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SIMULATION OF PMSG BASED WIND ENERGY CONVERSION SYSTEM CONNECTED TO A GRID

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Abstract –Renewable energy generated from wind turbines is considered one of the safest forms of energy. Wind turbine-based energy generators have the potential to produce significant amounts of electricity, provided that there is adequate wind speed and proper control mechanisms. This has the potential to reduce reliance on solar photovoltaic-based energy systems, which require large amounts of space for installation of the solar panels. However, the power output of a wind turbine can be influenced by the variability of wind velocity, which can be unpredictable. The mechanical power output needs to be effectively regulated in order to optimize the efficiency of the wind energy system. As such, the efficacy of the wind energy system is dependent on how effectively this uncertainty is managed. Designing and controlling wind turbine systems with a suitable interface between the power generator and the load remains a major challenge. This interface must be able to mitigate damage to the load caused by the variable voltages resulting from the fluctuating wind velocity. This paper takes into account these challenges and proposes various converter design methods for wind energy applications based on PMSG, ultimately recommending the most appropriate method for controller design. The overall analysis is presented through a comprehensive evaluation of quantitative results, utilizing time-domain performance index parameters to provide detailed assessment.

Keywords - Wind power, renewable energy, turbine model, PMSG.

INTRODUCTION

From a global energy perspective, there are two categories of energy sources: conventional and non-conventional (renewable)sources. Renewable sources are derived from the earth or its ecosystems and are abundant in quantity. These resources include wind energy, hydro-energy, solar energy, biomass, geothermal energy, and others, all of which are considered to be inexhaustible. Additionally, renewable resources offer a pollution-free alternative to conventional fossil fuel-based energy systems. As such, the energy sector is increasingly turning to renewables as a replacement for fast-depleting fossil fuels. Numerous studies have been conducted on the generation of electricity from renewable energy resources [1]. Of all the renewable resources, wind energy generation is considered the cleanest and most efficient source of energy. This is due in large part to the fact that it does not pollute the air, water, or soil in any way, and it also does not contribute to global warming, making it an ideal option for environmentally-conscious energy generation. Despite its advantages, the wind turbine-based energy system still faces significant challenges in the design and control of its wind turbine systems. Specifically, the need for a suitable interface between the power generator and the load, capable of mitigating damage caused by variable voltages resulting from fluctuating wind speeds, remains a major concern. Wind turbines are typically designed to operate in one of two ways: with variable speed or with fixed speed. Wind speed is an uncontrollable factor that can fluctuate rapidly, making it a complex challenge to control wind power operations effectively. Failure to properly control the power generated by wind turbines can result in damage to the load. One potential solution to this issue is to implement control measures that allow for the speed of the wind turbine generator to be regulated, thereby enabling more precise control over the power generated across a range of speeds. Given the potential for damage to the load caused by unpredictable changes in wind speed, it is critical to design a controller unit that can effectively regulate the wind turbine's speed under a wide range of conditions. Only through careful design and implementation of such a controller can wind turbines be used safely and effectively to generate renewable energy without risking damage to critical infrastructure or equipment. Many research studies are currently focused on regulating wind turbine speed using various methods, including speed control for direct drive permanent magnet wind turbine [2], non-variable speed control of wind turbine [3], sensor less control scheme for wind turbine in 1.5 MW doubly-fed induction generator (DFIG) application with maximum power point tracking (MPPT) facility [4], full-range speed control mechanism for an electromagnetic doubly-salient wind turbine plant [5], disturbance observer based speed control mechanism for fixed-pitch angle-based wind turbine [6], and modern or intelligent speed control methods, such as wind velocity forecasting concept-based predictive control method for wind turbines [7], adaptive MPPT based rotor speed control of DFIG wind turbine [8], intelligent speed control integrated with MPPT facility for medium power wind energy systems [9], protection and control mechanism for full wind speed range of a wind turbine power system [10], imperialist competitive algorithm-based induction motor’s speed control provision that was supplied by wind turbine [11], and model predictive control approach for speed control of a wind turbine energy system [12]. However, most of these controllers are based on PID (proportional-integral-derivative) controllers [13], which may not work effectively for nonlinear deviations of the system response.

Variable-Speed and Constant- Speed Wind Turbines

One of the major distinctions in wind turbines is between variable and constant speed turbines. In variable speed turbines, the rotor can run at varying speeds, while in constant speed turbines, the rotor is constrained to operate at a fixed speed determined by the frequency of the electrical system. Constant speed turbines can use simple generators, but variable speed turbines require power electronics, which can be more expensive. However, variable speed turbines can spend more time operating at maximum aerodynamic efficiency compared to constant speed turbines. This can be seen by plotting the performance coefficient, Cp, of a wind turbine against the tip speed ratio, λ, which is the ratio between the speed of the tips of the blades and the speed of the wind.

$$\lambda = \frac{V_{tip}}{V_{wind}} = \frac{\omega . R}{V} \quad (1)$$

The coefficient of performance, Cp, is a measure of the efficiency of a wind turbine and is defined as the ratio of the power extracted by the turbine to the power available in the wind stream. In other words, it is the fraction of the wind's kinetic energy that can be converted into mechanical energy by the wind turbine. A high Cp value indicates that the wind turbine is able to extract a large amount of energy from the wind and is therefore more efficient. The Cp value varies with the tip speed ratio, blade pitch angle, and other factors, and is typically highest at a certain optimal tip speed ratio.

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$$C_p = \frac{P_{extracted}}{P_{wind}} \qquad (2)$$

The coefficient of performance, Cp, is a key parameter for assessing the performance of wind turbines. It represents the ratio of the power captured by the wind turbine to the power available in the wind. The theoretical maximum Cp value is 0.59, as formulated by Betz in 1919. However, in reality, only a portion of the power in the wind can be converted to useful energy. The power available for a wind turbine is determined by the change in kinetic energy of the air passing through the rotor. The maximum theoretical Cp value applies to all types of wind turbines and is depicted in a typical Cp vs tip speed ratio plot. From the plot, it can be inferred that the maximum Cp value of 0.5 is achieved for a tip speed ratio of 10 and a pitch angle of 0. For fixed-speed wind turbines, which operate at a constant ω, the optimal efficiency corresponds to a particular wind speed. For all other wind speeds, the efficiency of the turbine is reduced. To always run at optimal efficiency, variable-speed wind turbines are designed to keep the particular λ that corresponds to the maximum Cp constant by adapting the blade velocity to wind speed changes. In contrast, constant-speed turbines transmit fluctuations in wind speed as mechanical torque and electrical power grid fluctuations. Using variable-speed wind turbines increases energy capture and makes the power electronics cost-effective. Therefore, the wind industry trend is to design and construct variable-speed wind turbines.

PROPOSED SYSTEM CONFIGURATION

The issue of global warming has been brought to the forefront due to the consumption of non-renewable resources like oil, coal, and natural gas for electricity production. Moreover, the reserves of these fuels are depleting at an alarming rate. Thus, the focus has now shifted to green alternative energy sources that are non-polluting and have minimal impact on the environment. Wind energy is one such renewable energy source that is being extensively explored as a replacement for traditional fuels since it has a significantly lower carbon footprint and helps in reducing the effects of global warming. In the past decade, wind capacity has been installed at a significant rate, with new installations every three years. Currently, around 83% of wind capacity is located in five countries: Germany, the United States, Denmark, India, and Spain. A typical wind energy conversion system (WECS) consists of several components, including a wind turbine, pitch angle control, drive train, generator, and power converter. Various types of generators are used in WECS, including the induction generator (IG), doubly fed induction generator (DFIG), and permanent magnet synchronous generator (PMSG). The PMSG can be connected to the turbine without using a gearbox, which reduces maintenance costs and

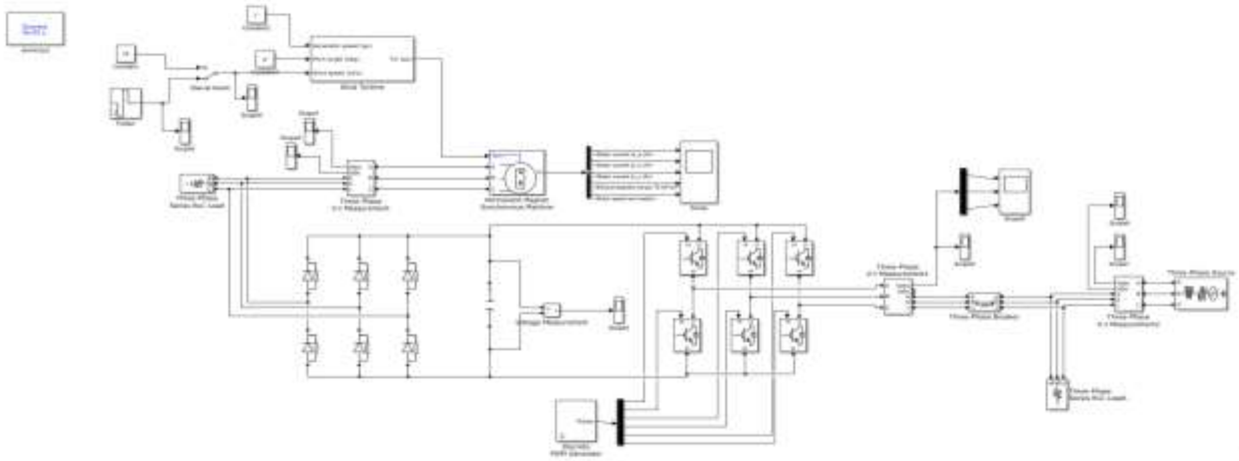

Fig 1 Proposed system configuration

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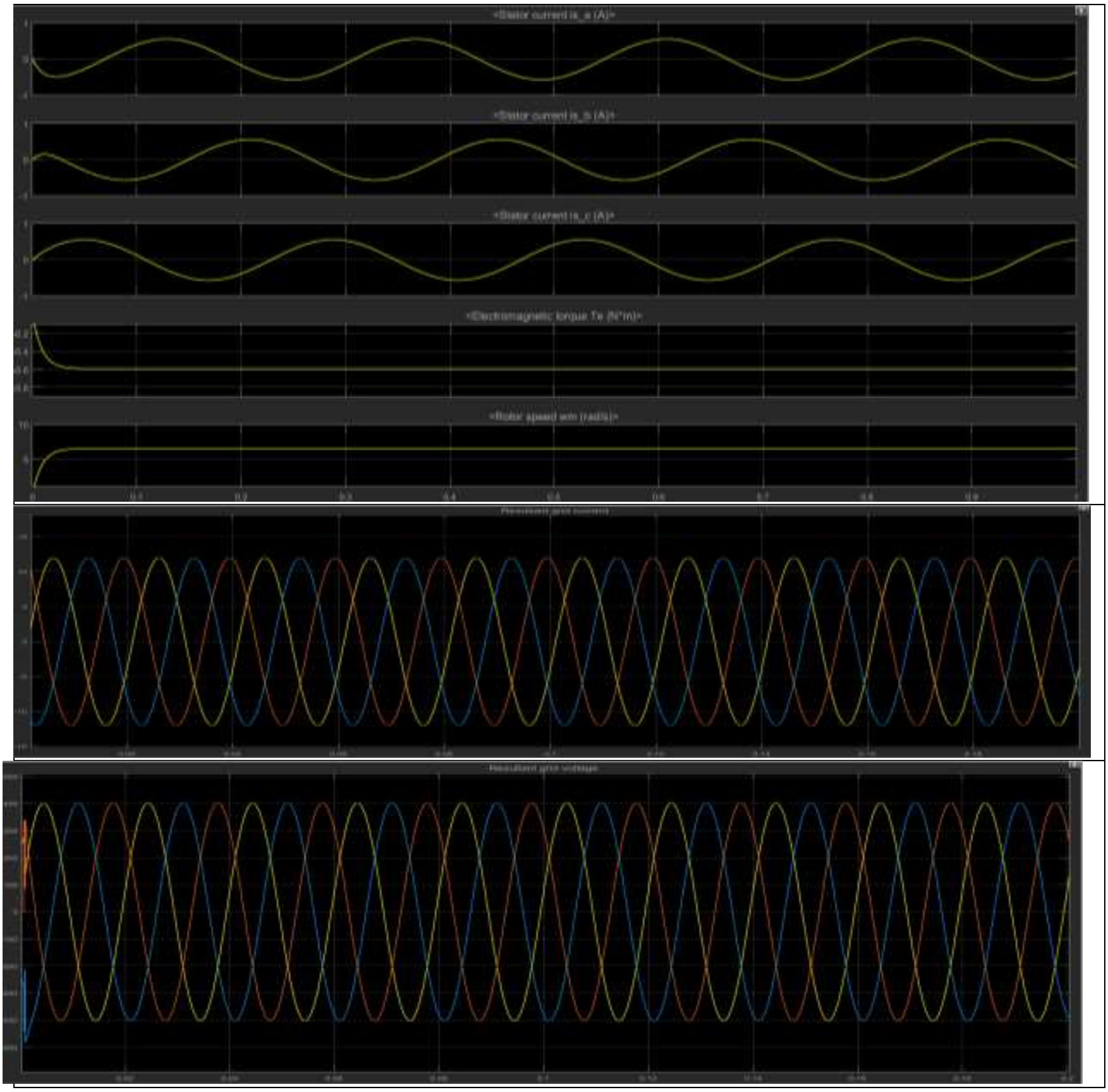
the weight of the nacelle. This research presents the working of the PMSG based WECs. In this the output of the PMSG which is uncontrolled is transformed into an output with constant amplitude and frequency to be used by grid. The input voltage to the grid for constant and variable wind speed is shown in the figures 1 and 2 below.



Fi. g 1: Wind system configuration under constant wind speed of 12 m/s with grid currents and voltages

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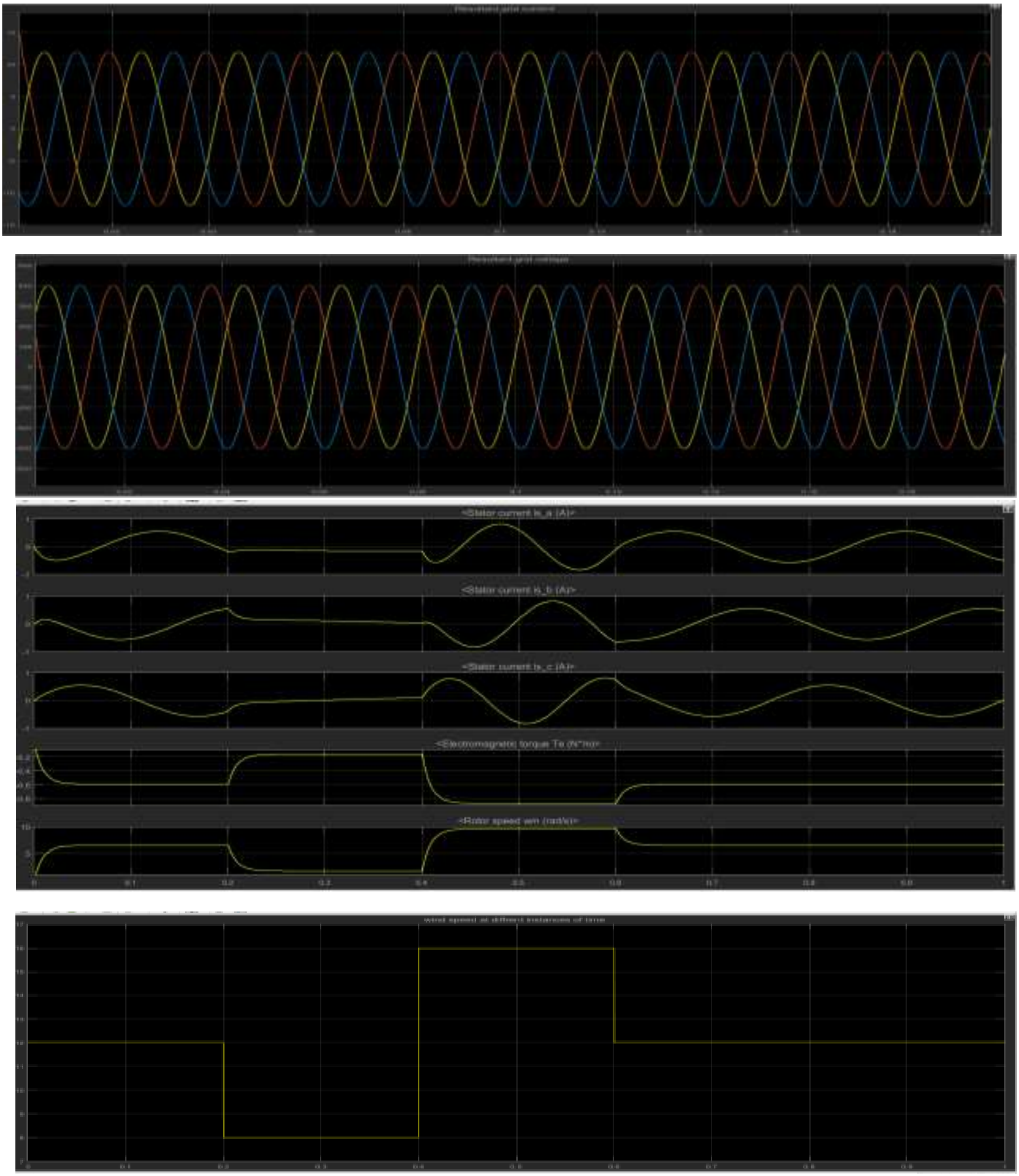

Fig 2: Wind system configuration under variable wind speed with grid currents and voltage

The MATLAB/SIMULINK software package is widely used in the research community for modelling, simulating, and analysing dynamic systems. It supports linear and nonlinear systems, both in continuous and sample time. Various studies have been presented using MATLAB/SIMULINK to model PMSG-based WECS [8-9]. To fully comprehend the principle of generating electricity from wind with WECS and analyse it before practical implementation, further investigation and study of PMSG-based WECS is required.

CONCLUSION

The paper proposes a model for a PMSG based on WECS, which includes the wind turbine, drive train, PMSG, pitch angle control, and power converter. The model is relevant in various applications, such as stand-alone systems, distributed generation systems, microgrids, and smart grids. To ensure efficient energy production and transfer, appropriate energy management processes must be employed. The proposed model includes PMSG and converter components and can be used to study and analyse the principles of wind energy production before implementing them in practical applications.

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