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Modelling of Wind/Micro Hydel Turbine driven Induction Generators for Distribution Load Flow Algorithms

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Abstract: Induction generators are very popular in Wind and small scale Hydro based generations which are available in distribution side. For such induction generators, this paper proposes two models which can be used for backward-forward sweep based radial load flow algorithm. The first model is developed using the solution of quadratic equation. In the second model, a methodology has been used which simplifies the induction generator into a two bus system such that the computation got reduced significantly. Using these models, reactive power drawn by the generator and sizing of capacitor to compensate the reactive power is calculated. The methodology is applied to a practical Indian distribution network and the results have been presented.

Keywords: Capacitor Sizing; Distributed Generation; Induction Generator Modelling; Reactive power compensation.

1. INTRODUCTION

Energy crisis and depletion of conventional energy sources are problems that people around the world are facing today. Due to these crisis, renewable energy sources are being integrated into the power network. Wind and Hydro energy sources are among them and these have fastest growing technology. Since wind and hydro energy potentials are distributed in different locations, the concept of dispersed generations are being utilised to overcome the deficiencies of conventional energy sources.

Induction generators are much popular for low and medium power generation in the distribution network (DN). This is mainly because of the low unit cost, less maintenance, ruggedness, self protection against faults, capability of generating power at varying speed etc. However it has certain drawbacks like reactive power consumption, poor voltage regulation etc. Thus the grid has to supply reactive power demand of the induction generator in addition to the load in order to consume the real power generated by this machine. This reduces the overall power factor of the network which will lead to the reduction of bus voltages and will increase the network losses. Therefore to improve power factor of the networks, reactive power compensation is required. By connecting suitable value of shunt capacitors at the point of common coupling (PCC), the reactive power consumption of generator from the grid can be reduced and the machine will operate in self excited mode. For designing such reactive power compensation, load flow analysis is essential for computing the power flows in all line sections. For distributions system, the conventional load flow algorithms like Fast Decoupled Load Flow which is popular in transmission cannot be used because of the high R/X ratio in the distribution systems. Various load flow algorithms developed in the literature by exploiting the specific features of the distribution system have been discussed by Srinivas (2000). Backward forward sweep method is one of the popular load flow techniques used in distribution systems. The earliest method in this category was proposed by Nagendra Rao and Prakasa Rao (1986) which fully exploits the radial feature of the network and considers all loads as constant power injections. In this scheme, the current flows in each line are accumulated in the backward sweep and after that the voltages at all buses are updated.

Induction generators cannot be directly incorporated in this kind of radial load flow algorithms. This is because the shaft power is specified using the turbine characteristics whereas the power injections on the PCC depends on the local terminal voltage. Eminoglu (2009) has explained the popular induction generator models available in the literature for obtaining the steady state solution of the network. A model which was proposed by Murthy et al. (1990) considers both the core loss and the magnetising component of the induction generator in addition to the other parameters of the machine. In this model, these shunt elements are inserted in between the rotor and stator components such that this consideration becomes realistic. Nagendra Rao and Deekshit (2005) used this model for computing the slip of the induction generator and using that the load flow solution was obtained. Feijoo and Cidras (2000) proposed a PQ model and a RX

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model for induction generators where only the magnetising component have been considered. This shunt element was lumped before the stator component which loses certain amount of accuracy in the computation. In the PQ model proposed in this method, it updates only the reactive power whereas the real power injection of the machine was maintained constant throughout the load flow computation. In RX model, the slip was computed by assuming that the stator resistance is negligible. A simplified version of the PQ model (Feijoo and Cidras (2000)) was proposed by Chen et al. (2006) where the Q is updated by assuming that the stator and rotor resistance is negligible.

A combination of PQ model and slip based RX model was proposed by Divya and Rao (2006). This model assumes that the core loss component is negligible and the magnetising susceptance is considered in between the stator and rotor elements. In this model, only Q has been updated in every iteration. Das (2014) has adopted this model, proposed by Divya and Rao (2006), for analysing the distribution system under various uncertainties of wind power using interval arithmetic based load flow algorithm. Eminoglu (2009) developed the induction generator model proposed by Feijoo and Cidras (2000) such that both the real and reactive power would be updated in every iteration. This model was further simplified by Padhy and Jasthi (2011) by assuming that the stator and rotor elements are negligible in certain parts of the model given by Eminoglu (2009). A simple RX model considering all the parameters of the induction generator was proposed by Haque (2013) in which the slip has been computed directly using the shaft power and the shunt components are handled as constant impedance load.

In this paper, two models of induction generator have been proposed. These models were developed considering both the core loss and magnetising components in between the stator and rotor components. Also these models do not neglect the stator and rotor impedances and use the direct solution of quadratic equation. Using this solution, both real and reactive power injections by the induction generator at the PCC are updated. The proposed models are incorporated in the radial load flow algorithm which was developed by James Ranjith Kumar and Nagendra Rao (2014) and tested in a 44 bus radial system which is a practical Indian distribution network. The converged load flow solution is used to calculate the necessary capacitance at the terminals of the induction generator such that it will operate in self excited mode. The paper is structured as follows. In Section 2, proposed methodology for modelling the Induction generators are described. Section 3 provides the details of the procedure followed for this work. The major results and relevant details of this work are given in Section 4. Finally, Section 5 concludes this work.

2. PROPOSED METHODOLOGY

Induction generators (IG) have been widely used in wind/micro-hydel power generations because of their advantages over synchronous generators. The main advantage is that the integration of induction generator with grid can be done without synchronising. So the cost of additional equipments for synchronisation is practically zero.

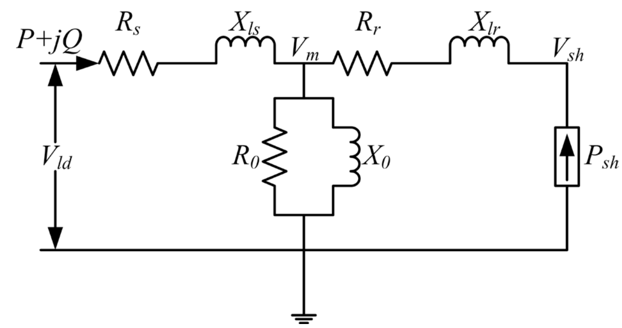

Fig. 1. Steady State Equivalent circuit of Induction generator

Therefore in distribution networks IGs are used more often in wind and micro-hydel sources. However on comparing synchronous generator and induction generator, modelling of induction generator (IG) is complicated. Modelling of IG is similar to transformer modelling because both works on the principle of mutual induction. In normal case, while modelling the induction generator, core loss components and voltage angle are neglected. However, the real performance of the system can only be known, if the full system is modelled by considering all the parameters. In this work, two modelling techniques are proposed by considering reactive power consumption of the induction generator.

2.1 Pi Model

In Fig. 1, the steady state equivalent circuit of an induction generator has been shown in which R_s, X_{ls}, R_r, X_{lr}, R_0, X_0 represent stator resistance, stator leakage reactance, rotor resistance, rotor leakage reactance, core loss resistance and magnetizing reactance respectively. The input mechanical power and the output electrical power are indicated as P_{sh} and (P+jQ) respectively. The parameters of the induction generator are converted to complex domain and given as follows

$$Z_s = R_s + jX_{ls} \tag{1}$$

$$Z_r = R_r + jX_{lr} \tag{2}$$

$$Z_0 = \frac{jR_0X_0}{R_0 + jX_0} \tag{3}$$

Fig. 2 shows the Pi model representation of Induction generator where the new terms Z_{link}, Z_{ig1} and Z_{ig2} can be defined as follows

$$Z_{link} = \frac{Z_0Z_r + Z_0Z_s + Z_sZ_r}{Z_0} \tag{4}$$

$$Z_{ig1} = \frac{Z_0Z_r + Z_0Z_s + Z_sZ_r}{Z_r} \tag{5}$$

$$Z_{ig2} = \frac{Z_0Z_r + Z_0Z_s + Z_sZ_r}{Z_s} \tag{6}$$

Since the induction generator has been directly converted into a two port network directly, the solution of quadratic equation can be used (James Ranjith Kumar and Nagendra Rao, 2014) to update the value V_{sh}