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A new synchronous generator based wind energy conversion system feeding an isolated load through variable frequency transformer

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ABSTRACT

This paper aims to explore the possibility of synchronous generator (SG) based wind energy generation system feeding an isolated load using a latest power transmission technology i.e. variable frequency transformer (VFT). The proposed configuration does not employ any power electronics based interface as in conventional SG based stand-alone wind energy conversion systems (SWECS). For analysis, the simulation models of proposed configuration as well as conventional configuration have been developed under MATLAB-Simulink environment. A series of studies on power fed from the SG to the different loads at various SG input speeds has been carried out with the developed models. Further to analyze the effectiveness of the proposed method; the efficiency, total harmonic distortion (THD) of output voltage and THD of output current of the proposed method have been compared with those of the conventional method. From obtained results, it is observed that the proposed method is simple and does not produce harmonics. Moreover to validate the proposed scheme, an experimental analysis has been carried out. Further, the cost analysis of both systems has also been carried out. From the cost analysis, it is observed that the proposed system is cheaper than the conventional system.

1. Introduction

Due to concern over the environment, the advent of renewable energy (RE) based power generation (wind, hydro, etc.), has increased their utilization in different forms. A customer with limited RE based generation (e.g. wind turbine), needs a connection with distribution system of bulk power grid for reliable power supply. In remote locations, isolated RE based power generation systems can be utilized to serve the local loads, eliminating the grid connection, transmission losses and transmission costs [1].

Nowadays, the wind based power generation has been emerged as one among the most promising RE based generation system. Due to this small installations of stand-alone wind energy conversion systems (SWECS) are quite promising in remote area electrification programmes. To utilize the wind energy, fixed speed and variable speed SWECS are used. In fixed-speed SWECS, the wind turbines are mostly equipped with an induction generator because of its simplicity, ruggedness and less maintenance [2,3]. Here, the isolated induction generator is directly connected to the loads. In order to supply constant voltage and frequency to the load, the speed of the turbine is controlled by the gearbox. The use of a gearbox causes many problems such as it requires continuous maintenance, enlarges the weight and size of the SWECS, generates noise, increases the power losses and hence reduces the efficiency of SWECS [4]. Variable-speed wind turbines possess many advantages over fixed-speed, such as larger energy capture, operation at maximum power point, better efficiency and quality of power. Hence, variable-speed wind turbines are the dominating type of turbines as far as present trend is concerned and used in SWECS for feeding an isolated load. In this operating mode, the wind turbines are equipped with either synchronous or doubly fed induction generator. The application of doubly fed induction generator for feeding isolated load is discussed in Refs. [5,6], whereas the application of synchronous generator (wound field or permanent magnet) feeding the isolated load is discussed in Refs. [7,8]. Both of these methods require suitable power electronics conversion system for feeding power to the load. These power electronics converters are costly, require sophisticated control system, cause harmonic distortion and thereby deteriorate the power quality. Moreover, they require suitable compensation in order to meet the standards for harmonic pollution which further increases the cost and complexity of the system [9–11].

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The main challenge faced in a synchronous generator (SG) based SWECS is the power quality. This challenge can be well answered by using a current power transmission technology termed as variable frequency transformer (VFT) [12,13]. The application of VFT for grid interconnection of wind power generation is discussed in Refs. [14–18]. But the application of VFT for SWECS has not been discussed so far. This paper deals with the analysis of a new configuration of SG based wind energy generation system for feeding power to an isolated load using VFT. The VFT is realized using a wound rotor induction machine (WRIM) whose rotor is mechanically coupled to the dc drive motor (DDM). The SG supplies power to the load at different levels of SG input speed. The requirements of costly power electronics converters are omitted. Hence, the proposed method is simple and does not produce harmonics. This paper has been organized in eight sections. The Section 2 of the paper describes the conventional SG based SWECS. Section 3 discusses the modeling and analysis of the proposed SG based SWECS. Sections 4 and 5 present the MATLAB-Simulink model; and results of the conventional method and the proposed method, respectively. Section 6 presents the experimental analysis of the proposed method. Section 7 shows the cost analysis of the proposed method and the conventional method. Finally Section 8 draws the conclusion of the paper.

2. Conventional method of SG based SWECS

In a conventional method of SG based SWECS, the wind turbine is connected to the rotor of the SG with or without gear box. The output power of the SG is fed to the load through a power electronics based interface. The power electronics based interface mainly consists of an ac-to-dc rectifier followed by a dc-to-ac inverter as shown in Fig. 1. The SG output ac power is first rectified into a dc power using uncontrolled ac-to-dc rectifier. The capacitor across the output of ac-to-dc rectifier is connected in order to filter out the ripples in the dc power. Then this dc power is converted again into the ac power using self-commutated inverter, which are mainly pulse width modulated (PWM) inverter employing insulated gate bipolar transistors (IGBTs). In this type of inverter, in addition to the control of the active power, the reactive power is also controllable. This interface produces inter-harmonics (harmonic distortion) and thereby deteriorates the quality of power supplied. A filter is required at the inverter side in order to meet the standards for harmonic pollution which further increases the cost and complexity of the system.

3. Proposed method

In the proposed method of SG based SWECS, VFT is used for feeding SG power to load. Here, the wind turbine is connected to the rotor of the SG without a gear box. The stator winding of the SG is connected to the rotor winding of the WRIM. The stator winding of the WRIM is connected to the isolated load as shown in Fig. 2. A DDM is coupled (mechanically) to the rotor of the WRIM in order to apply torque to the rotor of the WRIM.

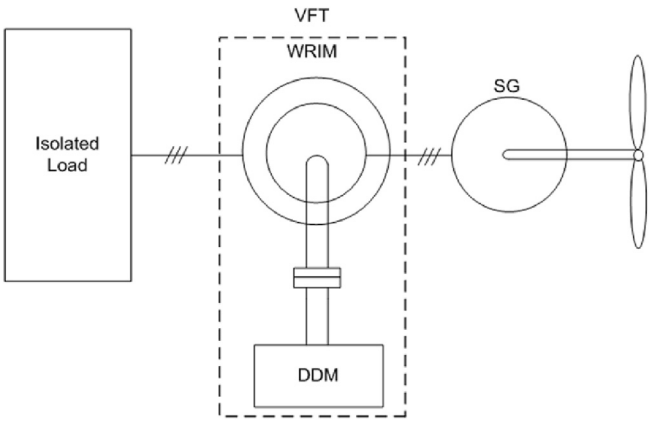

Fig. 2. Proposed system for SG based SWECS.

3.1. Modeling of proposed method

In modeling, the VFT is represented as a doubly-fed WRIM whose rotor is mechanically coupled to the DDM [19,20]. Here, DDM supplies mechanical power 'P_d' to the rotor of the WRIM as shown in Fig. 3. The three phase windings are available on both rotor and stator sides of the WRIM. The isolated load is connected to the stator windings of the WRIM having voltage 'V_L' and load angle 'θ_L'. The rotor windings of the WRIM is connected to the stator windings of the SG, energized by voltage 'V_s' with phase angle 'θ_s'. The rotor of the SG is mechanically coupled with the dc motor, where dc motor is working as prime mover of the SG in order to simulate the wind turbine. To transfer power from SG to load, the P_d is applied at the rotor of the WRIM. The power transfer through VFT is controlled by the magnitude of the applied P_d. In the power flow process, only real power transfer has being considered.

3.2. Analysis of proposed method

Considering VFT as an ideal and lossless machine and neglecting its magnetizing current and leakage reactance, the power balance equation for it will be written as:

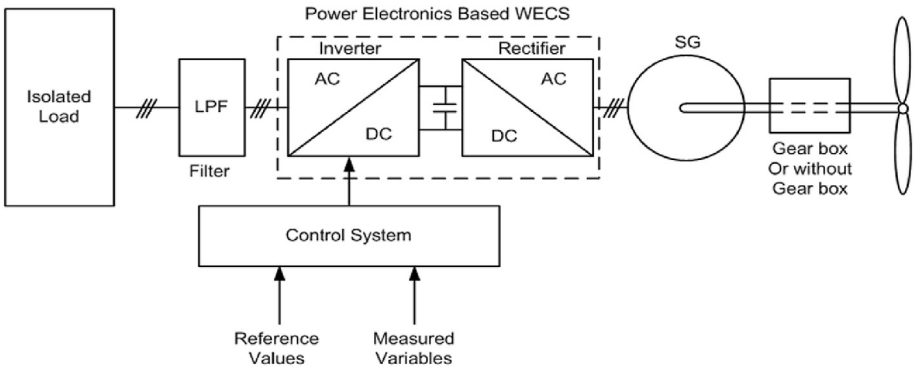

Fig. 1. Conventional method of SG based SWECS.