, *International Journal of Recent Trends in Electrical & Electronics Engg.*, Vo. 2, Issue. 1, May 2012, pp. 1-12.
36. Wee S.D., Shin M.H., and Hyun D.S., Stator-flux-oriented control of induction motor considering iron loss, *IEEE Transactions on Industrial Electronics,* Vol. 48, No. 3, June 2001, pp. 602-608.
37. Choi J.W., Chung D.W., and Sul S.K., Implementation of field oriented induction machine considering iron losses, *IEEE-APEC-96, Conference Proceedings,* 1996, pp. 375-379.
38. Levi E., Sokola M., Boglietti A., and Pastorelli M., Iron loss in rotor-flux-oriented induction machine: identification, assessment of detuning, and compensation, *IEEE Transactions on Power Electronics,* Vol. 11, 1996, pp. 698-709.
39. Wang L., and Ching-Huei L., A novel analysis on the performance of an isolated self-excited induction generator, *IEEE Transactions on EC,* Vol. 12, No. 2, June 1997, pp. 109-117.
40. Harish kumar, and Neel Kamal, Steady-state analysis of self-excited induction generator, *International Journal of Soft Computing and Engineering,* Vol. 1, Issue. 5, November 2011, pp. 248-253.
41. L.Wang, and C.H. Lee, A novel analysis of the performance of an isolated self-excited induction generator, *IEEE Transactions on Energy Conversions,* Vol. 12, No. 2, June 1996, pp. 338-343.
42. S.S. Muthy, B. singh, S.Gupta, and B.M. Gulati, General steady-state analysis of three-phase self-excited induction generator feeding three-phase unbalanced load/single-phase load for stand-alone applications, *IEE Proceeding Gener. Transmi Dlilrih,*Vol. 150, No. 1, January 2003, pp. 49-55.

43. B. Singh, and L.B. Shilpkar, Steady-state analysis of single-phase self-excited induction generator, *IEE Proc.-Gener. Transm. Dislrib.,* Vol. 146, No. 5, September 1999, pp. 421-426.
44. S.Rajakaruna, and R.Bonert, A technique for the steady state analysis of a induction generator with variable speed, *IEEE Transactions Energy Conversions,* Vol. 8, No. 3, September 1989, pp. 526-530.
45. C.S. Demoulias, and P.S. Dokopoulos, Transient behavior and self-excitation of wind-driven induction generator after its disconnection from the power grid, *IEEE Transaction Energy Conversions,* Vol. 5, No. 2, June 1990, pp. 272-278.
46. M.H. Saloma, and P.G. Holmes, Transient and steady state load performance of a stand-alone induction generator, *Proc. Inst. Elect. Engg. Elect. Power Appl.* Vol. 143, 1996, pp. 50-58.
47. L.Wang, and J.Y. Su, Dynamic performance of an isolated self-excited induction generator under various loading conditions, *IEEE Transactions Energy Conversion,* Vol. 14, No. 1, March 1999, pp. 93-100.
48. J.M. Elder, J.T. Boys, and J.L. Woodward, Integral cycle control of stand-alone generators, *IEE Proceedings,* Part C, Vol. 132, No. 2, pp. 57-66, 1985.
49. R.M.Hamouda, A.M. Eltamaly, and A.I. Alolah, Transient performance of an isolated induction generator under different loading conditions, *Australasian Universities Power Engineering Conference (AUPEC' 08),* Paper P-204, pp. 1-5, 2008.
50. L. Shridhar, B. Singh, and C.S. Jha, Transient performance of the self regulated short-shunt self excited induction generator, *IEEE Transaction Energy Conversions,* Vol. 20, No. 2, June 1995, pp. 261-267.
51. Li Wang, and Ruey-Yong Deng, Transient performance of an isolated induction generator under unbalanced excitation capacitors, *IEEE Transactions on Energy Conversions,* Vol. 14, No. 4, December 1999, pp. 887-893.
52. L. Wang, and C.H. Lee, Long-shunt and short shunt connections on a dynamic performance of a SEIG feeding an induction motor load, *IEEE Transactions on Energy Conversions,* Vol. 15, No. 1, March 2000, pp. 1-7.
53. M.L. Elhafyani, S.Zouggar, M. Benkaddour, and Y. Zidani, Permanent and dynamic behaviours of self-excited induction generator in balanced mode, *M.J. Condensed matter,* Vol. 7, No. 1, January 2006, pp. 49-53.
54. E. Suarez, and G. Bortolotto, Voltage-frequency control of a self-excited induction generator, *IEEE Transactions on Energy Conversions,* Vol. 12, No. 4, December 1997, pp. 368-374.
55. Shelly Vadhera, and K.S. Sandhu, Constant voltage operation of self-excited induction generator using optimization tools, *International Journal of Energy and Environment,* Vol. 2, Issue. 4, 2008, pp. 191-198.
56. N.H. Malik, and A.A. Mazi, Capacitive requirements of self excited induction generators, *IEEE Transaction on Energy Conversions,* Vol. EC-2, No. 1, March 1987, pp. 62-69.
57. Swati Devabhaktuni, S.V. Jayaram kumar, Design of excitation capacitance for self-excited induction generator, *International Journal of Computer Science & Communication Networks,* Vol. 1, No. 3, pp. 264-269.
58. M.A. Elsharkawi, S.S. Venkata, T.J. Williams, and N.G. Butlar, An adaptive power factor controller for three-phase induction generator, *IEEE Transactions on Power App. Ssystems,* Vol. PAS-104, No. 7, July 1985, pp. 1825-1831.
59. A.H. Al-Bahrani, and N.H. Malik, Steady state analysis of parallel-operated self-excited induction generators, *Proceeding IEE, Part*. C, Vol. 140, No.1, pp. 49-55, 1993.
60. D.B. Watson, and I.P. Milner, Autonomous and parallel operation of self-excited induction generators, *International Journal of Electrical Engineering Education,* Vol. 22, 1985, pp. 365-374.
61. A.H. Al-Bahrani, and N.H. Malik, Voltage control of parallel operated self-excited induction generators, *IEEE/PES Summer Meeting,* Seattle, Paper No. 92, SM 546-6 EC, 1992.

62. C. Chakraborty, M.Ishida, S.N. Bhadra, and A.K. Chattopadhyay, Analysis of parallel-operated self-excited induction generators, *IEEE Transactions on Energy Conversions*, Vol. 14, No.2, June 1999, pp. 209-216.
63. Yun Lei, Graeme M. Burt, and Adam Dysko, Analysis of parallel-operated single-phase self-excited induction generators, *CIRED 19th International Conference on Electricity Distribution*, Vienna, 21-24 May 2007, Paper 0454.
64. A.H.Albahrani, and N.H. Malik, Voltage control of parallel operated self-excited induction generators, *IEEE Transactions on Energy Conversions*, Vol. 8, No. 2, June 1993, pp. 236-242.

BIOGRAPHIES

Lalit Goyal was born in Jaipur in the Rajasthan, India, on June 18, 1977. He studied at Govt. College of Engineering and Technology (CTAE), Udaipur and received the electrical engineering degree from Maharana Pratap University, of Agriculture and Technology,Udaipur, India in 2002. He is pursuing M.Tech. (Research) from Jagannath University,Jaipur. His employment experience included the Rajasthan Rajya Vidhyut Prasaran Nigam Ltd. His special fields of interest are Special Protection Scheme in Power System, Power Transients.

Om Prakash Mahela was born in Sabalpura in the Rajasthan, India, on April 11, 1977. He studied at Govt. College of Engineering and Technology (CTAE), Udaipur and received the electrical engineering degree from Maharana Pratap University of Agriculture and Technology,Udaipur, India in 2002. He is pursuing M.Tech. (Research) from Jagannath University,Jaipur. His employment experience included the Rajasthan College of Engineering and Technology, Jaipur, the Rajasthan Rajya Vidhyut Prasaran Nigam Ltd. His special fields of interest are transmission and distribution (T&D) grid operations, Power Electronics in Power System, Power Quality and Load Forecasting. Mahela received University Rank certificate from MPUAT, Udaipur, in 2002.

Sunil Goyal was born in Alwar, Rajasthan, India, on June 25, 1976. He received the B.E. Degree in Electrical Engineering from Malviya National Institute of Technology (formerly known as MREC), Jaipur in 1998. He received M.E. (power system) from MNIT, Jaipur in 2000. He is pursuing Ph.D. from Rajasthan Technical University, Kota. His employment experience included the MNIT (Guest Faculty), Institute of Engineering & Technology (IET), Alwar, Gyan Vihar School of Engineering & Technology, Jaipur, and Apex Institute of Engineering & Technology, Jaipur. His special fields of interest are Electrical Power System, Electrical Machines, Isolated Power Generators, Wind and Micro Hydro Power Generation, efficient electric energy utilization.