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Modelling and Simulation of Grid Connected Wind Turbine Induction Generator for Windfarm

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Abstract

As the power generation sector moving towards the sustainability to achieve clean and renewable energy source, the wind power generation plays a vital role due to its abundance in nature. A big chunk of the decrease in carbon emission is a major attribute to the growth of the wind energy sector. Wind turbine production, structural development, logistics, maintenance and R&D are just some of the areas that could benefit from the growth of the wind energy industry. This brought out the attention of researchers of the electrical engineering to focus on wind power generation. It can be more efficient and cost-effective to operate wind turbines as a wind farm rather than individually. This has led to a surge in the construction of wind farms, both onshore and offshore wind farms. Therefore, in this paper, the study and analyse of single Induction generator with wind turbines and 33MW windfarm performance is presented. The simulation result demonstrates the efficiency of DFIG in producing energy at a constant wind speed, as well as its ability to regulate both active and reactive power at steady-state.

Keywords: Wind turbine generator; Induction Generator; DFIG wind turbine; Wind farm

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1. Introduction

Because of the ever-increasing demand for energy, scientists and energy experts are conducting research to identify potential alternatives to fossil fuels. Wind power has a lower cost and a higher reliability compared to solar power and other renewable energy sources. Wind power has now surpassed both solar and hydroelectric power as the renewable energy source with the fastest rising market share. Wind power is a potential choice for generating environmentally friendly electricity because the electricity it produces has a negligible impact on the surrounding environment. Wind is a renewable resource that will not become depleted over time, in contrast to coal and natural gas [1]. Wind power, on the other hand, cannot meet more than a marginal portion of the nation's electrical requirements and consumers should not rely completely on it due to the fact that it is unreliable. A number of knowledgeable individuals have investigated the possibility of storing electrical energy. Wind energy that is connected to the power grid is the most realistic alternative because the cost of storing huge amounts of electric energy is so high. A wind turbine, much like any other type of generator, has the ability to convert mechanical energy into generator torque, which may then be utilized in the generation of electrical power. It is distinguished by the fact that wind is employed to generate the mechanical energy. Wind turbines are intricate devices that require contributions from a wide variety of subfields within engineering. Wind turbines are currently undergoing technological advancements in order to make them more effective and better able to meet the requirements of the grid at a reduced cost [2].

The authors of [3] Global capacity for renewable energy sources reached 3064 GW by the end of the year 2021. When compared to other forms of renewable energy, hydropower has the highest capacity in the world with a total of 1211 gigawatts (GW), not considering the capacity for pure pumped storage. Following that, we have wind, solar, biofuel and geothermal as potential sources of power generation. In addition, Asia has contributed more than any other region to the world's renewable power capacity, which is presently 1.29 TW (or 46%). This figure is more than any other region. Alterations in China were a significant contributor to expansion. By the year 2050, more than 2,000 gigawatts (GW) of renewable energy sources will have been put into operation around the globe. The offshore wind power potential of the Indian states of Tamil Nadu and Gujarat combined is greater than 70 gigawatts (GW). Officials from the Indian government have stated that this is in excess of the 64 GW that is now available everywhere else in the world. It is proposed that a steady rollout of offshore wind power up to approximately 37 gigawatts by the year 2030 should take place. Both Tamil Nadu and Gujarat have inked contracts to acquire power from the first offshore wind projects at a tariff of approximately Rs 4 per unit. These projects are still in the development stage [4].

The authors of [5] also had a look at how a 400V 3 phase network interacted with a DFIG based wind turbine and its impacts. The system's performance in its steady state and during transitions are studied in this particular piece of work. The simulation takes into account a number of different scenarios, some of which are varying wind speeds, voltage drops across the network, and single-phase faults. DFIG based wind turbine were put to test and compared by authors of [6] for their respective power outputs. When evaluating the efficiency of the machines, a fault in all three phases of a transmission line at its terminal is taken into consideration [7]. Simulated a DFIG wind turbine by using MATLAB/SIMULINK. The turbine was connected to a grid. Similar to this, in [8], the modeling and analytic tool simulation is used to investigate about impacts of DFIG. Which helps to balance the demand with supply and voltage, efficiency of the system increased [9]. The majority of studies that have been conducted to evaluate the effectiveness of WTGs that are connected to the grid have only taken into consideration one mode of operation [10]. The DFIG based turbine is coupled to a grid system are depicted in an initial simulation model. As a following step, steady state at constant rated wind speed is simulated [11]. The simulation model that has been provided here can be used to study the performance of DFIG wind turbines. Three control methods that MPPT, PLL and Grid side inverter control discussed in [12]. Distributed Resources, such as wind turbines and synchronous generators, have been connected to the grid, with varying effects on the system being studied by means of simulation models [13]. Hence, in this paper, the performance analysis of DFIG is represented. In addition, the behavior of 33 MW wind farm connected to grid is analyzed for a steady state operation.

2. Wind Farm Modelling

The wind speed, the turbine, and the farm are the primary one of a model of a wind system. The primary models that make up this overall framework are depicted in Figure. 1. The wind speed model generates a wind speed sequence from left to right, with parameters selected by the user based on the local wind pattern. Then, using the wind speed and the characteristics of the wind farm, an equivalent wind speed for individual turbines is determined. Electric power provided by individual turbines is estimated using the equivalent wind speeds, the wind turbine model, and the rotor and generator properties [14]. The power aggregation block adds together the electrical outputs of the different turbines. This allows us to calculate how much energy the wind farm added to the grid.

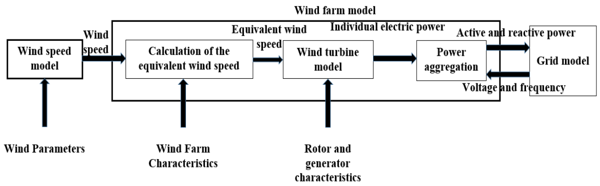

Figure 1. Wind Farm Model

2.1. Modelling of Wind Turbine

The main parameters which affect the generating power are Choice of pitch angle, Tip speed ratio, Coefficient of power, Rotor diameter.so properly have to select the values to attain maximum power.

Choice of pitch angle

If want the optimal angle of incidence at every point along the blade, need to change angle. This makes it simple to determine the optimal blade twist. The result is a twisted blade that, in essence, has varying pitch angles at various distances from the axis. In our system, the pitch angle starting with 0 deg is considered.

Tip speed ratio

To calculate the wind turbine's tip speed ratio (TSR), divide the rotor's no-load speed by the wind speed.

λ = Slope Ratio of the Tip

Tip speed ratios of 6-7 are typical for 3-blade turbines. It is usually above 50 m/sec wind speed.

Coefficient of power

The efficiency is measured by its coefficient of power (Cp). It differs from system efficiency because it does not factor in mechanical gearbox losses or electrical generation losses. Betz limit refers to the theoretical upper bound for horizontal axis machines. Here Cp is 0.358.

Rotor Diameter

Since the amount of power generated is mainly depending on the rotor's diameter. The optimal power to be generated is by applying the average wind speed. Our method uses a rotor with a diameter of 130 meters.

3. Simulation of Induction machine driven by wind turbine

The equation used for modelling of Induction generator are described in this section. The simulations are carried out in MATLAB/SIMULINK platform. The Induction machine, Turbine and Drive train are made to be a single WTG [15]. The stator phase voltages can be written as

$$v_a = V_m\cos(\omega_e t)$$
$$v_b = V_m\cos(\omega_e t - 2\pi/3) \qquad (3.1)$$
$$v_c = V_m\cos(\omega_e t - 4\pi/3)$$

The electromechanical torque for the P-poles machine is

$$T_{em} = \frac{P}{2\omega_b}(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}) \quad \text{N.m.} \qquad (3.2)$$

The value of T_{em} from the above expression is positive for motoring operation and negative for generating operation. Equating the net acceleration torque, we have

$$T_{em} + T_{mech} - T_{damp} = \frac{2H}{} \frac{d(\omega_r/\omega_b)}{dt} \text{ in per unit} \qquad (3.3)$$

Where

V_a, V_b, V_c = Stator Input voltages
T_{mech} = mechanical power input in p.u
T_{em} = electrical power output in p.u
V_m = magnitude of stator phase voltage.
Ψ_{ds}, Ψ_{qs} = winding flux linkages for q and d axis
ω_b = base electrical angular frequency
ω_r = rotor speed
P = number of poles
H = inertia constant

Table: 1 Parameters of Induction Generator

Sl.No	Parameters	Value
1	Power rating	750 VA
2	Line to line voltage	400V
3	Power factor	0.8
4	Number of poles	4
5	Rated frequency	60 Hz
6	Stator winding resistance	3.35 ohms
7	Stator leakage reactance	6.94 mwb
8	Stator magnetizing reactance	163.73 mwb
9	Rotor winding resistance	1.99 ohms
10	Rotor damping coefficient	0

Table: 2 Parameters of Wind Turbine

Sl.No	Parameters	Value
1	Inertia constant H (s)	4.32
2	Shaft - Spring constant	1.11 pu
3	Shaft - mutual damping	1.5 pu
4	Shaft base speed	175 rad/s
5	Initial speed	1.2 pu
6	Output torque	0.83 pu
7	Sample time	5 μsec
	Parameters of Drive Train	
1	Nominal mechanical output power	9.0 MW
2	Coefficients [c1 ... c8]	[0.645 116 0.4 5 21 0.00912 0.08 0.035]
3	Parameters [K1 K2]	[91.203 10142.7498]
4	Initial wind speed	1 m/s
5	Sample time	5 μsec

The parameters used for simulating the wind turbine generator are presented in **Table1 & Table2**.
The simulation consists of three major components such as Induction Generator, Wind Turbine and Drive Train.

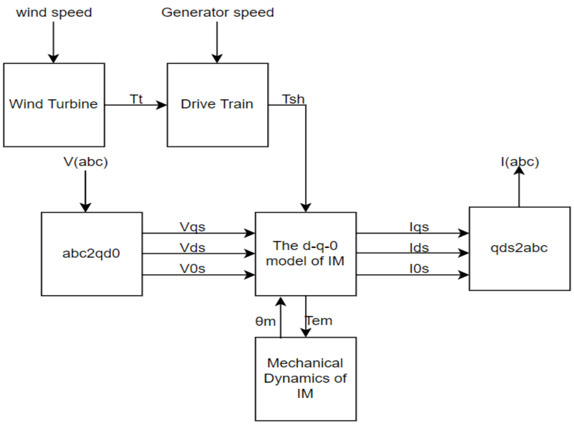

Figure 2. Simulation model for Induction Generator with Turbine and Drive Train

The model is simulated in the MATLAB / SIMULINK platform and the performance of Induction Generator is depicted in **Figure 2**.

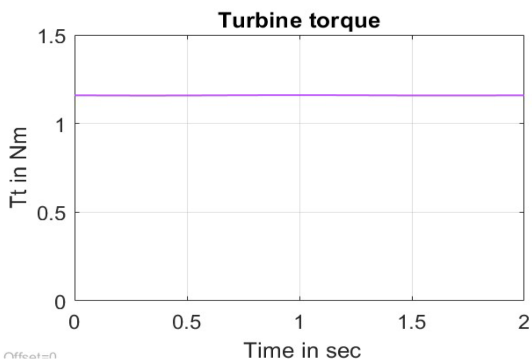

Figure 2(a). Turbine Torque

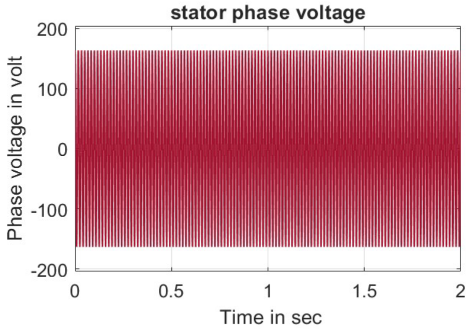

Figure 2(b). Stator phase voltage

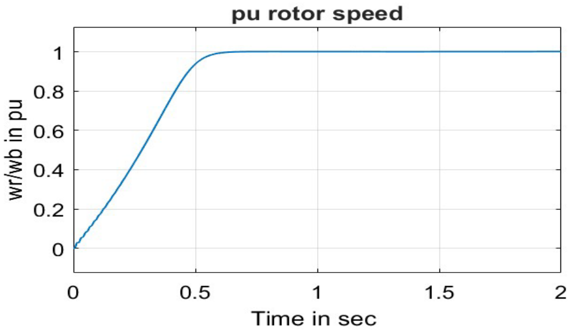

Figure 2(c). pu rotor speed

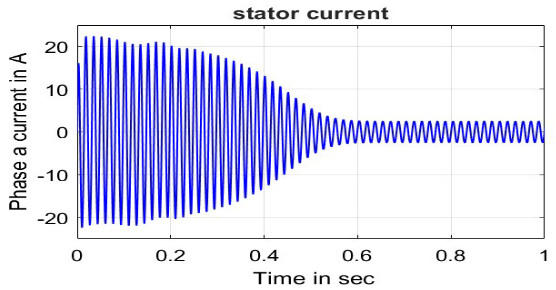

Figure 2(d). Stator current

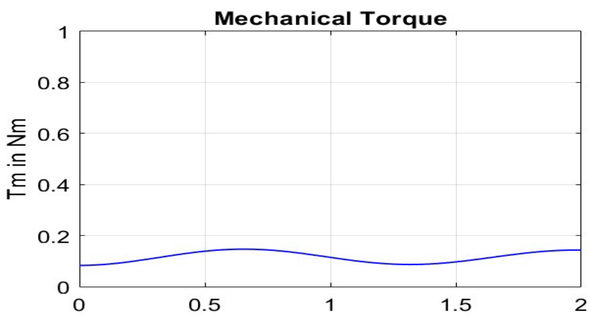

Figure 2(e). Mechanical Torque

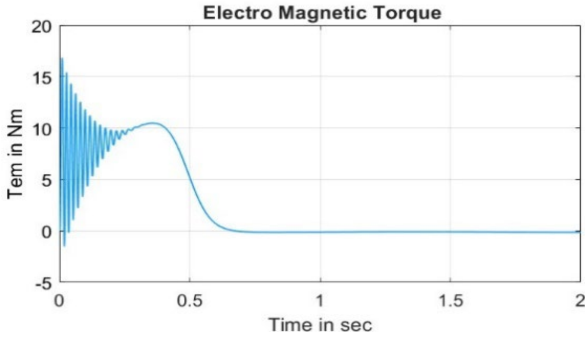

Figure 2(f). Electro Magnetic Torque

Table: 3 Variations of Torques with respect to wind speed

SL.NO	WIND SPEED M/S	T_{EM} PU	T_T PU	T_{MECH} PU
1	9	-0.0154	0.3135	0.01587
2	10	-0.0349	0.4606	0.03521
3	11	-0.0562	0.6248	0.0564
4	12	-0.0790	0.7999	0.07906
5	13	-0.1031	0.98	0.1032
6	14	-0.1285	1.16	0.1281
7	15	-0.1553	1.334	0.1547
8	16	-0.1841	1.498	0.1831

The **Figure 2(a).** Shows torque value of wind turbine in Nm which is developed by wind turbine, and it is fed to the rotor of Induction Generator through drive train. The electrical input voltage of phase a with magnitude of 160V supplied to the stator of Induction Generator is presented in **Figure 2(b).** In **Figure 2(c)**. the settling value of 1 pu clearly demonstrates that the rotor gains its rated speed within 0.5 sec. The variations of Stator current in phase a is presented in **Figure 2(d)**. Mechanical torque which is from drive train to rotor is shown in **Figure 2(e)**. and T_{em} is shown in **Figure 2(f).** which is slowly settled down to zero.

As the characteristics of wind speed is varying in nature, the study of performance at different wind speed becomes mandatory. Therefore, the variations of Electromechanical Torque, Turbine torque and Mechanical Torque with respect to the various wind speed is tabulated in **Table 3.**

As T_{em} to be negative and T_{mech} is positive for generator, Table 3 clearly depicts these characteristics in values. As the wind speed increases, the torques also shows increasing order.

4. Simulation of 33MW windfarm

The study of standalone DFIG is extended to modelling of 33 MW wind farm. The single line diagram comprises of windfarm, Offshore substation, Onshore substation and Grid is presented in **Figure 3**. A 30 km transmission line connecting the onshore substation with offshore substation. Offshore substation is connected to grid.

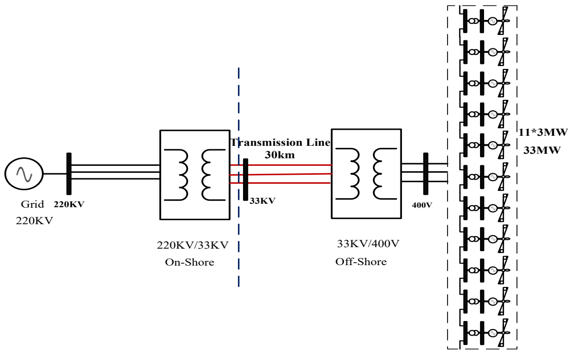

Figure 3. Single Line Diagram of 33 MW windfarm

The simulation model is built with 11 WTG producing 33 MW to study. The windfarm would have a total of eleven units, and the maximum output capacity for each unit would be 3 MW. Because of this, the total amount of power that may be generated by each WTG is 33 MW (which is equivalent to the addition of 11 units of 3 MW). Initially wind speed is 15 m/s fixed to the DFIG. In addition, a step-up transformer with a voltage range of 0.400 kV to 33 kV connects the DFIG wind turbine to the 33 kV distribution system. This system then sends the power it generates to the 220 kV grid via an overhead transmission line that is 30 kilometers in length. The pi-model and a transmission line that is 30 kilometers in length are used. Because the grid is shown to be a 220 kV system, a step-up transformer with a voltage ratio of 33 kV to 220 kV is connected to the grid.

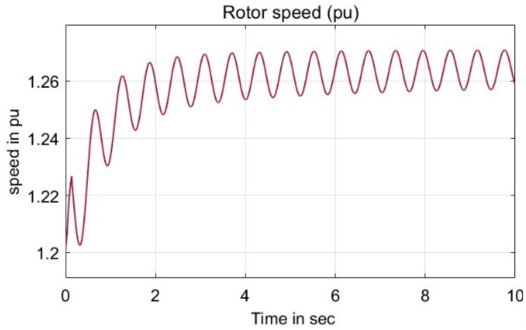

Figure 4(a). Rotor speed

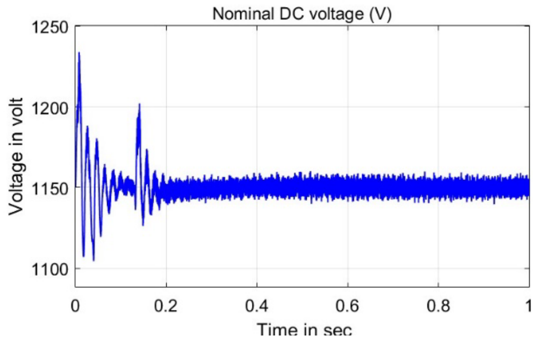

Figure 4(b). Nominal DC Voltage

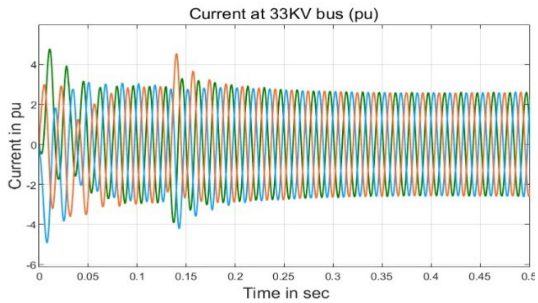

Figure 4(c). Current at 33KV bus

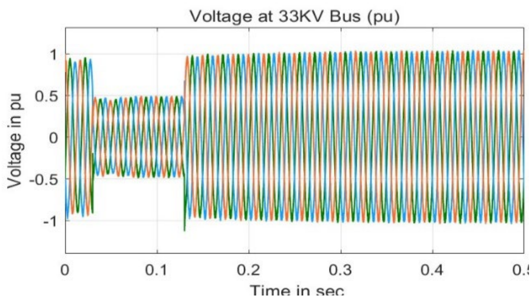

Figure 4(d). Voltage at 33KV bus

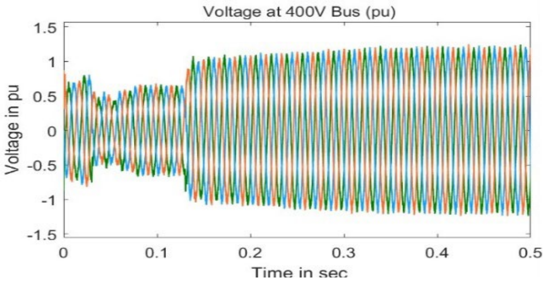

Figure 4(e). Voltage at 400V bus

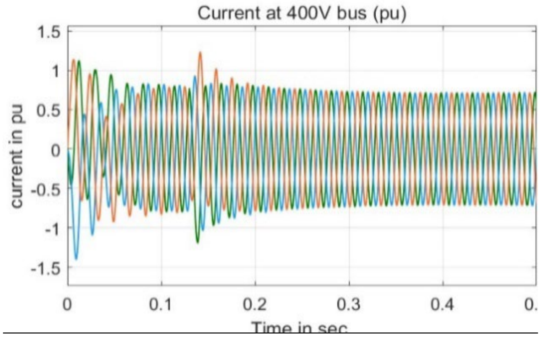

Figure 4(f). Current at 33KV bus

Figure 4. Performance characteristics of 33 MW Windfarm

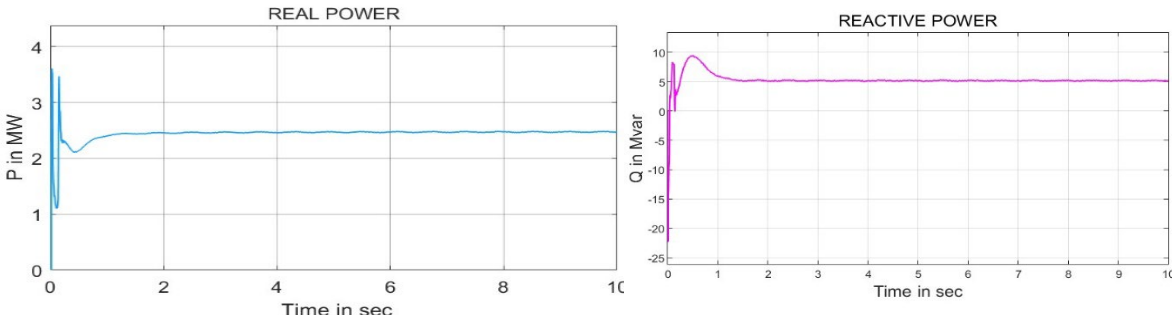

Figure 5. Real and Reactive Power of 3MW WTG

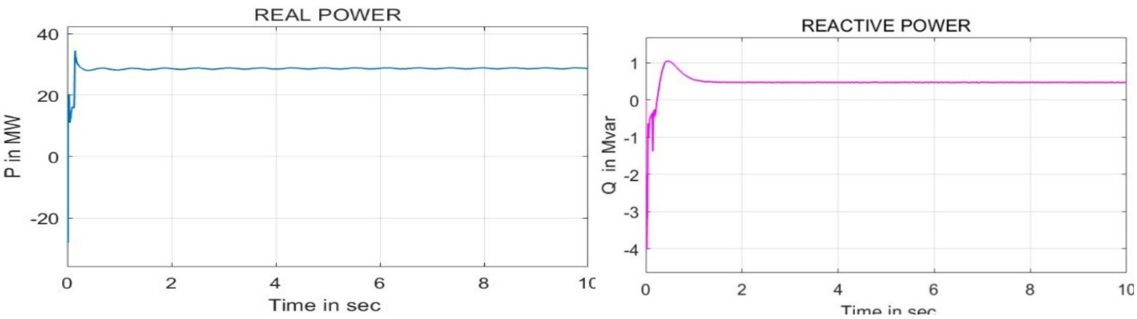

Figure 6. Real and Reactive Power of 33MW Windfarm

The simulated results of 33 MW windfarm is presented in Figure 5. The rotor speed of Induction Generator depicted in **Figure 4(a)** shows the variation within the range of 1.25 pu to 1.27 pu. The nominal DC voltage of about 1150V applied in the converters which is shown in **Figure 4(b)** The response of voltage and current at 33 KV bus bar are presented in **Figure 4(c)** and **4(d)** Similarly, the response of voltage and current at 400v bus bar are shown in **Figure 4(e)** and **4(f).** The power generation of 3 MW standalone WTG is shown in **Figure 5**. It clearly depicts that the value of power settle at 3MW after a few oscillations in the initial time.

This 3 MW WTG is utilized to develop the 33 MW wind farm comprising of 11 WTG. The response of real and reactive power is presented in **Figure 6**. The real power is achieved as 29 MW, which can be further increased with a special design.

5. Conclusion

As Wind Power has been developing rapidly in the world, the analysis of Induction Generator wind turbine is essential to understand its operating characteristics. This paper described the mathematical model composed of Induction Generator wind turbine and drive system. The performance evaluation of standalone Induction Generator fed by wind turbine and drive system is presented at steady state operating condition. In addition to that the characteristics of 33MW windfarm comprising of 11 wind turbines is also presented in this paper. The simulation results verify the effectiveness of the modelled system and clearly demonstrated the response of rotor speed, voltage and current at 400 V and 33 kV bus bar, real power, reactive power and torque. Future investigation into this work could take into account a wider range of input variables, including pitch angle and wake effect. The RSC and GSC schemes performance can also be compared to those of alternative controller types based on artificial intelligence, model reference adaptive system.

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