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Self-excited induction generator research—a survey

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Abstract

The increasing importance of fuel saving has been responsible for the revival of interest in so-called alternative source of energy. Thus, the drive towards the decentralization of power generation and increasing use of non-conventional energy sources such as wind energy, bio-gas, solar and hydro potential, etc. has become essential to adopt a low cost generating system, which is capable of operating in the remote areas, and in conjunction with the variety of prime movers. With the renewed interest in wind turbines and micro-hydro-generators as an alternative energy source, the induction generators are being considered as an alternative choice to the well-developed synchronous generators because of their lower unit cost, inherent ruggedness, operational and maintenance simplicity. The induction generator's ability to generate power at varying speed facilitates its application in various modes such as self-excited stand-alone (isolated) mode; in parallel with synchronous generator to supplement the local load, and in grid-connected mode. The research has been underway for the last three decades 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 to feed the power to remote locations and far flung areas, where extension of grid is economically not feasible. This paper, therefore, reviews the progress made in induction generator particularly, the self-excited induction generator (SEIG) research and development since its inception. Attempts are made to highlight the current and future issues involved in the development of induction generator technology for its large-scale future applications.

Keywords: Induction generator; Renewable energy source; Voltage and frequency regulator; Self-excited induction generator; Mini-hydro and wind energy

1. Introduction

The increasing concern for the environment and resources has motivated the world towards rationalizing the use of conventional energy resources and exploring the non-conventional energy sources to meet the ever-increasing energy demand. A number of renewable energy sources like mini/micro hydro, wind, solar, industrial waste, geothermal, etc. were studied. 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-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.

Traditionally, synchronous generators have been used for power generation but induction generators are increasingly being used these days because of their relative advantageous features over conventional synchronous generators. These features are brush less and rugged construction, low cost, maintenance and operational simplicity, self-protection against faults, good dynamic response, and capability to generate power at varying speed. The later feature facilitates the induction generator operation in stand-alone/isolated mode to supply far flung and remote areas where extension of grid is not economically viable; in conjunction with the synchronous generator to fulfill the increased local power requirement, and in grid-connected mode to supplement the real power demand of the grid by integrating power from resources located at different sites.

A detailed study of the performance of the induction generator operating in the above referred modes during steady-state and various transient conditions is important for the optimum utilization of its advantageous features. The analysis of steady-state performance is important for ensuring good quality power and assessing the suitability of the configuration for a particular application, while the analysis during transient conditions helps in determining the

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induction generator technology for electric power generation utilizing non-conventional energy resources.

References

[1] E.D. Basset, F.M. Potter, Capacitive excitation for induction generator, AIEE Trans. (Elect. Eng.) 54 (1935) 540–545.
[2] C.F. Wagner, Self excitation of induction motors, AIEE Trans. (Elect. Eng.) 58 (1939) 47–51.
[3] J.E. Barkle, R.W. Ferguson, Induction generator theory and application, AIEE Trans. (Elect. Eng.) 73 (1954) 12–19.
[4] B.T. Ooi, R.A. David, Induction generator/synchronous condenser system for wind turbine power, IEE Proc. 126 (1) (1979) 69–74.
[5] H.C. Stanley, An analysis of induction machine, AIEE Trans. 57 (1938) 751–757.
[6] P.C. Krause, C.H. Thomas, Simulation of symmetrical induction machinery, IEEE Trans. Power Apparatus Syst. 84 (11) (1965) 1038–1053.
[7] A. Alexandrovitz, D. Katz, Analysis of transient phenomena in three-phase induction motor represented in phase axes by digital simulation, Electric Machines Electromech. 17 (1982) 305–324.
[8] I. Colak, S.D. Garvey, M.T. Wright, Simulation of induction machines using phase variables and explicit inverse inductance matrix, Int. J. Electrical Eng. Educ. 32 (1995) 354–365.
[9] V. Donescu, A. Charelte, Z. Yao, V. Rajagopalan, Modelling and simulation of saturated induction motors in phase quantities, IEEE Trans. Energy Conversion 14 (3) (1999) 386–393.
[10] P.C. Krause, Analysis of Electrical Machinery, McGraw-Hill, New York, 1986.
[11] R.J. Lee, P. Pillay, R.G. Harley, D–Q reference frames for the simulation of induction motors, Electric Power Syst. Res. 8 (1984) 15–26.
[12] C.S. Moo, C.C. wei, C.L. Huang, C.T. Liu, Hybrid model for dynamic simulation of solid-state controlled induction machines, Electric Machines Power Syst. 17 (1989) 269–282.
[13] J.A.A. Melkebeek, D.W. Novotny, Small signal dynamic analysis of regeneration and self-excitation in induction machines, Electric Machines Power Syst. 8 (1983) 259–280.
[14] O. Wasynczuk, Y.M. Diao, P.C. Krause, Theory and comparison of reduced order models of induction machines, IEEE Trans. Power Apparatus Syst. 104 (3) (1985) 598–606.
[15] C.T. Liu, W.L. Chang, A generalized technique for modeling switched controlled induction machine circuits, IEEE Trans. Energy Conversion 7 (4) (1992) 168–179.
[16] S.S. Murthy, O.P. Malik, A.K. Tandon, Analysis of self excited induction generators, IEE Proc., Generation, Transm. Distribution 129 (6) (1982) 260–265.
[17] A. Al-Jabri, Direct evaluation of output frequency and magnetizing reactance of three-phase isolated self-excited induction generators, IEEE Trans. Energy Conversion 5 (2) (1990) 350–357.
[18] T.F. Chan, Steady-state analysis of self-excited induction generator, IEEE Trans. Energy Conversion 9 (2) (1994) 288–296.
[19] X.S. Chen, A.J. Flechsig, C.W. Pang, L.M. Jhuang, Digital Modeling of an Induction Generator, in: Proceedings of the IEE International Conference on Advances in Power System Control, Operation and Management, IEE Hong Kong Centre, 1991, pp. 720–726.
[20] S.P. Singh, B. Singh, M.P. Jain, A new technique for the analysis of self excited induction generator, Electric Machines Power Syst. 23 (6) (1995) 647–656.
[21] J.M. Elder, J.T. Boys, J.L. Woodward, The process of self excitation in induction generators, IEE Proc. Electric Power Applic. 130 (2) (1983) 103–108.
[22] L. Quazene, G. Mc Pherson Jr., Analysis of the isolated induction generators, IEEE Trans. Power Apparatus Syst. 102 (8) (1983) 2793–2798.
[23] N.H. Malik, S.E. Haque, Steady-state analysis and performance of an isolated self excited induction generator, IEEE Trans. Energy Conversion 1 (3) (1986) 134–139.
[24] S.M. Alghuwainem, Steady-state analysis of an induction generator self excited by a capacitor in parallel with saturable reactor, Electric Machines Power Syst. 26 (1998) 617–625.
[25] S.M. Alghuwainem, Steady-state analysis of an isolated self excited induction generator driven by regulated and unregulated turbines, IEEE Trans. Energy Conversion 14 (3) (1999) 718–723.
[26] N. Ammasaigounden, M. Subbiah, M.R. Krishnamurthy, Wind driven self excited pole changing induction generators, IEE Proc. Electric Power Applic. 133 (5) (1986) 315–321.
[27] T.F. Chan, Capacitance requirements of self excited induction generators, IEEE Trans. Energy Conversion 8 (2) (1993) 304–311.
[28] T.F. Chan, Self regulated induction generators driven by regulated and unregulated turbibes, IEEE Trans. Energy Conversion 11 (2) (1996) 338–343.
[29] N.H. Malik, A.A. Mazi, Capacitance requirements for isolated self excited induction generators, IEEE Trans. Energy Conversion 2 (1) (1987) 62–69.
[30] S.S. Murthy, B.P. Singh, C. Nagamani, K.V.V. Satyanarayana, Studies on the use of conventional induction motors as self excited induction generators, IEEE Trans. Energy Conversion 3 (4) (1988) 842–848.
[31] Y.H.A. Rahim, A.L. Mohamdien, A.S. Al-Khalaf, Comparison between the steady-state performance of self excited reluctance and induction generators, IEEE Trans. Energy Conversion 5 (3) (1990) 519–525.
[32] S. Rajakaruna, R. Bonert, A technique for the steady-state analysis of a self excited induction generator with variable speed, IEEE Trans. Energy Conversion 8 (4) (1993) 57–761.
[33] Y. Uctug, M. Demirekler, Modelling, analysis and control of a wind turbine driven self excited induction generator, IEE Proc. Generation, Transm. Distribution 135 (4) (1988) 268–275.
[34] S.S. Yegnanarayanan, V.J. Johnny, Contributions to the steady-state analysis of wind turbine driven self excited induction generators, IEEE Trans. Energy Conversion 1 (1) (1986) 169–176.
[35] A. Al-Jabri, A.I. Alolah, Limits on the performance of the three-phase self excited induction generators, IEEE Trans. Energy Conversion 5 (2) (1990) 113–131.
[36] F.P. Demellow, G.W. Walsh, Reclosing transients in induction motors with terminal capacitors, AIEE Trans. (Elect. Eng.) 80 (1961) 1206–1213.
[37] J. Reynaud, P. Pillay, Reclosing transients in induction machines including the effect of saturation of magnetizing branch and a practical case study, IEEE Trans. Energy Conversion 9 (2) (1994) 383–389.
[38] E. Levi, Modelling of saturated induction machines using flux linkages as state variables, in: Proceedings of the International Power Engineering Conference IPEC'95, Singapore, 1995, pp. 533–538.
[39] J.A.A. Melkebeek, Magnetizing field saturation and dynamic behavior of induction machines. Part I. Improved calculation method for induction machine dynamics. Part II. Stability limit of voltage fed induction motor and self excited generator, IEE Proc. Electric Power Applic. 130 (1) (1983) 1–17.
[40] P. Vas, K.E. Hallenius, J.E. Brown, Cross saturation in smooth air gap electrical machines, IEEE Trans. Energy Conversion 1 (1) (1986) 103–106.
[41] L. Shridhar, B. Singh, C.S. Jha, Transient performance of the self regulated short shunt self excited induction generator, IEEE Trans. Energy Conversion 10 (2) (1995) 261–267.
[42] E. Levi, V. Vuckoid, Magnetizing curve representation methods in digital simulation of induction machine dynamics, Int. J. Modelling Simulation 10 (2) (1990) 52–56.
[43] E. Levi, Application of current space model in analysis of saturated induction machine, Electric Power Syst. Res. 31 (1994) 203–216.

[44] E. Levi, Analytical approach to main flux saturation modeling in d–q axis model of induction machine, IEEE Trans. Energy Conversion 10 (3) (1995) 305–313.
[45] E. Levi, Impact of cross saturation on accuracy of saturated induction machine model, IEEE Trans. Energy Conversion 12 (3) (1997) 211–216.
[46] Y.W.E. Levi, Modelling and simulation of a stand alone induction generator with rotor flux oriented control, Electric Power Syst. Res. 46 (1998) 141–150.
[47] H. Frank, B. Landstorm, Power factor correction with thyristor controlled capacitors, ASEA J. 44 (1971) 180–184.
[48] M.B. Brennen, A. Abbandanti, Static exciters for induction generators, IEEE Trans. Ind. Applic. 13 (5) (1977) 422–428.
[49] A.E. Hammad, R.M. Mathur, A new generalized concept for the design of thyristor phase controlled VAR compensator, IEEE Trans. Power Apparatus Syst. 98 (1979) 219–231.
[50] S.S. Murthy, O.P. Malik, P. Walsh, Capacitive requirements of self excited induction generator to achieve desired voltage regulation, in: Proceedings of the IEEE, Industrial and Commercial Power System Conference, Milwaukee, 1983.
[51] E. Bim, J. Szajner, Y. Burian, Voltage compensation of an induction generator with long shunt connection, IEEE Trans. Energy Conversion 10 (3) (1995) 305–313.
[52] R. Bonert, S. Rajakaruna, Self excited generator with excellent voltage and frequency control, IEE Proc. Generation, Transm. Distribution 145 (1) (1998) 33–39.
[53] T.J. Hammons, S.C. Lai, Voltage dip due to direct connection of induction generator in low head hydro electric systems, IEEE Trans. Energy Conversion 9 (3) (1994) 460–465.
[54] P. Freere, Electronic load/excitation controller for a self excited squirrel cage generator micro hydro scheme, IEE Conf., Paper 241 (1991) 266–270.
[55] L. Wang, J.Y. Su, Effect of long shunt and short shunt connections on voltage variations of a self excited induction generator, IEEE Trans. Energy Conversion 12 (4) (1997) 368–374.
[56] M.A. El-Sharkawi, S.S. Venkata, T.J. Williams, N.G. Butler, An adaptive power factor controller for three-phase induction generators, IEEE Trans. Power Apparatus Syst. 104 (7) (1985) 1825–1851.
[57] R.K. Mishra, B. Singh, M.K. Vasantha, Voltage regulators for self excited cage induction generators, Electric Power Syst. Res. 24 (1992) 75–83.
[58] S.P. Singh, B. Singh, M.P. Jain, Performance characteristics and optimum utilization of a cage machine as capacitor excited induction generator, IEEE Trans. Energy Conversion 5 (4) (1990) 679–684.
[59] L. Shridhar, B. Singh, C.S. Jha, B.P. Singh, S.S. Murthy, Selection of capacitors for the self regulated short shunt self excited induction generator, in: Proceedings of the IEEE Power Engineering Society Winter Meetings, 93 WM 226-1EC, 1993, pp. 1–7.
[60] O. Ojo, Performance of self excited single phase induction generators with short shunt and long shunt excitation connections, IEEE Trans. Energy Conversion 11 (3) (1996) 477–482.
[61] O.P. Malik, D. Divan, S.S. Murthy, T. Grant, P. Walsh, A solid state voltage regulator for self excited induction generators, in: Proceedings of the IEEE Industrial and Commercial Power System Conference, Milwaukee, 1983.
[62] J.M. Elder, J.T. Boys, J.L. Woodward, Self excited induction generator as a small low cost generator, IEE Proc. Generation, Transm. Distribution 131 (2) (1984) 3–40.
[63] R. Bonert, G. Hoops, Stand alone induction generator with terminal impedance controller and no turbibe controls, IEEE Trans. Energy Conversion 5 (1) (1990) 28–31.
[64] J.M. Elder, J.T. Boys, J.L. Woodward, Integral cycle control of stand alone generators, IEE Proc. Generation, Transm. Distribution 132 (2) (1985) 57–66.
[65] D. Henderson, An advanced electrical load governor for control of micro hydro electric generator, IEEE Trans. Energy Conversion 13 (3) (1998) 300–304.
[66] S. Kormilo, P. Robinson, Electronic control of small hydroelectric schemes using a microcomputer, IEE Proc. Part E 131 (4) (1984) 132–136.
[67] W.M. Stein, J.F. Manwell, J.G. McGowan, A power electronic based power shedding control for wind/diesel systems, Int. J. Ambient Energy 13 (2) (1992) 65–71.
[68] D.B. Watson, R.M. Watson, Microprocessor control of a self excited induction generator, Int. J. Electrical Eng. Educ. 22 (1985) 69–82.
[69] J.L. Woodward, Appropriate speed and frequency control of micro hydro plants, in: Proceedings of the Workshop on Microhydro Installati, Papua, New Guinea.
[70] N. Mohan, T.M. Undeland, W.P. Robinson, Power Electronics-Converters, Application and Design, Wiley, second ed., 1995.
[71] P.C. Krause, Analysis of Electrical Machinery, McGraw-Hill, New York, 1987.
[72] H.O. Nush, The truth about standby generator excitation support system, IEEE Trans. Ind. Applic. 26 (4) (1990) 726–734.
[73] L. Shridhar, B. Singh, C.S. Jha, B.P. Singh, Analysis of self excite induction generator feeding induction motor, in: IEEE Power Engineering Society Summer Meetings, 93 SM 453-1EC, 1994, pp. 1–7.
[74] L.B. Shilpakar, B. Singh, B.P. Singh, Transient analysis of three-phase induction generator self excited with C–2C configuration for balanced operation under single phase loading, in: Proceedings of the National Power System Conference, IIT Kanpur, India, 1996.
[75] T. Erisa, S. Takata, R. Ueda, Dynamic performance of self excited induction generator with voltage controller, IEEE Trans. Ind. Applic. 2 (1980) 508–513.
[76] A.A. Mahmould, T.H. Ortmeyer, R.G. Harley, C. Calabrese, Effects of reactive compensation on induction motor dynamic performance, IEEE Trans. Power Apparatus Syst. 99 (1980) 841–846.
[77] S.E.M. DeOdiveira, Starting transients of saturated induction motors with capacitors on supply, IEEE Trans. Energy Conversion 1 (3) (1986) 205–210.
[78] C.G. Grantham, D. Sutanto, B. Mismail, Steady-state and transient analysis of self excited induction generator, IEE Proc. Electric Power Applic. 136 (2) (1989) 61–68.
[79] C.S. Demoulias, P.S. Dokopoulos, Transient behavior and self excitation of wind driven induction generators after its disconnection from the power grid, IEEE Trans. Energy Conversion 5 (2) (1990) 272–278.
[80] M.G. Loannides, Doubly fed induction machine state variable model and dynamic response, IEEE Trans. Energy Conversion 6 (1) (1991) 56–61.
[81] K.E. Hallenius, P. Vas, J.E. Brown, The analysis of a saturated self excited asynchronous generator, IEEE Trans. Energy Conversion 6 (2) (1997) 336–344.
[82] M.G. Loannides, A new approach for the prediction and identification of generated harmonics by induction generators in transient state, IEEE Trans. Energy Conversion 10 (1) (1995) 118–125.
[83] C.T. Liu, W.L. Chang, Transient simulation technique for studies of self excited generator systems, Electric Power Syst. Res. 33 (1995) 101–109.
[84] C.S. Demoulias, P.S. Dokopoulos, Electrical transients of wind turbines in a small power grid, IEEE Trans. Energy Conversion 11 (3) (1996) 636–642.
[85] L. Wang, C.H. Lee, A novel analysis of the performance of an isolated self excited induction generator, IEEE Trans. Energy Conversion 12 (2) (1997) 109–117.
[86] L. Wang, C.H. Lee, Dynamic analysis of parallel operated self excited induction generators feeding an induction motor load, IEEE Trans. Energy Conversion 14 (3) (1999) 479–485.
[87] D.D. Robb, P.C. Krause, Dynamic simulation of generator faults using combined abc and 0dq variables, IEEE Trans. Power Apparatus Syst. 94 (6) (1975) 2084–2091.

[88] G.G. Richard, O.T. Tan, Simplified models for induction machine transients under balanced and unbalanced conditions, IEEE Trans. Ind. Applic. 17 (1) (1981) 15–21.
[89] L. Wang, J.Y. Su, Dynamic performance of isolated induction generator under various loading conditions, IEEE Trans. Energy Conversion 14 (1) (1999) 93–100.
[90] S.K. Jain, J.D. Sharma, S.P. Singh, Transient performance of three-phase self excited induction generator during balanced and unbalanced faults, IEE Proc. Generation, Transm. Distribution 149 (1) (Jan 2002) 50–57.
[91] D.N.J. Limebeer, R.G. Harley, Subsynchronous resonance of single cage induction motor, in: IEE Proceedings of the Electric Power Applications, vol. 128, no. 1, 1981.
[92] W.H. Kershing, W.H. Phillips, Phase frame analysis of the effects of voltage unbalance on induction machine, IEEE Trans. Ind. Applic. 33 (2) (1999) 415–420.
[93] W.C. Lin, C.E. Lin, C.L. Huang, S.L. Chen, Y.T. Wang, Prediction of transient performance of induction machine, Electric Power Syst. Res. 10 (1986) 241–246.