ENHANCING WIND POWER GENERATION EFFICIENCY: A NOVEL CONTROL ALGORITHM FOR DFIG WIND TURBINES USING FUZZY LOGIC AND NONLINEAR ESTIMATION TECHNIQUES

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ABSTARACT

The control algorithm for a wind turbine equipped with a doubly fed induction generator (DFIG) is presented in detail in this study. A Gaussian radial basis function network—a nonlinear input-output mapping technique—is used to assess the wind turbine's aerodynamic parameters. A nonlinear mapping is used to predict the wind speed. It takes into account the electrical output power of the generator, its power losses, and the dynamics of the wind turbine generator (WTG) shaft system. The creation and thorough assessment of the fuzzy logic controller are part of the new control approach. In the end, the wind generation system uses the technique that this study describes. The calculated wind speed is then utilized to determine the optimal command for the DFIG rotor speed in order to maximize wind power extraction. The Doubly Fed Induction Generator's (DFIG) speed controller is suitably designed to effectively reduce the impact of low-frequency torsional oscillations. The WTG system does away with the requirement for mechanical anemometers while producing the maximum amount of electrical power output to the grid with exceptional dependability and efficiency.

Keywords: Doubly fed induction generator, wind turbine generator, wind speed estimation.

1. INTRODUCTION

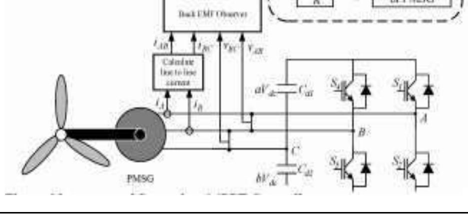
For the purpose of producing electricity, small and medium-sized wind turbine systems frequently employ permanent magnet generators (PMGs) [1], [2]. There are various benefits to using PMGs as opposed to wind turbines fitted with induction generators. Due to the lack of external excitation and copper losses in the rotor circuit, PMGs may firstly generate power with high efficiency and high reliability. Second, the weight and cost of the wind turbine generator (WTG) system are decreased by the tiny size of the high-power-density PMGs. In addition, the wind turbine that has a direct-drive PMG eliminates the requirement for a gearbox. Based on the statistical data presented in [3], gearbox failures account for approximately 19.4% of WTG downtime. The WTG systems are more reliable, require less maintenance, and have less downtime when they don't have gearboxes. Well-calibrated mechanical sensors, such as anemometers and rotor position sensors, can measure wind speed and generator rotor position/speed, which are necessary for controlling, monitoring, and safeguarding wind turbine generators. Nevertheless, WTG systems become more expensive and prone to failure when these mechanical sensors are used. More than 14% of WTG system failures, according to [3], are attributable to sensor failures, and over 40% of failures are linked to sensor failures and the ensuing failures of the control or electrical systems. The process of fixing malfunctioning components entails extra expenses and results in a notable reduction in the generation of electricity. Mechanical sensor less control offers a solution to the issues associated with the use of mechanical sensors. The generator rotor position or speed was still measured for wind speed estimation and WTG control in [4] and [5], even though the wind speed was estimated based on power signal feedback. The control systems in [6]–[8] tracked the wind turbine's maximum power point using an incremental control action and a hill-climb searching algorithm. The wind speed data is not required for that strategy to work. That approach can, however, require a lengthy search period to find the ideal operating point.

Consequently, if the wind speed fluctuates periodically, the WTG may commonly operate under suboptimal conditions. Through the use of historical data, an autoregressive statistical model was used in [9] to estimate the wind speed for WTG control. The majority of these projects still made use of generator rotor speed and position data. Rotor position sensors are utilized in the current WTG control systems to regulate the frequency of the power electronic converters in addition to providing information about shaft speed. Prior studies pertaining to rotor position sensor-less control have mostly examined permanent magnet (PM) motor drives. For instance, a sliding-mode observer was created in [10] to operate PM synchronous motors without the need for a rotor position sensor. Reference [11] made the observation that in a nonsalient PM synchronous motor, the information about rotor position faults would be present in the output voltage of the drive system's d-axis current regulator. The output of a PI controller would contain the rotor position information if it was used to control the position errors to zero. In this study, a unique mechanical sensorless control for direct-drive PMG wind turbines is proposed, in which wind speed and generator rotor position data are not required. The PMG's rotor position is ascertained by first estimating the back electromotive force (EMF) of the PMG using a sliding-mode observer. Second, the estimated back EMF from the sliding-mode observer is used by a model adaptive reference system (MRAS) observer to determine the rotating speed of the PMG. Third, the mechanical power of the wind turbine is evaluated by accounting for the system's power losses, based on the measured electrical power and estimated rotor speed of the PMG. Fourth, a back-propagation artificial neural network is used to estimate the wind speed using the mechanical power and WTG shaft speed data (BPANN). The ideal shaft speed reference is then found using the expected wind speed. A sensorless control is designed for PMG wind turbines based on the suggested estimate methods. This control allows the turbines to continually produce the greatest amount of electrical power without the need for any rotor position or wind speed sensors.

2. EXISTING SYSTEM

This section presents a maximum power tracking approach called sensorless Power Signal Feedback (PSF) method. The method has the capability of providing a power reference for the controller corresponding to maximum power point without measuring the turbine shaft speed. The maximum power curves for power mapping are established by running several simulations or offline experiments at various wind velocities and turbine speeds. In the system under study, the generator is connected to the turbine. Based on this, the generator shaft speed and corresponding power generated are measured and the quadratic optimal power-speed-curve is drawn. Figure2 shows the complete block diagram of the proposed WECS with sensorless speed estimator MPPT controller. This method has strikingly reduced the number of controller block. This controller is a very smart sensorless scheme that simply takes into account the cyclic nature of the generated voltage whose frequency is directly proportional to the speed of the generator. Knowing the number of rotor poles and measuring the time between two

Fig. 1: Proposed Sensorless MPPT Controller



Once the time taken for one cycle of the generated voltage is found, the corresponding frequency of the generated voltage can be obtained. Hence, the speed of the generator is given by

3. PROPOSED SYSTEM

In this, various design and modelling aspects of different components of the Wind Energy Conversion System like the basic models of synchronous generator, AC-DC-AC PWM converter, wind turbine, drive train and their control system are described

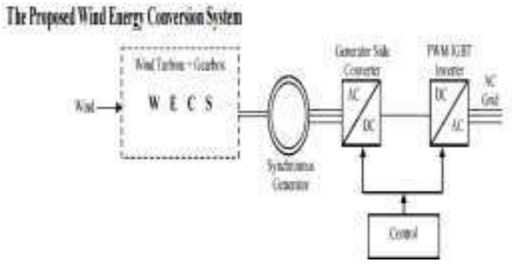


Fig. 2: Proposed Wind Energy Conversion System

- The proposed WECS system consists of wind turbine, two mass drive train, permanent magnet synchronous machine (PMSM) which is torque controlled and AC-DC-AC PWM converter.
- synchronous machine (PMSM) which is torque controlled and AC-DC-AC PWM converter.
- Permanent Magnet Synchronous Generator (PMSG)

The PMSG is a Synchronous Machine, where the DC excitation circuit is replaced by permanent magnets, by eliminating the brushes. PMSG has a smaller physical size, a low moment of inertia which means a higher reliability and power density per volume ratio as it has permanent magnets instead of brushes and the slip rings. Also by having permanent magnets in the rotor circuit, the electrical losses in the rotor are eliminated. The PMSG are becoming an interesting solution for wind turbine applications [1]. However, the disadvantages of the permanent magnet excitation are high costs for permanent magnet materials and a fixed excitation, which cannot be changed according to the operational point. The PMSG can be classified according to the rotor configuration agnet type (IPMSG) for this configuration, the magnets is buried inside the rotor. The interior magnet PMSG usually presents magnetic saliency. The d-axis inductance is smaller than the q-axis inductance (Ld < Lq), because the effective air gap of the d-axis is bigger than the q-axis air gap. This results in a component of reluctance torque in addition to the torque produced by the magnet. Because of this, the rotor position is much easier to detect. Surface mounted magnet type (SPMSG) The SPMSG has the magnets mounted on the surface of the rotor. As the permeability of the permanent magnets is approximately equal to 1, permanent magnets act like air in magnetic circuits. This means that the air gap is very large and constant. The d- and q-axis inductances are nearly identical and the saliency ratio (= Lq/Ld) is 1. Therefore no reluctance torque occurs. One advantage of the SPMSG is that the surface mounted magnets lead to a very simple rotor design with a low weight.

4. SIMULATION RESULTS

his section, simulation results are presented to verify the validity of operations of the proposed system under steady- state and transient conditions. The simulated system parameters are listed in Table T. These simulations were performed using control systems mentioned in Section IV. The variable frequency mode of six switch AC/AC converter is selected since two three phase terminals of the converter work with different frequency

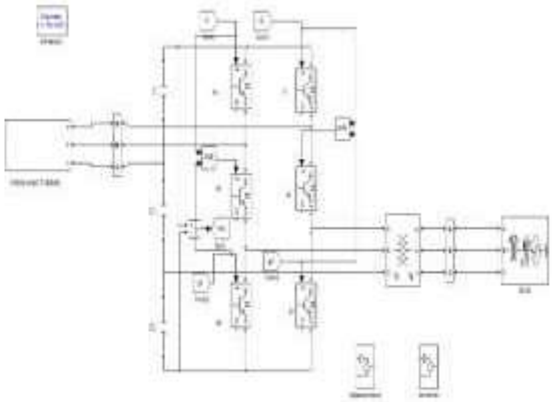


Fig. 3: Simulink model of proposed system

Operation of Constant Wind Speed

In this section, the steady state operation of the proposed system is verified through simulation results. For this purpose the wind speed is considered a constant value which is equal to 13 m/s. The DC-link voltage waveform is shown in Fig 4. As it can be seen in this figure, the grid side control system in Fig. 8 works properly and the DC link voltage remains almost constant (220 0V). Another function of the grid side control system is to set the reactive power injected to the grid. In this paper the unity power operation of wind energy system is desirable and Fig. 13 shows that the control system has successfully fulfilled this criterion and the grid voltage and the input current are 180 degrees out of phase.

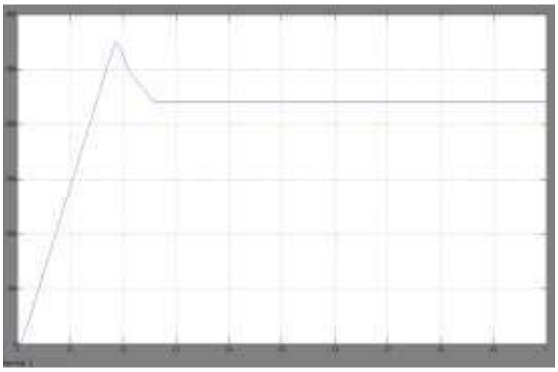


Fig. 4: Dc link voltage

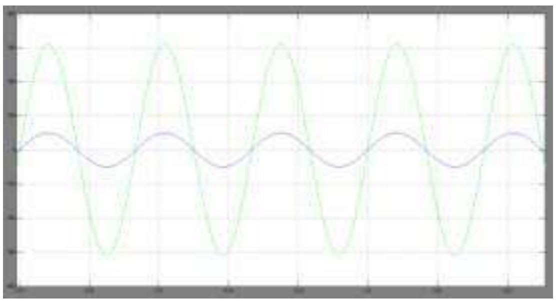


Fig. 5: the grid voltage and the input current

Fig. 4 shows the extracted mechanical power from the wind and the electrical power delivered to the grid. As it is obvious in the figure, these two values are different from each other. It is because that a small portion of the mechanical power extracted from wind is dissipated in electrical and mechanical parts of WECS. In order to always track MPP, the reference value of PMSG rotor speed is set using TSR method and compared with the estimated rotor speed. The real and estimated rotor speeds as well as the obtained rotor speed from MPPT are illustrated in Fig. 5. This figure clearly shows the ability of proposed sensorless system to accurately estimate the rotor speed.

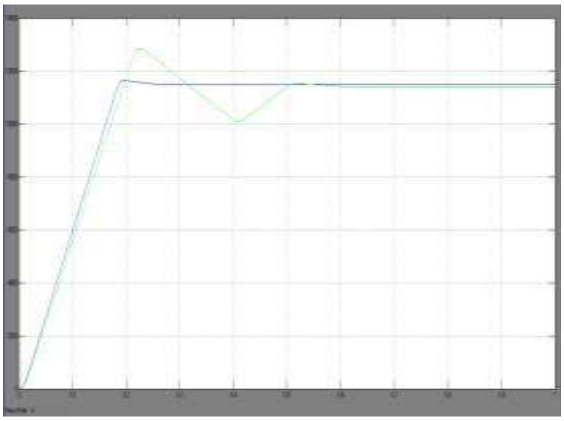


Fig. 6: power delivered to the grid and extracted mechanical power

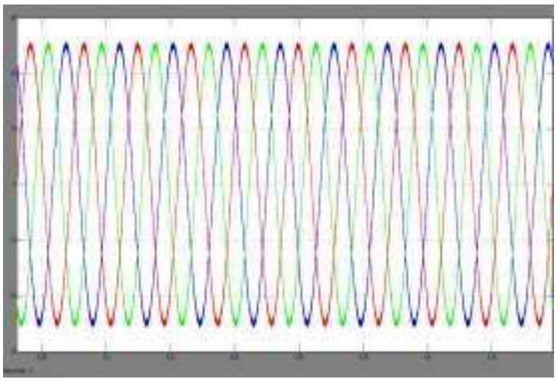


Fig. 7: Injected three phase currents to the Grid.

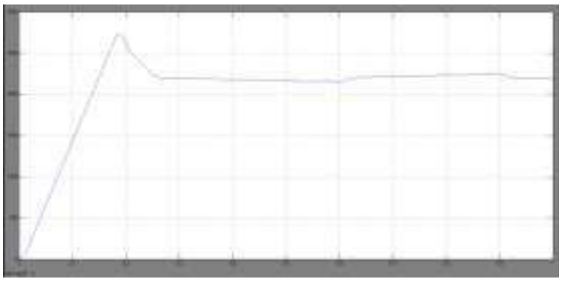


Fig. 8: Dc link voltage

In order to examine the proposed system performance under the transient condition, wind speed has been varied from 13 mls to 9 mls in t=0.6 sec and then from 9 mls to 11 mls in t=0.9 sec. The previous simulation is rerun in this transient condition and the simulation results are shown in Fig. 8 to Fig. 9 . DC-link voltage is displayed in Fig. 16 which is almost constant although the wind speed undergoes two transient changes.

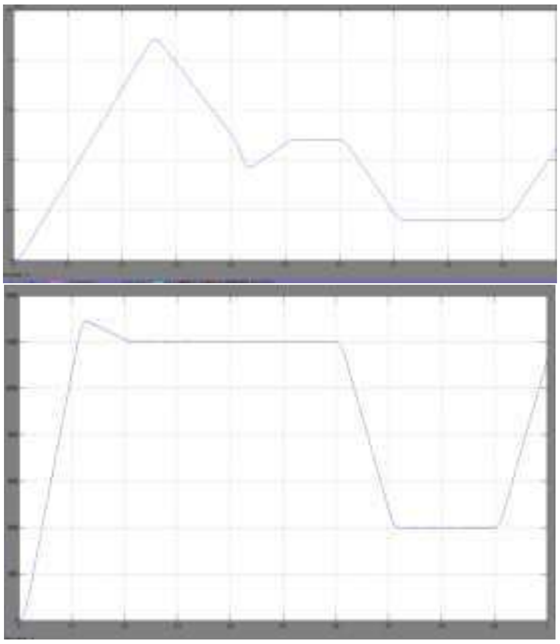


Fig. 9: mechanical power

5. CONCLUSION

In this paper the fuzzy control of wind energy conversion system in order to get constant output power is obtained and verified through the simulation. The main goal of implementing fuzzy controller is to continuously adapt the constant power of the generator and the wind speed in a way that the turbine operates at its optimum. The advantages of using fuzzy controller are verified by its simulation results, fast response, and parameter insensitivity. Implemented system has satisfactory, dynamic and static performance.

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