Review of Literature on Induction generators And Controllers for pico Hydro Applications

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Abstract

Operation of Induction motors as induction generators in grid connected and self excitation mode is well known. In many countries induction generators are used for electrical power generation by wind energy. Low cost, robustness and ease of maintenance are attractive features of induction generators. Even though these generators are used at some places for micro hydro power generation, very small scale generation known as pico hydro generation offers excellent opportunity for them. Slip ring induction motors are used for micro power generation and squirrel cage induction motors are used for pico power generation. These generators have an inherent problem of terminal voltage variation with increase in load. Several different types of controllers are developed and tested. This paper presents a review of literature related to the present status of research work on self excited induction generators (SEIG), their terminal voltage control strategies and their applications.

Key words- Dump load, Electronic controller, Self excited induction generator, Pico hydro generation,

INTRODUCTION

Many under developed and developing countries are currently facing shortage of electrical power. Conventional methods except hydro power generation employ various types of fossil fuels such as coal, gas and oil. In India 66 % of the electrical power generation is from thermal power stations by using coal, oil and gas, 3 % from nuclear, 11 % from renewable energy sources and 20 % of from hydro power generation [1]. It shows our dependence on fossil fuels. According to survey, these fuels are depleting at faster rate and becoming extinct, moreover the cost of these fuels is also increasing, and therefore in future we cannot depend on them. Hydro, wind and solar energy sources are renewable and abundantly available. Hydro power generation technique is well developed but these plants require huge capital, long term planning and large space. Due to these constraints there is not much increase in the capacity of large hydro power plants. On the other hand small size generating units can be installed where small waterfalls or flows are available. Use of induction generator can help in reducing the per unit cost and the total cost of the project. Such small scale power units are economical at locations where population is thin and transmission distribution costs are more. At many places water flows are available throughout the year. These water flows can be utilized for electric power generation. Moreover a hybrid system with hydro and solar power can be implemented. In India still there are many villages where electric power is not available.

Three phase or single phase induction motors can operate as induction generators when driven by external mechanical power and supplied with reactive power. These generators operate in two modes. When these generators are connected to supply grid they are called as grid connected induction generators and when they are not connected to supply grid, they are called as self excited induction generators (SEIG). These generators offer natural protection against over loads, short circuits; they are available in various ratings with low cost. Solid squirrel cage construction of the rotor helps in absorbing the sudden variations in the input speed. Self excited induction generators are used in wind power generation and micro hydro power plants.

SELF EXCITED INDUCTION GENERATORS

An induction motor can operate as an induction generator provided that there is residual magnetism present in the rotor and proper reactive power is supplied to it. The required reactive power is supplied by connecting capacitors of proper value to the motor terminals. For any given load, there is a maximum and a minimum value of capacitor which can excite the generator. Any capacitor beyond these two extremes cannot excite the generator. Estimation of terminal capacitors and their effect on the terminal voltage and frequency is explained by Ali M. Eltamaly using steady state model. A simple formula is developed by using nodal analysis. When an induction motor is connected to supply, it draws lagging current and the rotating magnetic field in the air gap induces emf in the rotor bars causing rotor current. The rotor current lags the air gap voltage. When the speed of the rotor is increased up to synchronous speed by external prime mover, the rotor current becomes zero. If the rotor speed is increased beyond synchronous speed, the direction of induced emf and current in the rotor changes. Stator current also changes its direction and the motor acts as a generator. Stator current has active and reactive components, and the reactive component is either supplied by connecting capacitors to generator terminals or from the supply system. Phasor diagram of the generator is shown in fig.1.

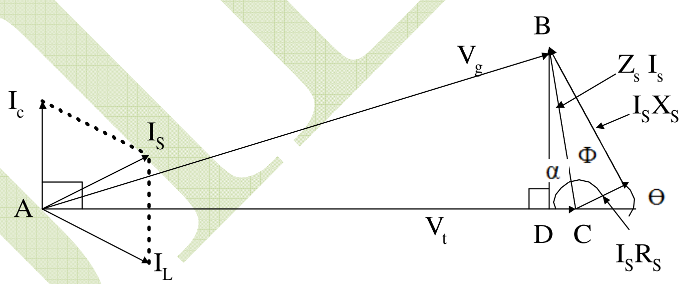

Fig. 1 Phasor diagram of induction generator

For simplification, only stator side is shown. V_t is the terminal voltage, I_L is the load current. I_C is the capacitor current. V_g is the generated voltage. In absence of external terminal capacitor, the generator draws reactive power from the grid. The standard equivalent circuit of a three phase induction generator which is used for steady state analysis is shown in fig. 2. It is drawn on per phase per unit at base frequency.

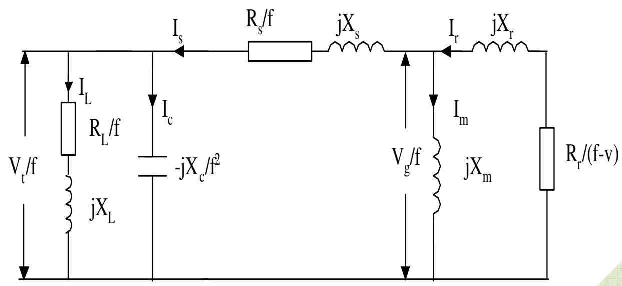

Fig.2 Per phase per unit equivalent circuit diagram of SEIG at base frequency

Impedance of the circuit shown in fig.2 is separated in to two sections. Z_1andZ_2. Where Z_1 is the impedance of the load-capacitor combination and Z_2 is the impedance of the generator. Voltage across load is V_t. Using loop analysis, product of total impedance and current I_s is zero.

$$Z_t \cdot I_s = 0 \quad (1)$$

When the generator excites, $I_s \neq 0$

$$\therefore Z_t = Z_1 + Z_2 = 0 \quad (2)$$

The real and reactive components of the impedances are combined and equated to zero. [2]. T.F. Chan presented a method by using nodal analysis of the equivalent circuit. He suggested that the value of magnetizing reactance and the combined reactance of load capacitor combination should be equal [3]. A.K. Al Jabri et al developed a simple formula to find the minimum capacitance for a given load directly [4]. Malik A.H. et al developed a formula from equivalent circuit to calculate the maximum and minimum values of terminal capacitance. The effects of terminal capacitance on frequency, terminal voltage and power output are also discussed [5]. Robert J. Harrington et al presented a simple method of capacitor estimation. In this method, one equation is formed from the conventional equivalent circuit. The equation is solved by using iterative method and frequency is calculated. The value of the capacitance is calculated from this frequency [6]. S. N. Mahato et al discussed the method of calculating terminal capacitor for a three phase induction generator used for feeding single phase load. The equivalent circuit is developed first, then the real and imaginary parts of circuit elements are equated to zero [7]. A three phase induction motor can operate as an induction generator in various configurations. The induction motor may be either delta or star connected. The capacitors can be connected in either star or delta across the three phase windings. Four different combinations are possible. One more type of configuration is C-2C. In this configuration, a three phase delta connected induction motor can be used as a single phase induction generator. A capacitor of value 'C' is connected across one of the windings and another capacitor of value '2C' is connected across another winding. J. B. Ekanayake discussed the operation of an induction generator in C-2C mode and presented a detailed analysis of it. A load equal to 80 % of three phase capacity of motor can be connected to one of the windings across which capacitor 'C' is connected. These generators can be used for Pico hydro generation [8].

While analyzing performance of an induction generator, it is necessary to develop a mathematical model of it. There are two types of models which are helpful in the analysis. The first one is simple and is called as a steady state model. It is developed from the equivalent circuit of the generator. The limitation of this model is that it cannot give clear idea about the behavior of the generator during dynamic changes. Second type of model is complex and called as dynamic model. It gives complete idea about steady state as well as transient behavior.

A.H. Al-Bahrani et al presented a detailed analysis of a three phase star or delta connected induction motor using a single capacitor for single phase load. It is stated that for a given capacitor value, there is a minimum speed for which the generator excites at no load. Delta connection of motor gives more current output at lower terminal voltage but the currents and voltages in delta or star connection are unbalanced [9]. M. H. Haque presented steady state analysis by using equivalent circuit in the form of P-Q load model and solving the equations using MATLAB software [10]. T. F. Chan presented an iterative technique of analysis which requires lesser calculations and is simple. Initially per unit frequency is assumed and other terms in the equation are calculated. After a few iterations, the final values can be found [11]. D. Seyoum et al presented analysis of an induction generator using SIMNON software. The terminal voltage and frequency depend on the load and the speed. There is a maximum and minimum speed at which the generator excites for a given value of capacitor and load. A dynamic model of induction generator is presented [12]. R. C. Bansal et al discussed the process of self excitation, voltage buildup, steady state and transient model and advantages of self excited induction generators over conventional alternators. Study on reactive power control and parallel operation of induction generators is also presented [13] [14]. Gurung K. et al presented method of symbolic computation by using MATLAB for steady state analysis. This method reduces the efforts of solving tedious calculations and is much faster [15]. S. P. Sing et al have given performance characteristics of a cage induction machine when operating as a self excited induction generator (SEIG). A capacitor bank is used for self excitation of the machine and to maintain its terminal voltage constant. The developed analytical technique is implemented to estimate the number of steps of switching capacitors for loading the machine while maintaining the terminal voltage within desired limits [16]. S.S. Murthy et al presented a method of steady state analysis by using graphical user interface tool in MATLAB. A program is developed for estimating various parameters avoiding tedious calculations and iterations to save time. In another paper analysis for unbalance loading conditions is presented by using symmetrical component method by using equivalent circuit [17-19]. Kinh D. Pham discussed issue of co generation, parallel operation of induction generator with grid and advantages of induction generator over conventional alternators [20]. E. D. Basset et al discussed the self excitation process of induction generator by using capacitors, D. Seyoum et al presented analysis of an isolated induction generator when loaded. Effect on operating frequency and generated voltage due to change in the operating slip is discussed. Effects of magnetizing inductance on self excitation are explained as it is the main factor that stabilizes the initial transients of generated voltage [21-22].

CONTROLLERS

Any induction generator whether single phase or three phase, in any configuration has one major problem of variation of terminal voltage and frequency during load changes. These variations are severe in absence of a controller and the generator may stop generating during sudden load variations. Various types of controllers are developed to maintain the terminal voltage and frequency within limit. Such controllers and their analysis is presented by many authors. Mainly the load on the generator is kept constant or the excitation capacitor current is controlled. In the first method, which is called as dump load control, a dummy resistive load equal to the full load capacity of the generator is parmanently connected to the generator terminals. This dummy load is controlled according to the external load variations so that the total load on the generator is always constant. This method is very simple. The main drawback of this method is that the generator is always loaded irrespective of consumer load. Chris Greacen explained this method [23].

T. Chandra Sekhar et al discussed various methods of voltage control. The reactive power required for induction generator in self excitation mode is supplied by a capacitor bank. Instead of switching the capacitors, their current is controlled by using different types of schemes, such as series capacitor control, thyristor controlled capacitor bank, Inductively loaded AC/DC converter, terminal voltage control using STATCOM, magnetic amplifier and electronic load controller [24].

Shashank Wankhede et al explained modelling of a controller using hysteresis current controlled inverter without requirement of a sensor for variable speed constant voltage operation of a self excited induction generator. Results of a prototype and simulation are presented [25-26]. Fuminobu Naito et al and Fransisco Danang Wijaya et al discussed methods such as static VAR compensation, shunt capacitor current control, and electronic load controller and presented analysis of a terminal voltage controller using micro power system simulator [27-28]. D. K. Palwalia et al presented design of a digital signal processor based dump load controller for single phase supply by using a three phase induction generator [29]. Woei-luen et al presented modeling, controller design and steady state analysis of SEIG for wind mills and simulation results of effects of various system disturbances on the dynamic performance of SEIG [30]. Dheeraj Joshi et al proposed a new method of terminal voltage control by using genetic algorithm and artificial neural network. Experimental and simulation results are presented [31]. Eduardo Sukez et al presented an analysis of voltage control when the generator is operating in the linear region of its magnetization curve. In this region, there is scope for increasing or decreasing the magnetization according to need. Only simulation results are presented [32]. Bhim Singh et al presented an analysis of voltage regulator using static compensator (STATCOM). In this method a current controlled voltage source inverter (CC-VSI) is used. Mathematical model and MATLAB simulation results are presented [33]. Mustafa A. A1-Saffar et al explained capacitor current control scheme using IGBTs as power switches. In this method, generator voltage and load current are sensed and fed to an electronic controller, which in turn operates the anti parallel IGBT switches. Switching losses are reduced by employing zero voltage switching [34].

APPLICATIONS

In India there is a huge gap between demand and supply of electric power. Every year this gap is widening and to cope up with the increasing demand, load shedding is often resorted to. Installation of new power plants require huge capital and land. Due to these constraints, pace of growth in generation is low. Many developing countries are facing this problem. Development on the renewable energy front is also very slow due to their pertinent issues. Small scale electrical power generation is becoming popular in many countries as it helps in reducing the cost of electricity, the stress on the main system and transmission distribution expenses to remote areas. Electric generation with capacity 5 Kw-100 Kw is classified as micro and below 5 Kw is classified as pico generation. Traditionally conventional permanent magnet alternators are in use for pico generation. But due to their obvious operational advantages and owing to availability of modern control techniques, induction generators are assuming significance. Induction generators employing slip ring induction motors are already in use for wind power generation in grid connected mode [35].

When an induction generator is not connected to supply grid, it is said to be operating in self excited mode. In this mode, normally small induction motors are used, and capacitors are connected to its terminals for the supply of required reactive power. These generators can be used for wind and picot hydro generation [36].

In India, small waterfalls and water flows at many places are found to be running throughout the year. If the height of water fall is more than 10 meters, it is possible to generate electricity by using micro turbines and small induction generators. Where more small water flows with lower head are available, the flow can be aggregated with minor civil construction and, electricity can be generated. For developing a Pico hydro generation unit, it is necessary to measure the head of water, its discharge or flow, suitable location for construction of a dam if necessary, selection of turbine and generator and their location etc. [37].

Small water turbines are now available in different sizes and there is a scope to select a proper turbine from available range. A substitute for turbine can be a centrifugal pump, which can be used as turbine with little modifications. The problem however is that the water pressure required for a pump to work as a turbine is high and this technology is not yet fully proven. Dr. Punit Singh et al presented a study conducted in Tanzania for 10 KW generation by using a pump as turbine [38]. D. A. Howey, presented a scheme of pico hydro generation by using a small propeller turbine. Instead of using an induction generator, he developed an axial flux permanent magnet alternator which was capable of developing a power of 200 watts at 230 volts [39]. Edward CG Ando et al, discussed a novel application of Pico hydro generation for telecommunication system. He presented a detailed economic analysis of the complete unit right from small dam up to the alternator [40]. Ahmed M.A. Haidar et al presented a case study of Pico hydro generation for domestic and commercial loads. They used a water pump as turbine and an alternator. MATLAB analysis of the unit is also presented. The output is used for charging storage batteries [41]. H. Zainuddin et al proposed a new idea of using the consumer water distribution network and installing small generating units in the path of water flow to charge storage batteries. They were able to generate electric power up to 1.2 Watts [42].

CONCLUSION

Current accute shortage of electrical power can be met to some extent by deploying small generating units on small water falls or small water flows, low power winds in decentralized mode to feed power to remotely located population throughout the year. These pico generating units are less expensive and can be afforded by individuals. Storage batteries can be charged for later use of the power and an inverter can supply the power at rated voltage and frequency.

Extensive research work is being done in many countries to develop alternative renewable energy sources and specially in the field of pico hydro generation. It is quite possible that in future we will witness many such units around us.

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