AIMS Energy

http://www.aimspress.com/journal/energy

AIMS Energy, 6(5): 832–845.
DOI: 10.3934/energy.2018.5.832
Received: 12 July 2018
Accepted: 03 September 2018
Published: 08 October 2018

Research article

Stability impact of integrated small scale hybrid (PV/Wind) system with electric distribution network

Zeid Al Qaisi[1], Qais Alsafasfeh[2] and Ahmad Harb[1,*]

[1] School of Natural Resources Engineering, German Jordanian University, Amman, Jordan
[2] Energy Engineering Departments, College of Engineering, Al Hussein Technical University, Amman 25175, Jordan; Sabbatical leave from Tafila Technical University, Department of Electrical power and Mechatronics, Tafila, Jordan

* **Correspondence:** Email: aharb48@gmail.com.

Abstract: Small-scale renewable energy systems are becoming increasingly popular due to soaring fuel prices and technological advancements that reduce the cost of manufacturing. Solar photovoltaic (PV) and wind turbine (WT) are the most common renewable sources used now. It is well known that these renewable energy sources are intermittent in nature, which impose a challenging to integrate them into the power grid. This paper aims to examine the dynamic behavior of the hybrid PV-WT model under different operating conditions, and the impact of the hybrid PV-WT on the system stability when a fault applied at a point of common coupling (PCC). In this paper, a model of grid connected PV/WT hybrid system is presented. It consists of PV, WT, induction generator, controller and converters. The model is implemented using MATLAB/SIMULINK. Perturb and Observe (P & O) algorithm is used for maximizing the output power from PV array. The fixed speed wind turbine with induction generator is used. This paper shows a good dynamic performance of hybrid PV-WT under different operating conditions. This system has minor impacts on power quality. The transient stability of this system is affected by hybrid PV-WT. The fault clearing time is improved with renewable sources, and become less critical than the system without renewable ones.

Keywords: micro-grid (μG); distributed generation (DG); hybrid PV-WT; stability

1. Introduction

The future energy demand is increasing rapidly while the conventional energy resources are depleted. As a result, the world is looking for alternative sources of energy [1–4]. There are promising sources of hybrid distributed generation, such as; wind generator, solar PV, fuel cell, small hydro, biomass, geothermal, tides, wave generator. Wind generator and solar PV are the most commonly used [5].

The integration of small modular generation and energy storage to low or medium voltage distribution systems forms a new type of power system, named the microgrid (μG). The μG can operate in grid-connected mode or in islanded mode, where it appears to the main grid as a single load or source depending on whether load is higher than the generating source in the area. Moreover, DGs and loads may be located close to each other or distributed geographically. Therefore, it provides higher flexibility and reliability [6–8]. Grid-connected μG is capable of supplying energy on its own, allowing it to operate in connection with an electrical power system, or to form an independent system for power supply [9,10].

Small-scale systems represent one type of the key renewable energy applications. Multi-source hybrid renewable energy sources overcome the intermittency, uncertainty, and low availability of single-source renewable energy systems, which amkes the power supply more reliable [11,12].

PV and wind power are complment to each other as it is in certion regions when solar enegy is low wind tends to be stronger [13,14]. Enormous studies discussed the complementarity of solar radiation and wind speed [15]. In [16] the solar and wind complmentary in canda has shown that spatial dispersion of solar and wind resources smooth there power output. Aanother analysis presented the complementarity of solar and wind resources in china can reduce the occurrence of zero and peak power yield hours [17]. Moreover, wind speed has the most significant impact on the efficiency of any solar PV plants [18]. By cooling the PV panels, the output power generated from PV system is enhanced. The most-cost effective method to increase cooling of PV panels is taking advantage of natural wind [19]. Therefore, hybrid PV-Wind systems have higher availability and reliability than systems based on individual PV or wind sources [20,21].

As mentioned early that renewable energy sources are intermittent in nature, there is a challenging task to integrate renewable energy sources into the power grid. From a technical aspect, renewable energy poses some impacts on power systems, especially to the operations of distribution systems. They mainly include voltage issue, protection, power quality, stability and security [22–24].

Solar penetration changes the voltage profile and frequency response of the system [25]. Induction generator (IG) generates power fluctations & stability problems due to their lack of control ability. This can decrease the power quality and causes transient instabilty. Therfore, suitable devices such as FACTS devices, rotor circuit control, Dynamic Voltage restorers (DVR), and breaking resistors are used for improving stability problems [26].

The integration of hybrid PV-WT system into grid can improve the realibility of renewable power generation to supply the load and minmizing the overall cost. The grid takes excess renewable power generated and supplies power to loads when required. Recently, many studies have been conducted on the realibility of hybrid PV-WT system. The study in [27] has prposed a new realiblity indicator, which can be used to optimize hybrid PV/Wind energy systems. The energy reliability-constrained (ERC) method was used in the design and the performance of grid connected hybrid system [28]. This paper focuses on studying the dynamic performance of a small-scale hybrid

PV-WT system under different operating conditions, such as solar irradiation, wind speed, and loads. The impacts of DGs on system stability when three phase to ground fault is applied are carried out.

The paper is organized as follows: Section 2 provides description and modelling of proposed hybrid PV-WTsystem. In Section 3, an overview of power system stability is presented. Finally, in Section 4, the dynamice performance and transient stability of the prposed system are disccused.

2. System- architecture & modeling

The proposed system is shown in Figure 1, which is composed of PV arrays, DC/DC converter, with MPTT, AC/DC inverter, a Fixed Speed Wind turbine system with induction generator and three phase load. The DGs are connected in AC architecture. WT is directly connected to PCC, whereas PV arrays are connected to PCC via boost converter and voltage source inverter (VSI).

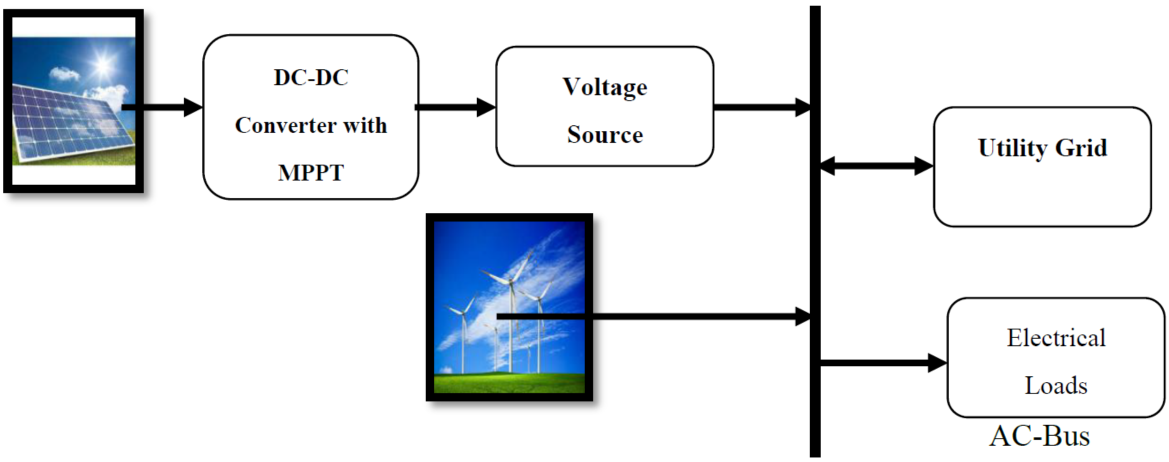

Figure 1. System archeticutre of small scale hybreid PV-WT grid connected system.

2.1. Modeling of PV arrays

The PV array consists of several solar modules. Basically, modules are connected in series to increase the voltage capability of the array. To increase the current capability of the array, additional modules are connected in parallel. The output voltage of the array is highly nonlinear with respect to the current [29].

The equivalent circuit of PV cell is shown in Figure 2. The mathmatical model of PV array used in this paper is taken from [30].

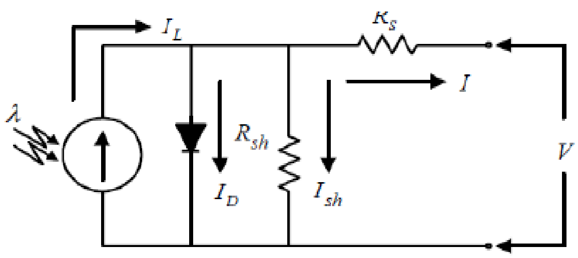

Figure 2. Equivalent circuit of PV cell.

The electrical characteristics of the PV module are generally represented by the current verses voltage (I-V) and the Power verses Voltage (P-V) curves [31].

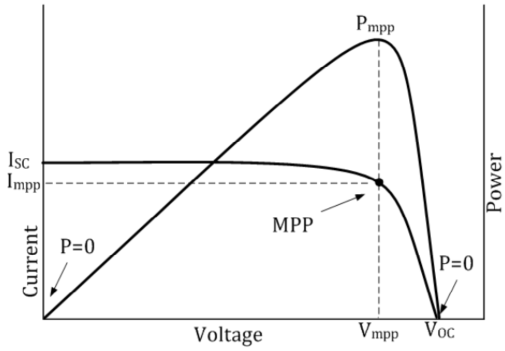

Figure 3. I-V & P-V curves of PV module.

The PV array must operate electrically at certain voltage which corresponds to the maximum power point under the given operating conditions. A maximum power point tracking technique (MPPT) should be applied to maximize the output power of PV system. There are various MPPT techniques like look-up table methods, perturbation and observation (P & O) methods and computational methods [32]. The perturbation and observation (P & O) method is used in this paper.

2.2. Perturbation & observation MPPT technique (P & O)

The P & O MPPT algorithm is mostly used, due to its ease of implementation. It is based on the following criterion: If the operating voltage of the PV array is perturbed in a given direction and if the power drawn from the PV array increases, this means that the operating point has moved toward the MPP and, therefore, the operating voltage must be further perturbed in the same direction. Otherwise, if the power drawn from the PV array decreases, the operating point has moved away from the MPP and, therefore, the direction of the operating voltage perturbation must be reversed. In the next perturbation cycle the algorithm continues in the same way. When the steady state is reached the algorithm oscillates around the peak point [33]. Figure 4 depicts a flowchart witch describe the P & O technique.

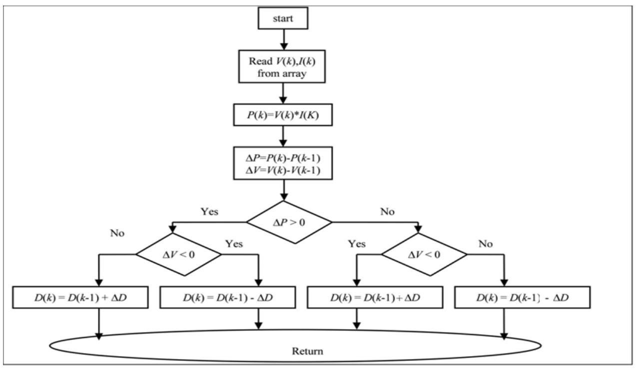

Figure 4. Flowchart describes the P & O method.

2.3. Modeling of wind turbine with ınduction generator (WTIG)

The advantages of a fixed-speed wind turbine are a simple design with high reliability and low investment and maintenance costs. The WTIG is consisits of two parts; the electrical part representing the induction generator, and the mechanical part representing the wind turbine operation. The stator winding of squirrel cage induction generator (SCIG) is connected directly to the grid and its rotor is driven by the wind turbine, as shown in Figure 5. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The electrical part of the machine is represented by space model and the mechanical part by second-order system as discussed in [34].

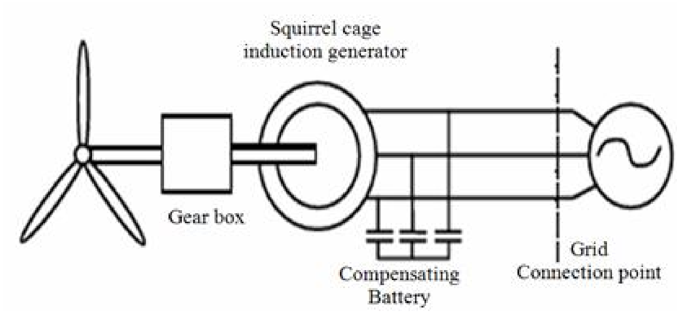

Figure 5. System structure of fixed-speed wind turbine with direct connected squirrel cage induction generator.

WTs convert the kinetic energy in wind into mechanical energy. The amount of kinetic energy generated depends on the air density and wind speed. This is due to the energy contained in wind is in the form of kinetic energy.

The power generated from wind turbines is given by:

$$P_m = 0.5\, \rho\, C_p\, A\, V^3 \tag{1}$$

Where P_m is the mechnical output power of the turbin, C_p is power coefficient, ρ is the air density in $\frac{kg}{m^3}$, A is the area of turbine blade in m^2, V is the velocity of wind in $\frac{m}{s}$.

2.4. Voltage source inverter

The VSI is connected to the DC link of PV system. The inverter's control strategy is based on current control mode. Inverter is operated in line with the output bus of the system. It is controlled to extract all the available active power to the load. The proposed control scheme of the PV VSI is considered as a cascade of two dependent control loops, as shown in Figure 6. Usually the reactive current (i_{qref}) is set to zero for unity power factor operation of the PV-DG system [35].

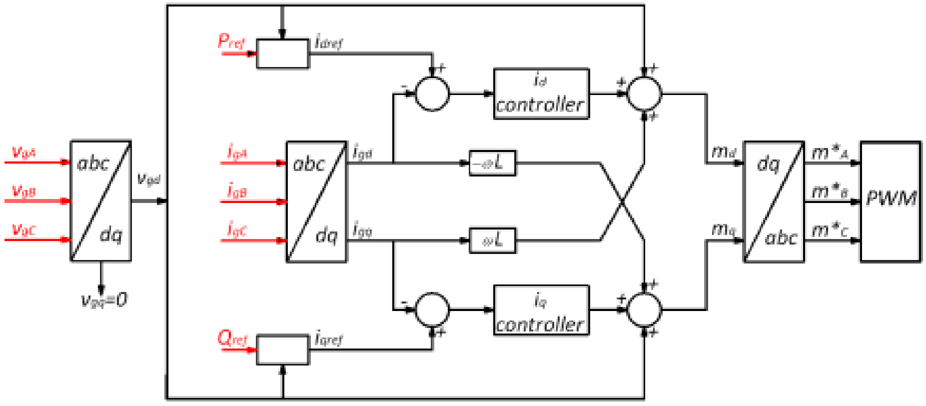

Figure 6. Control block diagram of VSI.

3. Fundemntal of power system stability

Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact [36].

The stability of a power system can be classified into the following 3 types [36]:

(1) Steady state stability: The steady state stability of a power system is defined as the ability of the system to bring itself back to its stable configuration following a small disturbance in the network (like normal load fluctuation).

(2) Transient stability: The Transient stability refers to the ability of the system to reach a stable condition following a large disturbance in the network condition (like sudden application or removal of load, switching operations, and line faults).

(3) Dynamic Stability: Dynamic stability of a system denotes the artificial stability given to an inherently unstable system by automatic controlled means. It is generally concerned to small disturbances lasting for about 10 to 30 seconds.

4. Simulation results AND discussions

The block diagram of integrated PV-WT system is shown in Figure 1. The system is simulated using MATLAB/SIMULNK. It is composed of 12.6 kW PV and 9 kW WT which are supplying a local load. The base wind speed is 9 m/s. First, the dynamic behaviour of this system is analyized under different operating condtions. Then, the impact of hybrid PV-WT on grid stability when a fault is applied at the PCC is discussed.

4.1. Dynamic behaviour of hybrid PV-WT grid connected system

The dynamic performance of Hybrid PV-WT Grid connected system is studied under different operating condtions such as solar irradiation, wind speed, and loads. The solar irradiation and wind speed signals are shown in Figures 7 and 8, respectively. The load power curve of the prposed system is presented in Figure 9.

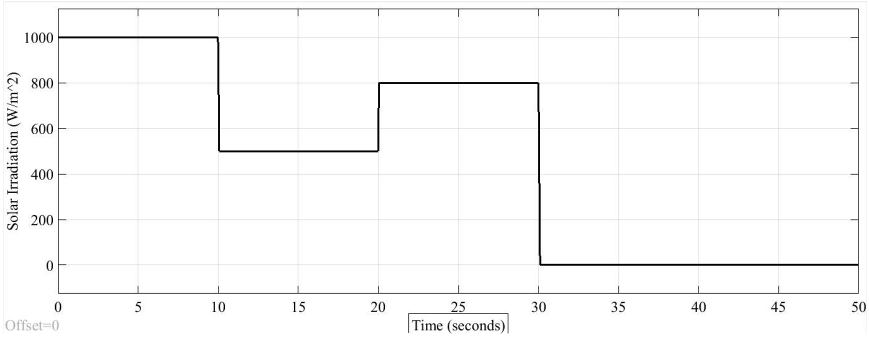

Figure 7. Solar irradiation signal.

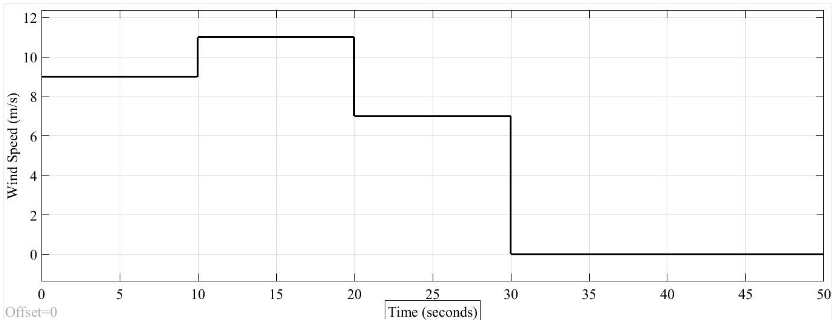

Figure 8. Wind speed signal.

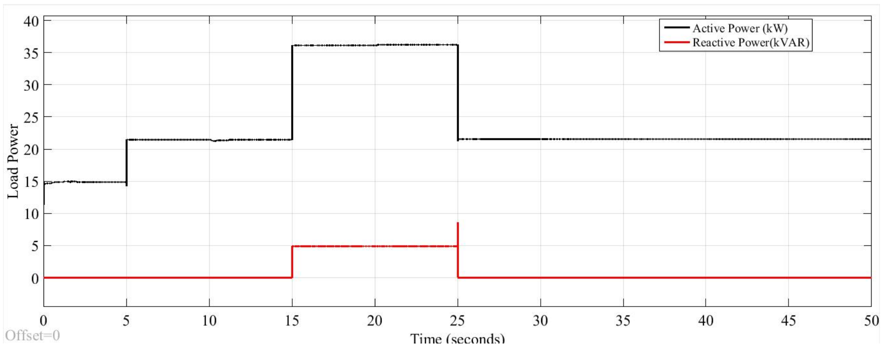

Figure 9. Load power curve.

The output power of the PV depends on solar irradiation and ambient temperature. Solar irradiation has the major influence on the performance of the PV system, the output power is directly proportional to the insolation level. The output power of the PV is depicted in Figure 10. As it is shown in Figure 10, the output power of the PV decreses when solar irradition decreased. For each 10 s the solar irradition signal varies, therfore, the output power of the PV system is fluctuated.

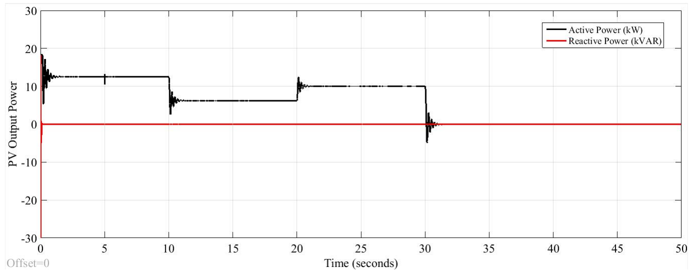

Figure 10. The output power of PV system.

The output power of WT depends on wind speed. As shown in Figure 11, the output power of WT varies each 10 s due to change in wind speed. At 10 s the wind speed became larger than base wind speed, the pitch control system is activated at this moment to change the beta angle of WT. At 17 s the pitch control is deactivated and the output power of WT is 9 kW which is the rated power of WT.

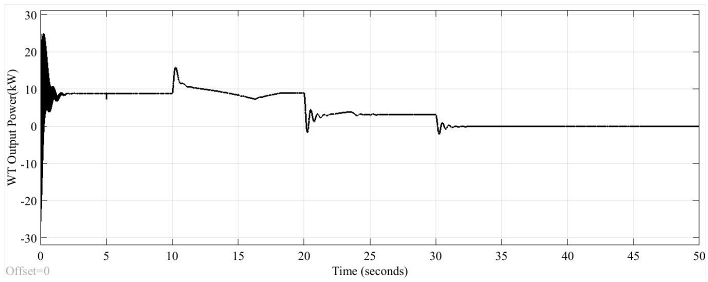

Figure 11. The output power of WT system.

The interaction between the exisiting grid and hybrid PV-WT system is shown in Figure 12. The grid power is depending on weather condtions and load curve. For the first 5 s the power generated from PV-WT system is more than the load power, so the excess power is transferred into the grid. Whereas the grid provides reactive power to the WT because the induction generator is not self excited generator. At t = 5 s, the load increased, and the power generated from PV-WT is equal to the total load, therfore the grid power is zero for the next 5 s. At t = 10 s, the grid is supplied power to the load because of variations in solar irradiation. The grid power is increased at t = 15 s because the electricl load increased. Then the grid power variation depends on weather condtions and load. Finally, At t = 30 s, there is no output power generated from hybrid PV-Wt, therfore, the load power is supplied by the grid.

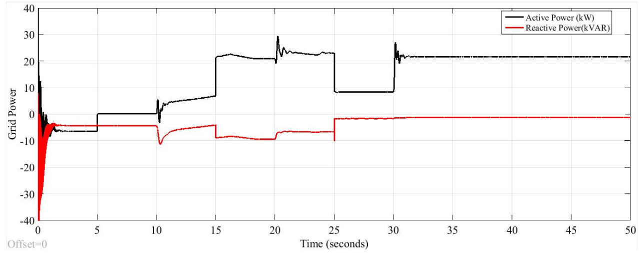

Figure 12. The grid power of hybrid PV-WT grid-connected system.

Wave form of ac line to ground voltage of the proposed system is shown in the Figure 13.

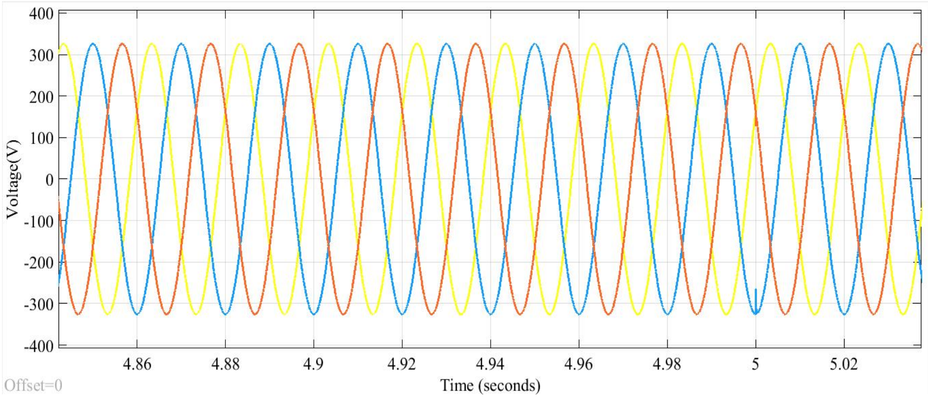

Figure 13. The load voltage of the prposed system.

Frequency of the system is presented in Figure 14. One can see that the frequency is regulated to 50 Hz. The fluctations in the frequency is a result of the variations in weather condtions and load.

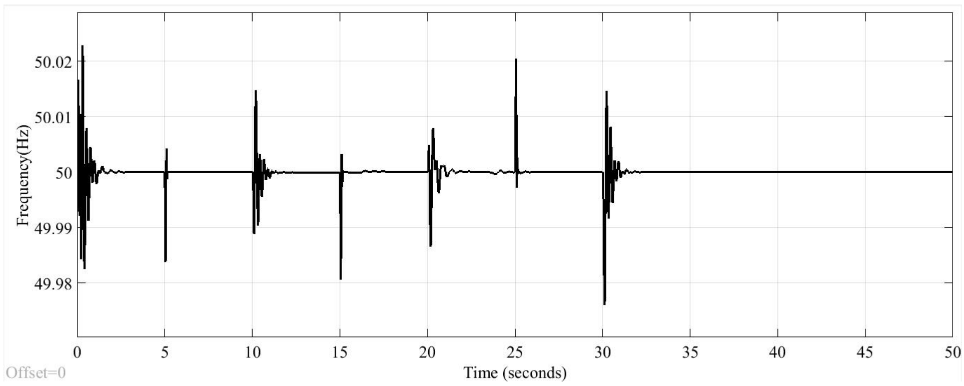

Figure 14. Frequency of the hybrid PV-WTIG grid connected system in case 1.

4.2. Transient stability of hybrid PV-WT grid connected system

After we studied the dynamic performance of the prposed system the transient stability of three phase short circuit is analysed. In this case, the renewable DGs operates in ideal conditions (G = 1000 W/m^2, T = 25 deg and W = 9 m/s). To investigte the impact of PV-WT on the transient stability, two cases are considered: 1) the fault is applied for 0.2 s, and 2) the fault is applied for 1 s.

Case 1: The fault is applied for 0.2 s

In case 1, the fault is applied at t = 15 s for 0.2 s. Figures 13–15 show the output power of renewable DGs system and grid, when three phase short circuit is applied for 0.2 s. As shown in these figures, there are transient state in output power of PV, WT, and grid due to the fault is applied at 15 s and after 4 s from clearing the fault the system returend to it’s stable state as shown in Figure 15–17 .

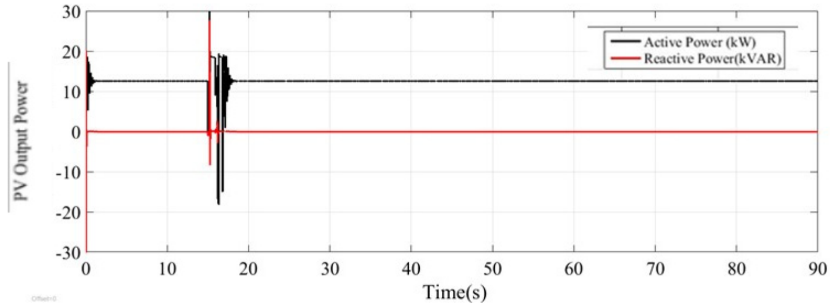

Figure 15. The output power of PV system when three phase to ground fault is applied for 0.2 s.

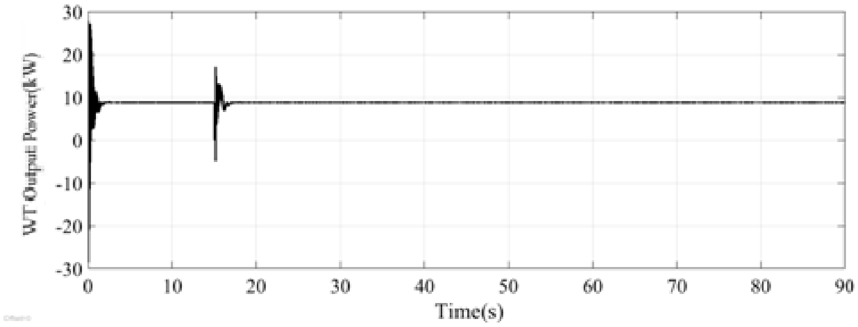

Figure 16. The output power of WT when three phase to ground fault is applied for 0.2 s.

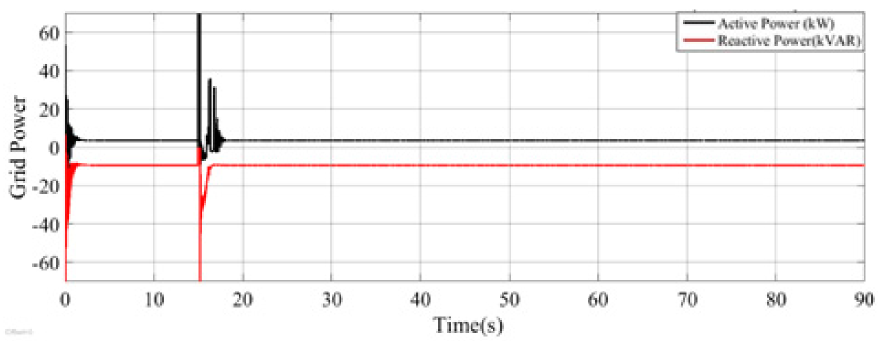

Figure 17. The grid power when three phase to ground fault is applied for 0.2 s.

4.3. Case 2: The fault is appliedfor 1 s

Figures 18–20 show the output power of renewable DGs system and grid when three phase short circuit is applied for 1 s. As shown in these figures, there is transient state in output power and after clearing the fault the system is unstable. The unstability of the system ocurred because of the WT has not the ability of fault ride-through. We find that the critical clearing time of the fault for the prposed system is 0.25 s.

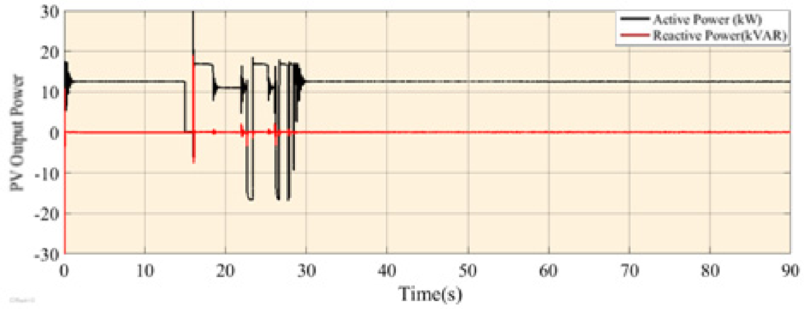

Figure 18. The output power of PV when three phase to ground fault is applied for 1 s.

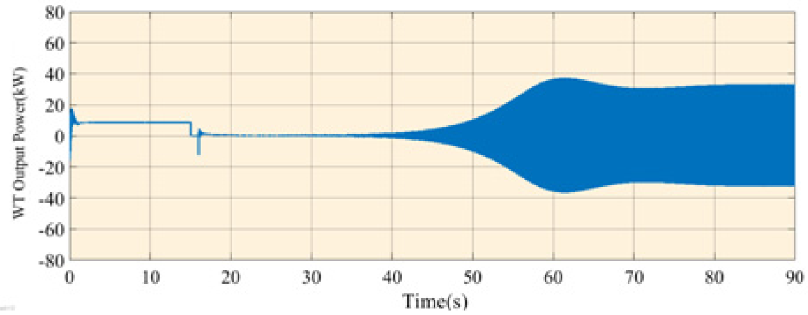

Figure 19. The output power of WT when three phase to ground fault is applied for 1 s.

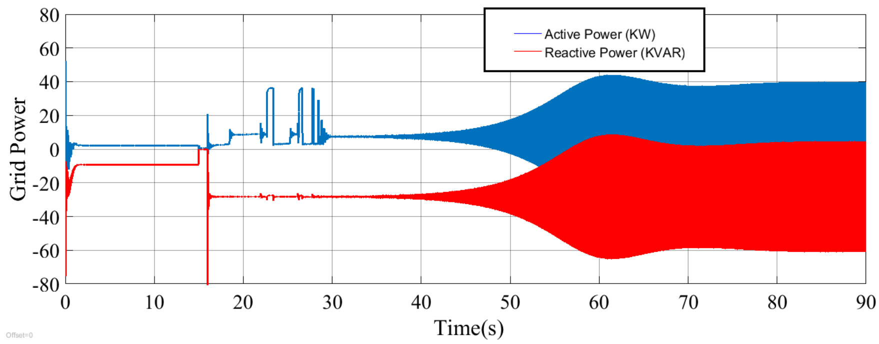

Figure 20. The output power of grid when three phase to ground fault is applied for 1 s.

5. Conclusion

In this paper, a small scale hybrid PV-WTIG grid connected was modeled using Matlab/Simulink. The dynamic performances of the hybrid system at different weather conditions are analyzed. The frequency of the system is regulated by grid. When the generated power from renewable DGs is more than the load, the excess generation is transferred into the grid. On the other hand, when the load power is more than power generated by renewable DGs, the grid provides shortage to the load.

In PV system, Perturb & observe MPTT technique was used to statisfy the maximum output power of PV arrays at different weather condtions. VSI is assumed to operate at unity power factor. WTSCIG generats maximum power only at base wind speed.

SCIG generates power fluctations & stability problems due to their lack of control ability. This can decrease the power quality and causes transient instabilty. Therfore, suitable devices such as FACTS devices, rotor circuit control, Dynamic Voltage restorers (DVR), and breaking resistors are used for improving SCIG stability problems.

The stability of the system was studied, under two fault conditions. The fault clearing time is the key element of the system stability. The analysis in this paper showed that the critical clearing time is 0.25 seconds, which means if the fault period is more than 0.25 seconds. Therefore, the system is unstable.

Conflict of interests

The authors declare no conflict of interest in this paper.

References

1. Organization Of The Petroleum Exporting Countries (OPEC) (2009) World oil outlook. Available from: http://www.opec.org/opec_web/en/.
2. Exxonmobil, Outlook for energy—A view to 2030. Available from: http://www.exxonmobil.com/.
3. Energy Information Administration (EIA) (2009) International energy outlook. Available from: www.eia.doe.gov/oiaf/ieo/index.html.B. Simpson.
4. Yorozu T, Hirano M, Oka K, et al. (1987) Electron spectroscopy studies on magneto-optical media and plastic substrate interface. *IEEE Transl J Magn Jpn* 2: 740–741.
5. Organization of The Petroleum Exporting Countries (OPEC) (2009) Available from: http://www.opec.org/opec_web/en/.
6. Nagliero A, Mastromauro RA, Monopoli VG, et al. (2010) Analysis of a universal inverter working in grid-connected, stand-alone and micro-grid. *IEEE Int Symp Ind Electron* 2010: 650–657.
7. Syed MH, Zeineldin HH, El Moursi MS (2013) Grid code violation during fault triggered islanding of hybrid micro-grid, In: Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES, 1–6.
8. Qiang L, Lin Z, Ke G (2012) Review on the dynamic characteristics of micro-grid system, In: Industrial Electronics and Applications (ICIEA), 2012 7th IEEE Conference on, 2069–2074.
9. Microgrids, Islanded Power Grids and Distributed Generation for Community, Commercial, and Institutional Applications, Navigant Research, Boulder (2009) Available from: http://www.navigantresearch.com.
10. Lasseter RH (2002) Microgrids, In: Power Engineering Society Winter Meeting, 1: 305–308.
11. Chen Y, Wei W, Liu F, et al. (2016) Distributionally robust hydro-thermal-wind economic dispatch. *Appl Energy* 173: 511–519.
12. Li FF, Qiu J (2016) Multi-objective optimization for integrated hydro–photovoltaic power system. *Appl Energy* 167: 377–384.

13. dos Anjos PS, da Silva ASA, Stošić B, et al. (2015) Long-term correlations and cross-correlations in wind speed and solar radiation temporal series from Fernando de Noronha Island, Brazil. *Phys A* 424: 90–96.
14. Monforti F, Huld T, Bódis K, et al. (2014) Assessing complementarity of wind and solar resources for energy production in Italy. A Monte Carlo approach. *Renew Energ* 63: 576–586.
15. Jurasz J, Wdowikowski M, Kaźmierczak B, et al. (2017) Temporal and spatial complementarity of wind and solar resources in Lower Silesia (Poland). In: E3S Web of Conferences, EDP Sciences, 22: 00074.
16. Chen T, Alsafasfeh Q, Pourbabak H, et al. (2017) The next-generation US retail electricity market with customers and prosumers—A bibliographical survey. *Energies* 11: 8.
17. Ajao A, Luo J, Liang Z, et al. (2017) Intelligent home energy management system for distributed renewable generators, dispatchable residential loads and distributed energy storage devices. *Renew Energ Congr* 2017: 1–6.
18. Louy M, Tareq Q, Al-Jufout S, et al. (2017) Effect of dust on the 1-MW photovoltaic power plant at Tafila Technical University. *Renew Energ Congr* 2017: 1–4.
19. Liang Z, Alsafasfeh Q, Jin T, et al. (2017) Risk-constrained optimal energy management for virtual power plants considering correlated demand response. *IEEE Trans Smart Grid*.
20. Refou O, Alsafasfeh Q, Alsoud M (2015) Evaluation of electric energy losses in southern governorates of Jordan distribution electric system. *Int J Energy Eng* 5: 25–33.
21. Vasel A, Iakovidis F (2017) The effect of wind direction on the performance of solar PV plants. *Energ Convers Manage* 153: 455–461.
22. Nižetić S, Papadopoulos AM, Giama E (2017) Comprehensive analysis and general economic-environmental evaluation of cooling techniques for photovoltaic panels, Part I: Passive cooling techniques. *Energ Convers Manage* 149: 334–354.
23. Liserre M, Sauter T, Hung JY (2010) Future energy systems: Integrating renewable energy sources into the smart power grid through industrial electronics. *IEEE Ind Electron Mag* 4: 18–37.
24. Wang C, Wang L, Shi L, et al. (2007) A survey on wind power technologies in power systems. *Power Eng Soc Gen Meet* 2007: 1–6.
25. Hadjsaid N, Canard JF, Dumas F (1999) Dispersed generation impact on distribution networks. *IEEE Comput Appl Power* 12: 22–28.
26. Woyte A, Van Thong V, Belmans R, et al. (2006) Voltage fluctuations on distribution level introduced by photovoltaic systems. *IEEE T Energ Convers* 21: 202–209.
27. Duong MQ, Grimaccia F, Leva S, et al. (2015) Improving transient stability in a grid-connected squirrel-cage induction generator wind turbine system using a fuzzy logic controller. *Energies* 8: 6328–6349.
28. Villalva MG, Gazoli JR, Filho ER (2009) Modeling and circuit-based simulation of photovoltaic arrays. *Power Electron Conf* 14: 1244–1254.
29. Acuña LG, Padilla RV, Mercado AS (2017) Measuring reliability of hybrid photovoltaic-wind energy systems: A new indicator. *Renew Energ* 106: 68–77.
30. Mazzeo D, Oliveti G, Baglivo C, et al. (2018) Energy reliability-constrained method for the multi-objective optimization of a photovoltaic-wind hybrid system with battery storage. *Energy* 156: 688–708.

31. Ahmed NA, Miyatake M (2009) A stand-alone hybrid generation system combining solar photovoltaic and wind turbine with simple maximum power point tracking control. *IEEE Int Power Electron Motion Con* 37: 1–7.
32. Zainudin HN, Mekhilef S (2010) Comparison study of maximum power point tracker techniques for pv systems. *Int Middle East Power Syst Conf,* 750–755.
33. Chellapilla SR, Chowdhury BH (2013) A dynamic model of induction generators for wind power studies. *Power Eng Soc Gen Meet* 4: 2340–2344.
34. El-Saadawi MM, Hassan AE, Abo-Al-Ez KM, et al. (2011) A proposed framework for dynamic modelling of photovoltaic systems for DG applications. *Int J Ambient Energy* 32: 2–17.
35. Reza M (2006) Stability analysis of transmission system with high penetration of distributed generation. Dissertation at Delft University of Technology.
36. Power System Stability (2018) Available from: www.electrical4u.com/power-system-stability.