Methods of Performance Evaluation of Induction Generators

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Abstract: To meet the ever growing power demand the utility is adding more alternatives of power generation with nonconventional energy resources like solar energy, wind energy, biomass and small hydro plants. To provide electricity to remote areas, a Self Excited Induction Generator (SIEG) is found to be functional for power generation from these non conventional energy resourses. Apart from the various advantages of SEIG, it suffers from major problem of poor voltage regulation and variable frequency. To overcome these vital issues an analysis of steady state behavior of this generator is essential under different operating conditions. In this paper, a brief overview of SEIG, different modeling techniques, performance evaluation and review of estimation of capacitance to meet the reactive power requirement has been included.

Keywords*: SEIG, Magnetizing reactance, Generate frequency, Capacitance Requirement*

I. INTRODUCTION

The rapid reduction in fossil fuels, global warming, and problems in extending existing grids in remote areas has compelled the utility to access and utilize the locally available renewable energy resources for power generation [1]. It has been seen that induction generator is the appropriate machine for these types of distributed power generations. Induction generator has low cost, brushless construction, reduced size, self short circuit protection, absence of DC supply for excitation and no synchronization problem. When induction motor is connected to constant voltage and constant frequency source and made to run above its synchronous speed, it will start working as induction generator. This induction generator works in either grid connected mode or isolated mode. In grid connected mode, the terminal voltage and frequency is fixed and needed exciting current and reactive power is provided by the grid. Therefore for this type of operation of machine the performance evaluation is simple and easy. The frequency of generated voltage in this type of induction generator is same to that of main supply. The second mode of operation of induction generator is isolated mode or capacitor connected mode in which machine is not connected to any grid. In this mode the reactive power requirement of machine is met by connecting the capacitors to the stator terminals of induction machine [2-3]. This type of capacitor connected generator is called Self Excited Induction Generator (SEIG). In SEIG the frequency of voltage is not fixed, but depends upon various variable parameters such as, size of capacitors, connected load and speed of prime mover. The magnetizing requirement of the induction generator is met by connecting the capacitor bank to the stator terminals of SEIG. Initially on starting the motor, the residual magnetism in the rotor induces a very small voltage across the stator terminals. For the flow of capacitive current in the circuit a sufficient induced voltage is required and due to this capacitive current, magnetic flux is produced which further helps the residual magnetism in the rotor to increase. This increased flux leads to further increase in induced voltage and again increases the capacitive current. The induced voltage will keep on rising till the saturated state of machine is reached [5]. Thus for the occurrence of self excitation in SEIG following conditions are necessary:

- Residual magnetism must be there in rotor circuit
- Connected Capacitor must be of suitable size or rating

The residual magnetism is the inherent character of every machine but determination of suitable capacitance as per the machine requirements is a matter of research for various researchers [6]. As self excited mode of generator has unknown terminal voltage and frequency and its magnetizing reactance also changes with changed terminal voltage and frequency, thus it is necessary to evaluate the performance of SEIG to observe its behavior under varying conditions as otherwise it leads to poor voltage regulation [7]. This paper deals with the analysis techniques for calculation of magnetizing reactance and generated frequency and subsequently determination of terminal voltage and output power

II.PERFORMANCE CHARACTERISTICS OF SEIG

The performance characteristics of Self excited induction generator [6-7] depend upon following:

- **Dependence on parameters**: The performance of SEIG depend upon operating voltage of machine, operating temperature of machine, rated power and power factor. All other machine parameters also directly affect the system performance.

- **Dependence upon connected capacitance**: For standalone operation capacitor bank is necessary for excitation .The scheme of capacitor connected (star or delta) has direct impact on the performance of machine.

- **Load parameters**: Type of load connected, generated harmonics , starting torque , power factor and current has direct effect on the performance of machine

- **Prime move**: SEIG performance is affected on which source it is connected i.e source is hydro, wind, biomass or combination of any of these.

III.MODELING OF INDUCTION GENERATOR

For performance analysis of SEIG, the equivalent circuit and mathematical modeling are the necessary steps. Different models have been proposed by various researches and discussed briefly:

- **DQ reference model**: In this model [8], dynamic model of three phase induction machine is developed in which the three phases to two conversions is done using park transformation then all the equations have been developed .The open circuit and short circuit test are used to determine the parameters of equivalent circuit. By this d–q arrangement of an induction generator, the transient performance of generator and unbalancing in operation are also analyzed. In this model the wound rotor induction machine is used therefore no variation of rotor parameters are considered with the change in speed for an analysis.
- **Loop impedance model:** In this model [9-10-11] the equivalent circuit is solved by considering impedance of circuit to be zero. All the parameters are taken in per unit in this case. This model is further used in parallel operation and for studying the effect of harmonics on induction generator.
- **Admittance based model**: This model [12] is a single phase equivalent circuit model in which balanced resistive load is connected. In this circuit capacitive reactance is assumed to be varied with magnetic saturation and all other parameters are assumed to be constant. In addition to this effect of core loss and harmonics are ignored. Total admittance is calculated at each node of the circuit and then added. After this the admittance equated to zero for finding the generated frequency along with magnetizing reactance.
- **Operational circuit based model**: This is generalized operational equivalent circuit of self excited induction machines [11]. In this circuit all parameter except magnetizing reactance is assumed to be constant. MMF space harmonics and time harmonics in the induce voltage and current wave forms are ignored. In this circuit for finding Generated frequency the parameter F=Jp is introduced,

  Where, $p = \frac{1}{\omega}\frac{d}{dt}$ and $\omega = 2\pi f$

  After that the solution of fifth order polynomial is done to find the value of frequency and magnetizing reactance.
- **Power equation based model**: All model previously developed by researchers does not take care of multi machine system. The is developed by Bansal et.al [12,13,14] is called as power equation model of SEIG. This model is used in multi machine hybrid system in which every induction and synchronous generators is connected.
- **Impedance model with active voltage source:** It model was most innovative model of SEIG [15]. In this model of SEIG the active voltage source along with equivalent circuit is used. This equivalent circuit justifies the operation of induction machine as generator. Various individual uses this model currently to review the performance of SEIG under variable speed and load conditions.

IV.DETERMINATION OF MACHINES PARAMETERS FOR PERFORMANCE EVALUATION OF SEIG

Although the value of all important parameters are there on nameplate of the machine, but remaining parameters which are used in evaluating the performance of self excited induction generator can be find by performing following tests on induction machine. The various parameters needed for performance calculation are stator resistance and leakage reactance, rotor resistance and leakage reactance referred to stator and un-saturated magnetizing reactance. These parameters are computed using standard methods. But to analyze the complete performance of SEIG, saturated magnetizing reactance 'Xm' and air gap voltage 'E' are also required. For finding all these parameters following test are conducted.

- **No load test:** From this test, power, current and voltage may be measured and with the help of these values the no load losses, no load reactance and magnetizing reactance can be calculated.
- **Load test:** With this test the torque, input power, output power, input power factor and slip can be calculated.
- **Synchronous run test:** From this test magnetization curve is drawn, from which relationship between air gap voltages and magnetizing reactance is determined.

V.METHODS OF PERFORMANCE EVALUATION

After solving the equivalent circuit by any one model, a common point is that the performance of self excited induction generator mainly depends upon magnetizing reactance and generated frequency which are unknown parameters. On solving the equivalent circuit by above models a non linear equation is formed. This equation is solved in MATLAB to find its real and imaginary part. Symbolic math tool box command is used to separate this equation. With this command real and imaginary value of equation can be finding easily. After getting desired results in symbolic math these non linear equations are again solved to get the desired value of magnetizing reactance and generated frequency. Various studies have done in past to solve these two non linear equations and brief review of these technique is discussed below.

- **Newton Raphson Method:** S. S. Murthy in [18] explained Newton Raphson technique which is iterative technique because these non-linear equations are not simply solvable. This technique is very good in solving two nonlinear equations and gives answer in four to five iterations using Jacobian matrix. Starting values of unknown parameters i.e magnetizing reactance and generated frequency are assumed to be Xm(unsaturated) and supply frequency(v) for iterations. In this method the iterations will be done until convergence is reached.
- **Pattern Search:** PS [19] is another way of direct calculating technique of finding unknown parameter. These methods uses direct assessment of objective function and do not make use of approximate values. This technique searches the collection of point in the region of the existing point or actual point. This search continuous till the value of objective function is less than the value of finding. This technique also gives comparable results of magnetizing reactance and generated frequency of SEIG.
- **Quassi Newton**: This method [**20**] was the foremost strong and valuable algorithms which uses unconstrained optimism problem. It works on subsequent set of thoughts to find the unknown parameters till converge is reached.
- **Artificial Bee Colony:** The artificial bee colony [22] method supported forage activities of bees regarding optimization issues for judging the performance of self excited induction generator. The value of impedance or admittance is taken to be zero like all another techniques. This same equation can be treated as optimization trouble in this method also.
- **Genetic Algorithm:** Genetic algorithm (GA) **[23]** is one of the improvement methodologies that rely on process of natural selection. This algorithm repeatedly modifies the population of individual solution. GA selects random value from population and uses this value for new generation. Over successive iteration population moves towards optimum solution. The unknown parameters are determined by optimizing the fitness function which is our non linear equation.
- **Particle Swarm Optimization:** The technique **[24]** has proposed to solve problems based on user friendly software. This technique is different from conventional optimization methods proposed by Kennedy. This PSO uses the mechanism of swarm behavior in birds flocking and fish schooling to help the particles to search for optimal solutions. This particle swarm optimization algorithm is better than the above explained GA technique. It is fast in solving non linear equations, easy implementation, few parameters to adjust, computational time is less and less memory required.
- **Artificial Neural Network:** At present, Artificial Neural Networks (ANN) techniques **[25-26]** are towards great importance in field of engineering. These are the computational tools adopted by human brain. These involve two components i.e. neurons and synapses (weights). Neurons are present in different layers. Analysis using ANN's does not involve any cumbersome calculations as in conventional methods. When an input is applied in the network, based on the given data it will give training parameters to get the accurate results as output.
- **Fuzzy Logic:** Fuzzy logic **[27]** is rule base technique used to find the unknown parameters. In fuzzy system inputs are taken as parameters of the machine and outputs are taken as unknown variables. After selecting the range of all parameters the rules are made in fuzzy logic system which is used to calculate the exact value of unknown parameters.

V1.REVIEW ON ESTIMATION OF CAPACITANCE REQUIREMENT

After the determination of magnetizing reactance and generated frequency the analysis of induction generator become easy as these findings are further used for calculation of capacitance requirement, output power and terminal voltage [28-31]. Most of researches, regarding minimum value of capacitance are by using MATLAB programming, MATLAB GUI and simulations in

MATLAB. N. Mahato used an algorithmic in MATLAB was developed to find the value of optimum capacitors and power output in a single phase self excited induction generator. In this research the machine is fed with both inductive and capacitive loads. Closed loop impedance technique is used to solve the equivalent circuit first and then sequential unconstrained minimization technique is used for optimization to find the value of capacitance [28]. In another technique by S.S Murthy, [29] a MATLAB graphical program based methodology is used for the analysis of induction generator and the requirement of capacitance is estimated under different running conditions. It predicts the performance of SEIG with different type of prime mover types like small hydro turbine, oil and bio engines, wind turbine etc. The mathematical model also been simulated in MATLAB Graphical User Interface. MATLAB coding technique by M. Faisal Khan [30] is another technique for analysis of SEIG. Genetic Algorithmic is global search heuristics technique which is being programmed by Alok Kumar Mohanty [31] is another technique for deciding actual values to capacitance. Genetic algorithm technique uses inheritance, selection, crossover and mutation. K.S. Sandhu [32] uses the Artificial Neural Network technique to figure out the capacitance demand. In this technique no assumptions are made but each parameter is trained to get accuracy in results. Pulse Width Modulated (PWM) technique by A.M. Eltamaly [33] gives the direct formula for capacitance needed for excitation. Later on fuzzy technique is additionally used to determine the capacitance demand using mathematical logic technique within which totally different rules are created to seek out the value of magnetizing reactance, generated frequency and after that capacitance needed to keep up constant air gap voltage is additionally verified using this technique.

VII.CONCLUSION

Induction generator owing to its numerous advantages is gaining importance, but it has been seen that due to dependence on various parameters its study is getting complicated. With the use of soft computing tools the analysis of SEIG become easy and less time consuming. It is a common conclusion of various researches that by using a artificial intelligence techniques or optimization techniques the performance of any induction generator can be evaluated.

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