

Control and Operation of Microgrid Integrated with Solar PV and Wind Power (DFIG)



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Abstract This paper presents modeling and simulation of a renewable energy-based microgrid in a MATLAB environment for a particular selected load in different operating conditions. The microgrid technologies, that merge distributed generations, energy storage sections, and loads, lead to an effective approach to solving the interconnection of large-scale distributed generations with the main power grid. Wind and solar can be compatible with each other in time, therefore wind and solar PV power systems could make great use of clean energy and have greater reliability. The proposed microgrid system consists of a doubly-fed induction generator (DFIG) dependent wind energy conversion system (WECS), solar PV array, and loads. The wind turbine system is interfaced to the main utility grid along with the solar PV array system while the PV array is linked via an inverter and a boost converter with a maximum power point tracking system. Finally, simulation and analysis of the microgrid are carried out for various operating conditions.

Keywords Distribution generation system · DFIG wind turbine · Solar photovoltaic · Microgrid · Maximum power point tracking

1 Introduction

Under this section Distributed generation system, wind generation system, DFIG system, and PV system will be introduced. With the centralized facilities, large-scale generation of electricity can be achieved, and is referred to “centralized generation” which is a conventional system. Nowadays, unlike centralized generation, with small-scale generating units, the generation of electricity will be achieved, and it is known as de-centralized generation also known as distribution generation (DGs). DG refers to a variety of technologies that produce electricity at or near where it will be needed. DG can carry by a single structure, like a home or business or it can be a portion of a microgrid (MG). Meanwhile, at the same time the worldwide energy disaster,

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K. Namrata et al. (eds.), *Smart Energy and Advancement in Power Technologies*,
Lecture Notes in Electrical Engineering 927,
https://doi.org/10.1007/978-981-19-4975-3_14

Electricity demand, and large-scale power interruptions are there so to mitigate this problem DG will play a vital role. Due to the various advantages of integrating DG, it is always a research topic. In modern years, DG has set off as a well-organized and a better substitute to the conventional energy resources and modern technologies are making DGs economically suitable [1]. DG minimizes the amount of energy loss in transmitting electricity, as the electricity is generated very near to the load where it is utilized. DG allows you to collect energy from many sources and may offer lower environmental impacts and greater reliability and stability [2, 3].

By using the power of wind, the wind turbines (WTs) will make mechanical energy and with that mechanical energy, it will drive an electric generator that generates electricity. Generally, across the blades, the wind passes over and creates lift, and produces a rotating force. The WT blades which are rotating will rotate a shaft inside the nacelle, i.e., from the blade's swept area the WT draws kinetic energy. The gearbox here is having an important role that will maximize the rotational speed of the WT to drive the shaft of the generator. Based on Faraday's law of magnetic induction, mechanical energy is converted to electrical energy. Generated electrical energy is then converted to desired voltage level with the help of a power transformer. The WECSs at present are the most inexpensive, available, and viable renewable energy systems which have accomplished rapid growth in modern years. Wind energy systems incorporated with DFIGs have been effectively utilized in high-power generation as they use power-electronic converters with ratings below the rating of the WT generators [4–7].

The frequently used machine nowadays is the DFIG. The induction machine can be operated either as a motor or generator. The DFIG and WTs have secured and prominence in the utilization of generators in water and wind power plants because of their efficient capability for maintaining and flexibility. In this paper, the DFIG system and its modeling have been described in brief.

A PV system utilizes solar panels to convert solar energy into usable electrical energy. It is having different segments that include the PV modules, mechanical and electrical links, mountings, and means of regulating and adapting the electrical output [8, 9]. The PV system, when hit by the sunlight, will generate DC electricity without any impact on the environment. The fundamental components of PV arrays are the solar cell and primarily it is a P–N junction that turns sunlight energy into electrical energy. The PV module's output characteristic depends upon the temperature of the module's cell, solar irradiation, and output voltage.

2 Microgrid (MG)

2.1 Introduction

An MG is a localized group, i.e., a small-scale power grid. It has a small-scale network of electricity consumers with a domestic origin of supply either by solar generation or by WT or by diesel generators, which is nominally coupled to a centralized national grid but it is also able to function independently i.e., islanded mode. Power systems nowadays turning into a noticeable change in the operational process mainly due to an increase in distributed energy resources (DER) and deregulation. Having microsources adjacent to the load has the benefit of mitigating transmission losses and resolving congestion in the network, nowadays it is called a microgrid [10].

From the end-user point of view, MG can give both thermal and electricity needs and with that, it improves local reliability, enhances power quality by encouraging voltage and mitigating voltage dip, and perhaps it supplies power at a lower cost. The use of distributed energy sources can bring down bids for distribution and transmission facilities from the utility point of view [11, 12].

2.2 Advantages of MG

- i. A primary advantage of MG is its capability to seamlessly attached and detach itself from the utility grid and no disruption to the loads associated with the MG during a utility-grid disturbance.
- ii. It reduces the utility grid burden in peak load periods by lowering the load on the grid.
- iii. Usage of both electricity and heat allowed by the generator's close propinquity to the user, thereby increasing the overall energy efficiency.
- iv. By generating numerous or whole of its electricity needs, MG can act to diminish the electricity costs to its users.

2.3 Disadvantages of MG

- i. Voltage, frequency, and standard of power are the key points that must be contemplated and regulated according to appropriate standards while preserving the balance of power and energy.
- ii. The storage of electrical energy in battery banks is required in an MG therefore there is a need for space as well as maintenance.
- iii. It is difficult to resynchronize with the main grid.
- iv. MG protection faces the most difficult challenge.
- v. Issues related to stand-by charges and net metering may impede MG.

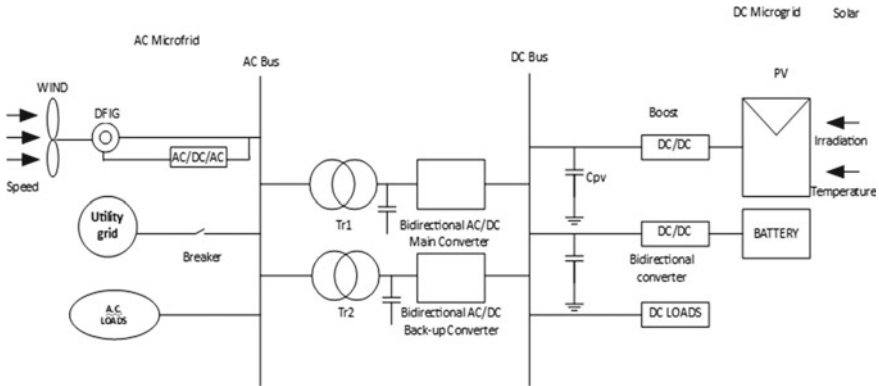


Fig. 1 A hybrid AC/DC MG system

2.4 Configuration of the Hybrid Microgrid (HMG)

Figure 1 deliberates the configuration of an HMG system that is consisting of AC and DC grids. These grids are having compatible sources, loads, power supplies, and a three-phase converter. The transformer and breaker are used to connect the AC bus to the main utility grid. In the proposed system, the PV array is linked to a DC bus to mimic DC sources with a boost converter. To mimic AC sources DFIG system is connected to an AC bus. To mimic the load which was connected in common to the grid and both the DFIG and solar PV system will deliver power to the load under different operating conditions.

3 Control and Modeling

3.1 DFIG

A comprehensive model of DFIG is described in Fig. 2. In the rotor circuit, two reverse transformers have been used. The main motivation of the machine side converter is that it can manage the real by handling the current units of the DC motor, while the grid-sided converter manages the DC-link voltage and make sure the operation of the unit’s power factor supply and keeps reactive power “Q” of the power system at zero. The simulated DGID model is shown in Fig. 3. In this DFIG Model, the performance of the DFIG system is analyzed under different values of wind speed. A load of 2 MW was connected at the load end and results of different parameters under varying wind speed have been observed.

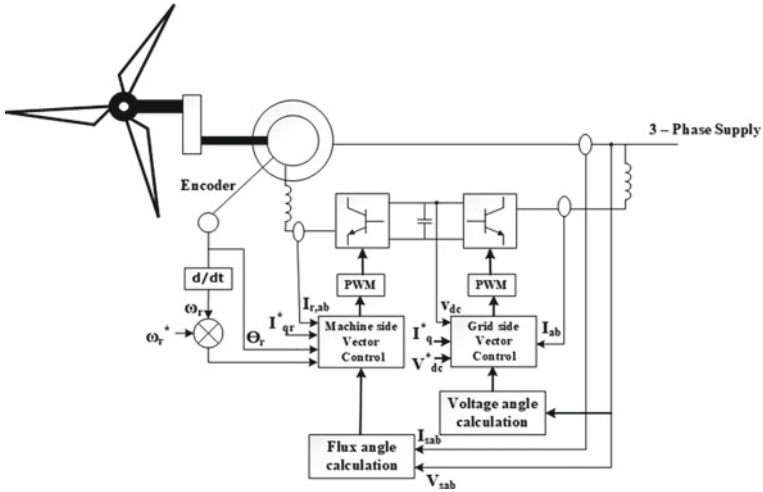


Fig. 2 Overall DFIG system

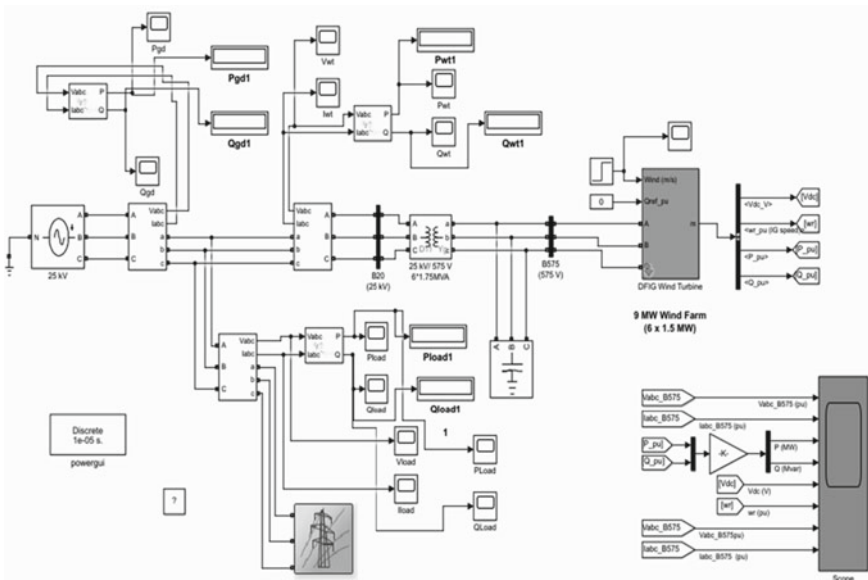


Fig. 3 DFIG model diagram

3.2 The Solar PV Array System

A comprehensive schematic diagram and model diagram of the solar PV array is represented in Figs. 4 and 5, respectively. The performance validation of the PV

array system had been carried out with variations in temperature and irradiance values. Here Max.PPT technique is used to track the maximum power peak point at which the panel has the peak energy. As from Fig. 4, the DC power obtained from the solar panel is converted into AC by using a 3-level bridge inverter after that the output level of the inverter will be converted to the desired level by using a transformer. The obtained AC supply is integrated into an already existed MG which is linked with DFIG to serve the resistive load of 2 MW which is connected at the end, and it can have been analyzed different parameters under variations in temperature and solar irradiance which is discussed in the result section.

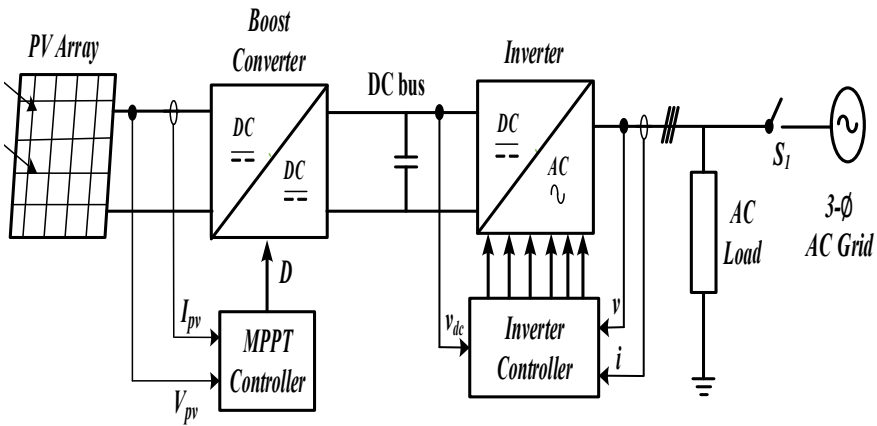


Fig. 4 Schematic diagram of Solar PV array system

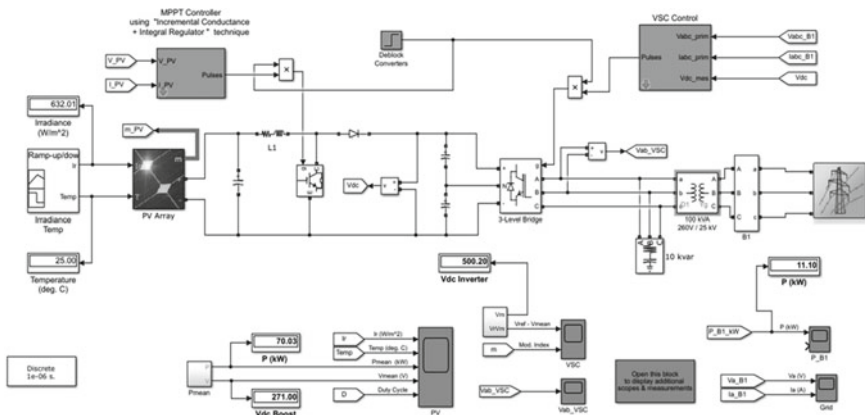


Fig. 5 Solar PV array model diagram

4 Results

An MG that is linked with a solar PV system and DFIG wind generation system is simulated using the MATLAB environment. The grid-connected mode has been considered for performance validation. The performance analysis is carried out with the HMG, DFIG, and PV Systems. With variation in the solar irradiation, the temperature of the cell, and the speed of the wind, a rigorous analysis of the MG has been done under MATLAB/Simulink environment.

4.1 PV Array Simulation

The only PV system is considered with the MG and corresponding simulated results are observed and discussed here. Figure 6 represents the output voltage (V_a) of the solar system, the output voltage taken at the secondary side of the boost transformer.

Figure 7 represents the output current (I_a) of the solar system, and it has been taken at the secondary side of the transformer.

Figure 8 depicts the output real power (P) which is produced by the solar PV system and here it produces slightly lesser than rated power of the PV system, i.e. 100 kW at steady state. The mean real power (P) produced by the solar system is 92.88 kW.

Figure 9 represents the output reactive power (Q)—as a purely resistive load has been taken, Q drawn by the load is 0 VAR. With a 2 MW load connected through a 5 km feeder, results of P and Q have been recorded. The temperature is kept at 50 °C

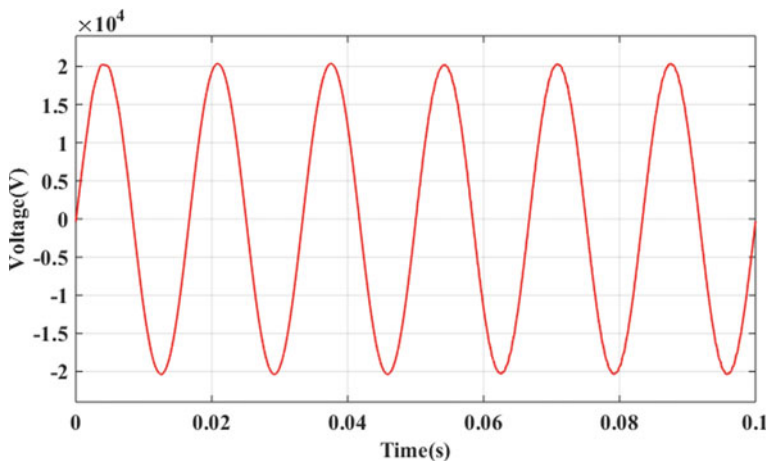


Fig. 6 PV array output voltage

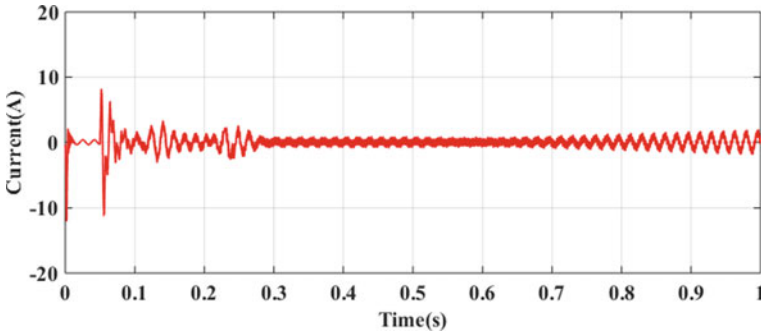


Fig. 7 PV array output current

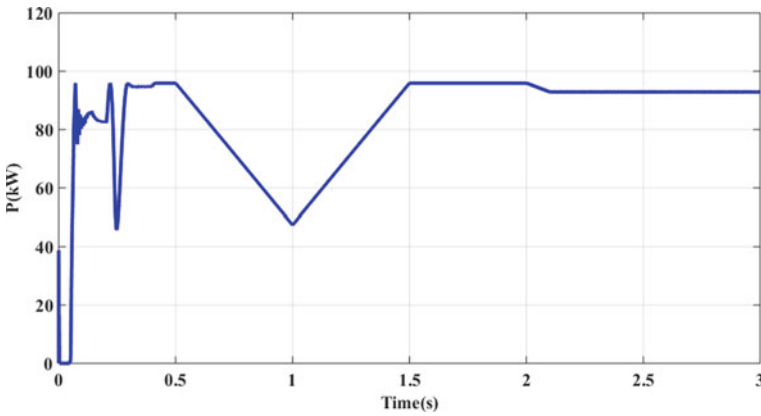


Fig. 8 Solar PV system output active power

and the solar irradiance at 1000 W/m^2 and P drawn by the load is 1.98 MW and the Q drawn by the load is 0 VAR —as the load is purely resistive.

In this simulation, Fig. 10 is showing the solar irradiance with variation in time. A signal builder has been taken such that the solar irradiance will vary from 0 s to 0.5 s it is 1000 W/m^2 and from 0.5 s it will bring down to 500 W/m^2 at 1 s and it raises from that point to 1000 W/m^2 and it continues to them till 3 s .

It can be seen from Fig. 11 that different values of the solar cell temperature have been considered. The temperature varies such that from 0 to 2 s it is at $40 \text{ }^\circ\text{C}$ and from that point, it increases to $50 \text{ }^\circ\text{C}$ and it continues to there till 3 s .

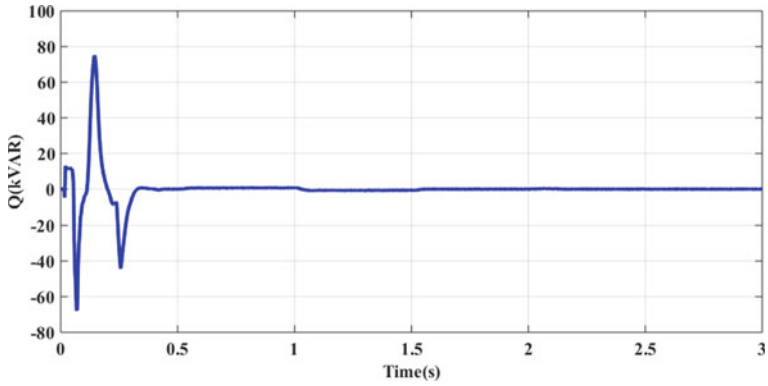


Fig. 9 Solar PV system output reactive power

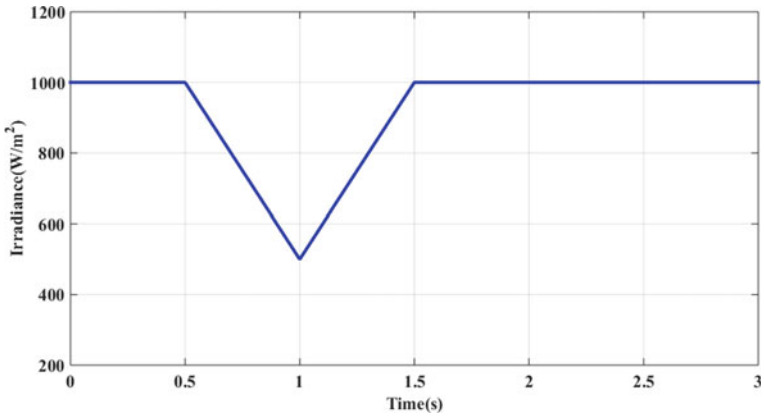


Fig. 10 Variation of irradiance considered

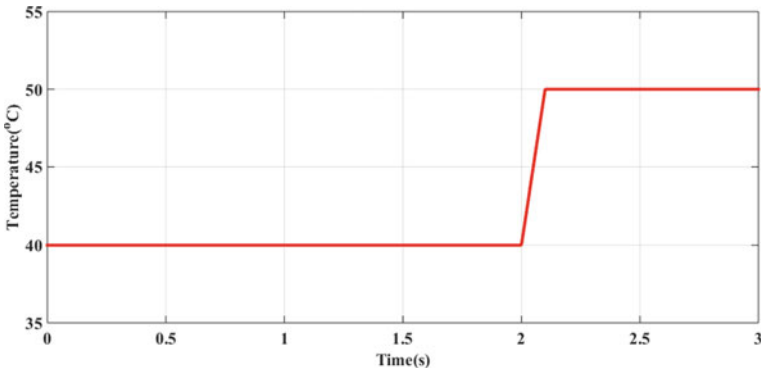


Fig. 11 Variation of solar cell temperature considered

4.2 DFIG Simulation

Here only the WGS with MG has been considered for performance evaluation. A DFIG WGS is connected to the main grid of 25 kV. In this model, the variation of wind speed considered is shown in Fig. 12. Initially, the wind speed is kept at 4 m/s after 2 s the wind speed increases to 40 m/s. The response of the wind speed is shown in Fig. 12.

In Fig. 13 the output voltage sampled at the output side of the WT was represented. Actually, in Fig. 13 the output voltage is represented per unit (P.U), the actual value of the output voltage which was generated by the DFIG WT is 575 V.

In Fig. 14 the output current sampled at the output side of the WT is represented. Actually, in Fig. 14 the output current is represented in the P.U system.

In Figs. 15 and 16, the output real power (P) and reactive power (Q) of the DFIG WGS are shown respectively. The P generated by the WGS at a steady state is nearly 8 MW and the Q is 0 VAR.

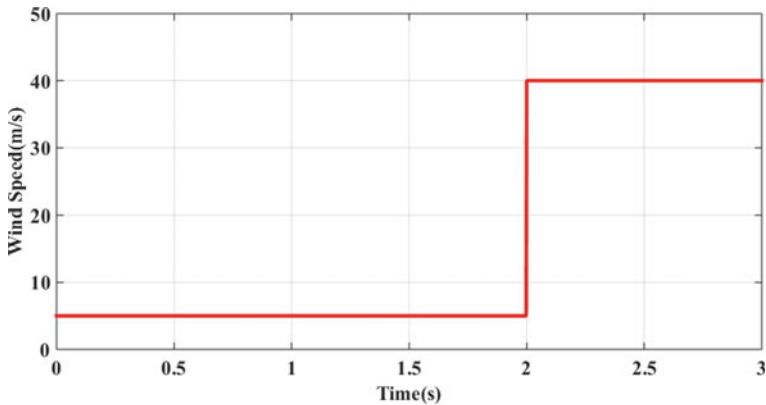


Fig. 12 Varying wind speed considered

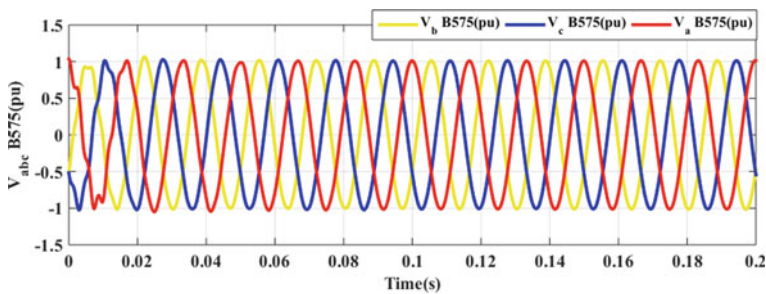


Fig. 13 DFIG 3-φ output voltage

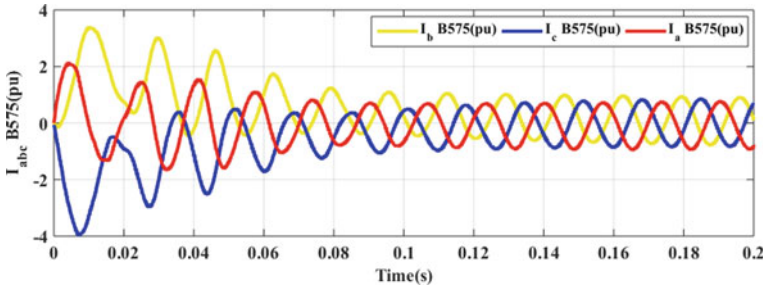


Fig. 14 DFIG 3- ϕ output current

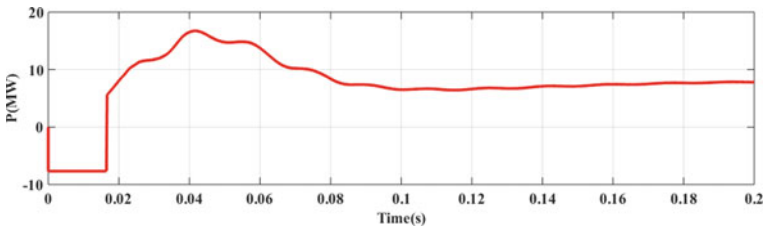


Fig. 15 DFIG output active power

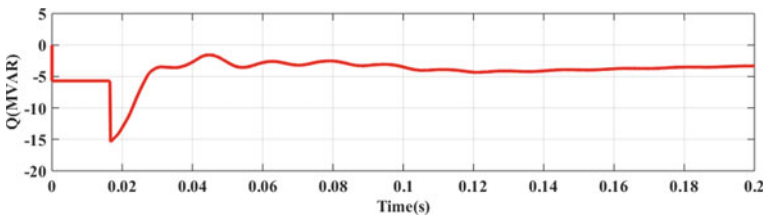


Fig. 16 DFIG output reactive power

In this model also a 2 MW load has been taken, which is connected at the end of a 5 km long feeder to the microgrid. The samples of P and Q have been used for analysis. The simulation runs for 3 s and at 3 s the P drawn by the load is 1.99 MW which is very much closer to the rated load and obviously, the reactive power drawn by the load is 0 VAR. The main utility grid taking 7.11 MW of P and 6.56 MVAR of Q and the load drawing P of 1.99 MW and the Q drawn is 0.7 kVAR which is the reactive VAR drawn by the feeder as the load is purely resistive. By observing these results, it is clear that the system is well balanced.

4.3 MG Simulation

In this Model, the PV array and the DFIG WT generation sources both are interconnected to a common utility grid and it is finally coupled to the main power grid like Grid-tied mode and a load of 2 MW is connected at the end of a 5 km feeder as same as in the PV array model and DFIG WT model. In Fig. 17 Solar PV system generated real power (P_{pv}) sample which is taken at the output end side of the solar PV system is shown. Here the solar PV system generates 92.70 kW of P_{pv} which is shown in the figure. In Fig. 18 Solar PV system generated reactive power (Q_{pv}) sample which is taken at the output end side of the solar PV system is shown. Here the solar PV system generates 0.68 kVAR and which is giving to the main grid. In Fig. 19, the real power (P_{dfig}) generated by the DFIG WT is shown. Here at time 3 s the P_{dfig} generated is 9.66 MW.

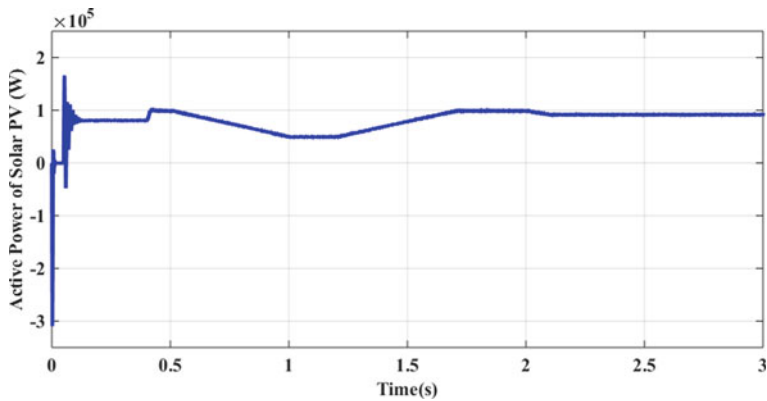


Fig. 17 Solar PV array real power

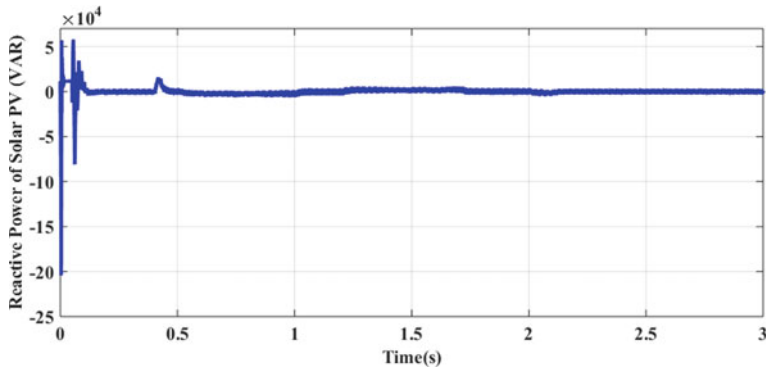


Fig. 18 Solar PV array’s reactive power

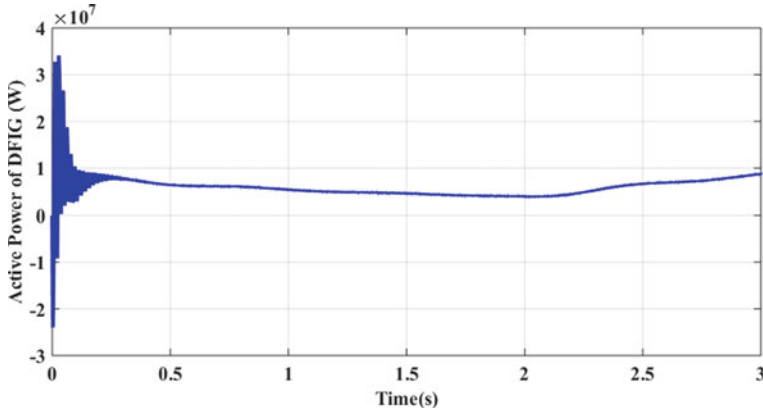


Fig. 19 DFIG real power

In Fig. 20, the Reactive power (Q_{dfig}) generated by the DFIG WT is shown. Here at time 3 s the Q_{dfig} generated is 8.26 MVAR. In Fig. 21 the real/active power (P_{load}) drawn by the load which is connected commonly to the MG is shown. Here the load drawing 1.99 MW of P_{load} from the grid at time 3 s.

In Fig. 22 the reactive power (Q_{load}) drawn by the load which is connected commonly to the MG is shown. Here the load drawing 0 VAR of Q_{load} from the grid at time 3 s but as we connected the load through a 5 km feeder so the feeder consuming some amount of reactive Vars which is 0.7 kVAR.

In this MG model, the P contributed by the DFIG WT generator is 9.66 MW, and the Q contributed by the DFIG WT generator is 8.26 MVAR, the P contributed by the PV array model is 92.7 kW and the Q contributed by the PV array is 676 VAR. Here it is observed that the power is received by the load at the starting of the feeder.

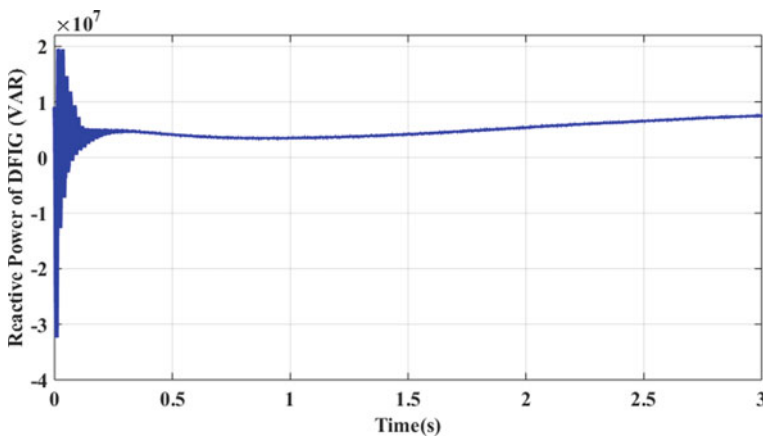


Fig. 20 DFIG reactive power

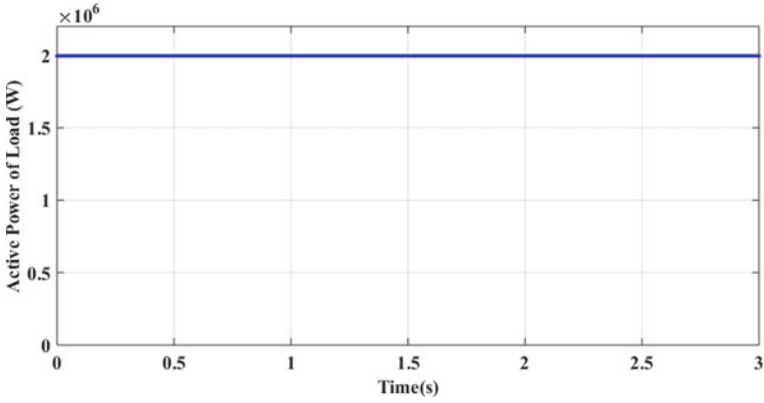


Fig. 21 Active power is drawn by the load

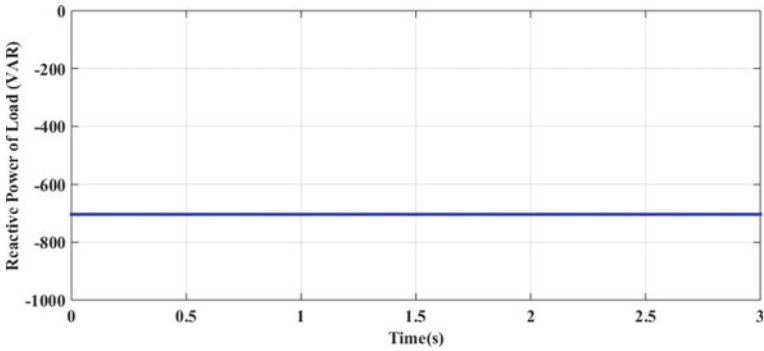


Fig. 22 Reactive power is drawn by the load

The samples of P and Q are taken, those values are 1.99 MW and -0.7 kVAR. Here the main power grid taking P of 3.54 MW and the Q taking by the main power grid is 3.83 MVAR. With a load of 2 MW and the load is drawing P of 1.99 MW, as it is a resistive load so the Q drawn by the load is 0 VAR.

5 Conclusion

A fully renewable-energy-dependent MG has been designed and the model was simulated for a particular chosen load and the simulation results are analyzed. From the simulation results, it was observed that the designed MG is successfully meeting the required load demand as a connected load of 2 MW, and the MG conveniently serving the load with 1.99 MW as the connected load is resistive so the reactive power

at the load end is zero. It is found that from this analysis, modeling of renewable energy-dependent MG was found to be feasible and functional for the desired load.

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