Impact of Hybrid Wind-Fuel Cell- Photovoltaic Renewable Energy Systems on the Distribution Network

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Abstract: In this paper, development and simulation in a centralized network small-scale of connected dc- bus, is proposed along with hybrid wind, photovoltaic, fuel cell plants and storage of compressed air to provide power on low-voltage distribution system. The hybrid system consists of wind and photovoltaic and energy storage of a primary power system. And fuel cell is added to wind and photovoltaic systems and storage of compressed air as a secondary system to ensure a continuous supply of power and taking care of nature. The main objective of this paper is to design and implement a hybrid system that guarantees the minimum continuity of energy supply. Simulation results show that the DC-DC converters in tracking the maximum power of wind, photovoltaic and storage of compressed air are effective and fuel cell controllers efficiently respond to deficit requests of power.
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1- Introduction

This research aims to study and simulation of distributed generation systems including wind energy, fuel cells and solar cells. The aim of this study is to evaluate control methods of distributed generation systems as well as to control coordinated of different new energy sources on distributed generation and to increase the reliability of distributed generation systems and thus proper connection of distributed generation sources to the network with an emphasis on stabilization of voltage, frequency, and quality of high power.

A photovoltaic hybrid fuel cell generation system that is designed of a electrolyser on battery and hydrogen generations for storage purposes, and is simulated in [1]. Results of the simulation of hybrid systems which use of electrolyser, FC and diesel generators is presented in [2]. In these systems, storage devices or backup energy sources as diesel generators are still used. L, Shutter at al., provided a wind hybrid power system of PV FC. Two Buck Boost Converter dcdc are used to search the maximum power point and a regulator with dc output voltage is used for each of the sub-systems of WEC and PV. As well as four logic fuzzy controllers are designed to adjust the duty cycle of two buck booster converter that be solved to MPPT and regulator with output voltage for wind and PV systems. Des et al., have introduced controllers of proportion modulator type, which controls the duty cycle of dcdc converters using PWM convert. In [3], Lava and Dariu, to provide isolated telecommunication tools, addressed to study technical and economic analysis of the possible implementation of renewable energy (photovoltaic and wind energy) on a plant.

Several techniques of MPPT have been studied in PV power applications. Disorder and observation modes (P & O) which move an operation point to the maximum power to increase or decrease voltage of antenna device periodically, in many PV systems are often used. The advantage of this approach is that when the solar radiation does not change in sync speed with time, it works well. But, P & O method is unsuccessful in fast tracking the maximum points of power [4]. Incremental conductance method is often used in PV systems. IncCond method track and follow the maximum power point by comparing incremental and instant conductance of antenna device. IncCord method offers good performance under weather conditions in three rapidly changing modes [5]. However, the mode of conducting has second part, and its structure is similar to the P & O algorithm because the condition of dP=dV=0 rarely occurs. In addition, in IncCord method four sensors are needed to do measure for calculations and decisions. A comparative study of three MPPT algorithms, that have been widely accepted, is presented in [6] with evaluation of their performance. While viewing MPPT performance or compare it with other methods is beyond the scope of this work, but a voltage-centered MPPT about PV and WEC systems is proposed for simplicity and fast tracking responses.

The purpose of this paper is to combine production systems of WEC, PC, FC and ESS to maximize output energy and reduce the frequency of output power for standalone applications. The proposed hybrid system of WECPVFC is connected to network by PWM converter as a distributed production system to relieve the pressure of demand for electricity in the network and operates as a power source that in the case of network disconnection there is no possibility to disconnect it. Hybrid system is in order to achieve MPPT.

Solar energy is the most unique source of renewable energy in the world and is the main source of all energy on earth. Using the solar and increasing of electrical energy is resulting of solar radiation during the day. Wind power plants that are installed in windy parts and use of mechanical energy of rotation to generate electricity. Market of fuel cell power generation is very large and involves government, military and industrial applications. As well as it is used as backup power in emergency in telecommunications, medical industries, offices, hospitals, large hotels and computer systems. Fuel cell power plants are relatively calm and quiet and have high electrical efficiency at a small spending, as well as in combination with natural gas power plants their electrical efficiency achieves to 70-80%. Another benefit of these plants is no environmental pollution. Output of the fuel cell plants is steam. Electricity storage technologies can be used to support in the event of instant power outage and to keep in the event of prolonged power outage. In combination with advanced electronic systems, storage systems can reduce the damaging effects caused by distortion waves during the current and destroy the existed disorders in voltage as much as possible. In combination with renewable energy sources, energy storage can increase the value of photovoltaic energy and produced wind energy, that this is the result of creating kind of balance between consumer demand and the delivered electricity.

2- The proposed approach

In this section, the proposed model for the use of renewable energies is described in compound way. Combination of three wind power, photovoltaic, fuel cell plants as well as energy storage was considered as an energy saving to supply energy in peak hours. Configuration of proposed system is different with the past cases. In this model, dc bus voltage can be adjusted in the presence of one or more energy sources existed in the converter output by controlling PWM converter. This leads to greater efficiency and power quality in electric power entered to the network from the converter. This system is modeled and simulated using MATLAB/Simulink software and impacts of REGS on the system performance for different levels of influence were examined in different loading and weather conditions.

2-1- Hybrid and supplement systems

Hybrid method is one of the various forms in using of renewable energies. In this method, renewable energy has become a form of mediation and is stored until in needed, for example, at peak times provides the need of consumer of distribution network. Methods of storing energy, wind energy, photovoltaic and fuel cell which will be discussed in this article can be kind of hybrid method. Hybrid systems are designed to design complement system, and to minimize investment and annual costs of maintenance [7].

Hybrid renewable energy systems are proper solution to supply electric energy of remote areas which construction of transmission power-lines to provide electricity for them is difficult and uneconomical. Also these systems are used to provide electric energy for strategic and certain areas such as border or offshore military barracks, telecommunications and television booster stations and etc. But in a different locations, weather conditions, including solar radiation, wind speed, temperature or everything usually change.

2-2- Controlling of WFC system

Application of dc-dc booster converter of WEC system, is to make distinct and different the voltage in the interior part appropriate with the wind speed. The interior voltage should be controlled in predetermined sizes appropriate with dc optimum voltage against the features of rotator speed according to Figure 1-3. The system should be measured the speed of generator rotator in any wind speed, and use it to control duty and operation of the cycle of dc-dc booster converter in the WEC system. Consequently, setting of duty and operating cycle is determined optimum value in dc-rectified voltage based on Figure 1-3. Due to setting of rectified dc output voltage, it can effectively control the AC voltage at the rectifier input. The final and output voltage of the generator is depend on rotator speed and thus varies with wind speed to achieve maximum power coefficient of the wind turbine and thus, MPPT of WECS is obtained. when the wind speed is changed fast and continuously, simulation results make reliable the MPPT impacts and fast dynamical performance of WECS systems and they have shown in [9].

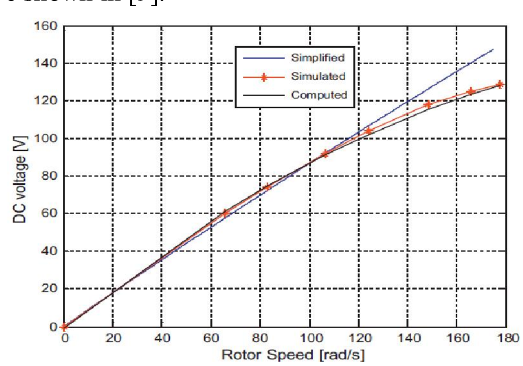


Figure (1-1) Optimum voltage with the characteristics of rotor speed.

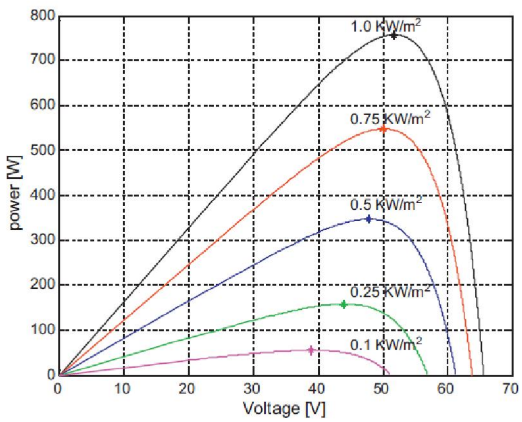


Figure (1-2) Features of power - voltage for PV systems.

3-2- Controlling of PV system

Examine the characteristics of PV array in a level of solar radiation shows that the maximum power point is approximately obtained with output voltage of V_{mp} that is in proportional connection with the open circuit voltage of V_{oc} of the PV array. As a result, detecting of open circuit voltage in a PV cell that is kept in the same environment as the manufacturer cells of power, provides information about actual solar radiation and calculates the reference value of $V_{PV\text{-}ref}$ for converter input voltage of PV array for MPPT of PV system. Operating voltage of the array of power generator is adjusted proportional to the needed amount that is correspond with the maximum power. when radiation is dramatically changing, simulation results make reliable the fast dynamical performance and the fast MPPT of PV system and have shown in [10].

2-4- Controlling of FC system

One of the weaknesses of FC among other cases is its time factor that are affected by fuel delivery systems. As a result, the demand for faster loading can cause severe voltage drop in the short term that is known as fuel shortages and famine phenomenon and definitely is harmful for FCs. Limiting the slope in an absolute maximum value of the few amperes per second provides safe operation of FC even during unstable electrical (power) demand. Consequently, in order to use FC in dynamic applications, its current slope or power gradient should be limited, for example, $4As^{-1}$ for a PEMFC, (0.5kW, 12.5V), a 2.5 kWs^{-1} for a PEMFC (40kW, 70V), $500Ws^{-1}$ for a PEMFC (2.5 kW, 22V) and 10As, $10As^{-1}$ and $50As^{-1}$ for a PEMFC20kW, 48V. FC of Nexa Ballard used in this study has a fast dynamic response, and only needs to 0.5 s to accelerate from zero load with its high output power. Also, it can reach (reduce) its output from rated power to 0.5 s. This reducing of power and force was considered in dynamic simulation of FC system.

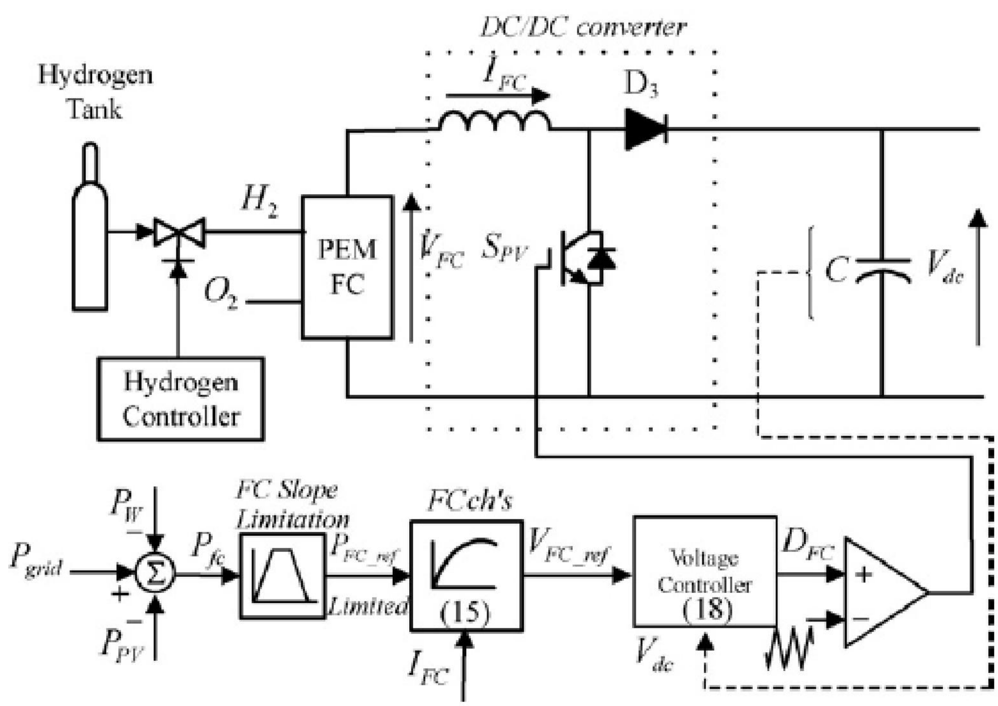


Figure (3-1) FC system connected to the DC bus line with a dc-dc boost converter

2-5- Compressed air storage

Energy storage in a smaller dimensions mostly are well known on battery and capacitor systems and stacked storage systems like Hydro pump, though there is less recognition about stacked systems such as compressed air [11]. Compressed air is placed at a certain pressure, usually greater than normal atmospheric pressure. Compressed Air System concept is this that in common and non-peak hours the air is compressed by the compressor and pumped into an underground tank, underground tanks are such as natural gas wells or salt or even artificial underground cavities, then during peak hours this compressed air can be sent with some heat into the cycle of a gas power plant.

2-6 ESS potential applications in micro-channels

Rapid fluctuations in output (at the range of 1 min) of wind generators power can cause to emergence disorders in voltage and frequency in the network, especially in isolated power systems, and thus vitiate the power quality [12]. In order to reduce the effects of power fluctuations it can be used of an ESS. Storage systems suitable for the application display high degrees of ramp power and the ability to top retrieve, because a fast electrical modulation and continuous operation are required. As a result, the batteries (except lead acid batteries commonly used), flow batteries, and especially short-time energy storage devices such as super capacitors, fly wheels and SMESs will they do it well.

Voltage control of wind power machines at the junction with the external network through a magnetic gradient of voltage (dip) is done in order to avoid disconnection of wind power systems which can result in the collapse of the network. In this regard, grid codes need that the wind power systems endure against magnetic gradients to 0% of rated voltage and for a certain period. As a result, the energy storage in these situations is not necessary but can protect of link-dc of converters against excessive voltage. Such as fluctuations removal services, suitable storage systems also provide the high degrees of ramp-up for this function that enables fast power modulation. As a result, batteries, flow batteries and energy storage devices in a short period, such as super capacitors, fly wheels and SMESs are also suited for the job.

Wind turbines that can drive DFIG, along with the sync generators of full-power converters are the ways to transmit power or part of generated electricity to the grid through power converters. With this topology, control the reactive power of wind generators and thus control the voltage at their connection point is possible. Also, by embracing support for energy storage, dynamic of voltage control can be improved. Batteries, flow batteries, and energy storage devices in a short period, such as super capacitors, fly wheels, SMESs are very useful for this aim, specially due to their high degrees of ramp. Since the storage device must be able to manage both active and reactive power.

2-7-Types of the batteries of energy storage system (ESS)

VRB is stored energy in two tanks, analytical and cathodic sources that have sulfuric acid solutions. At analytical source, V2+/V3 + is used as the electrolyte, while V4+/V5+ electrolytes are used in the cathodic source.

At ZBBs two water solutions, based on storage of Zinc and Bromine in two separate tank, flow through the electrolyte cells in which the electrochemical reactions are created. During the process of discharging, the ions of Br-2 becomes to Bromine Br-3 in the positive electrode which reacts with organic amine and produce heavy Bromine oil and go to the bottom of the tank.

PBSs performance which are called the regenerative fuel cells (regenerative) or Regenesys, are firmed based on electrochemical reactions between a salt-based electrolytes: bromine sodium, and sodium polysulfide. This electrolytes are separated with polymer membrane, that only make possible the interaction of positive sodium ions. During the charging cycle, bromine ions (Br-2) become to three bromine ions (Br-3) in the positive electrode of the cell. In the negative electrode, sodium unresolved components (S-42) in the electrolyte of polysulfide diminish to sulfide ions (S-22). Discharge cycle, occurs from the reverse process. These systems make a larger system based on this type of battery in 2003. The energy efficiency of this system is 75% with a relatively high life, and more than 15 years.

When the hydrogen is generated from wind power devices, it can be stored to use directly in fuel cell-or send them to users through tubes in order to produce electricity [13]. When hydrogen is stored, the used system is called regenerative fuel cell (regenerative) (RFC). As shown in Figure 4, the cell is made up of the following components: a water electrolyser system, a fuel cell system, a hydrogen storage system and a energy conversion system. This technology is responsible for the conversion of hydrogen to store energy in the form of electricity and injection of it into the grid in the form of electricity when it is needed. As previously mentioned, electrolysers are an important part of the RFC. By this means the water is decomposed into hydrogen and oxygen in the form of electrolyte. There are various types of electrolysers from conventional systems such as alkali electrolysers to its more modern types like polymer electrolyte membrane electrolysers (PEM). PEM electrolysers were invented in 1970, but hydrogen production by this technology is now done and production volume to 10 Nm $/h^3$ has reported.

A FESS is an electrochemical system that stores energy as kinetic energy. A substance rotates on two magnetic bearing to reduce friction at high speed, which is coupled to an electric machine. Whole structure is placed in a vacuum to reduce wind shear. The design of the system is shown in Figure 5. Time energy that machine acts as an engine (Fly wheel is speeding) is transmitted to charge the energy storage device. When the electric machine is restored through drive (making slow the fly wheel), FESS is discharged. In fact, the energy saved by fly wheel depends on the square of the speed of rotation and inertia.

2-8- Control of System

Taking into account the topology of DC-DC converter, the boost converter for the simplicity, low cost and high performance is counted as the most useful converter in this area. Boost DC-DC converter divides the voltage of system into two levels: alternating voltage at the output terminal, energy source of V_i and constant DC voltage in buss DCV_{dc}. The output voltage of the dc bus line of all converters have been determined in constant form and the output voltage can be controlled independently from each source.

Figure 5 shows the configuration of the main circuit of the proposed converter that connect the DC bus voltage of the hybrid system to the electricity grid and the load connected to the network via an inductor and a capacitor. This converter makes possible to convert electricity from DC-bus to the electricity network, as well as control the Network current in the unit power factor. On the other hand, the inverter controls the DC bus voltage at the input of the inverter.

Control of power plants has been always a challenge for power industry because the electric power has an important role in the development of civilization. Updating of automation systems (cable electromagnetic-logic relay) for modern systems that use of programmable logic controllers (PLC), is an important step in the development of automation systems used in power engineering (production, transport, distribution and consumption), followed by the reduction of cost.

Process control systems have hardware structure (and an additional software component) that guarantees the stability, accuracy and good delivery. These functions can be accomplished by PLCs connections and the central digital language. Programmable logic controller is used for automation of industrial processes and replacing the sequential command circuits in cable logic.

A PLC (Figure 3-7) is an example of a real time system of output results that must be made to answer to input conditions with a limited time, otherwise this will result in unintended operation. These structures are connected to various peripheral devices: graphing tools, sensors, brakes, engine, etc.

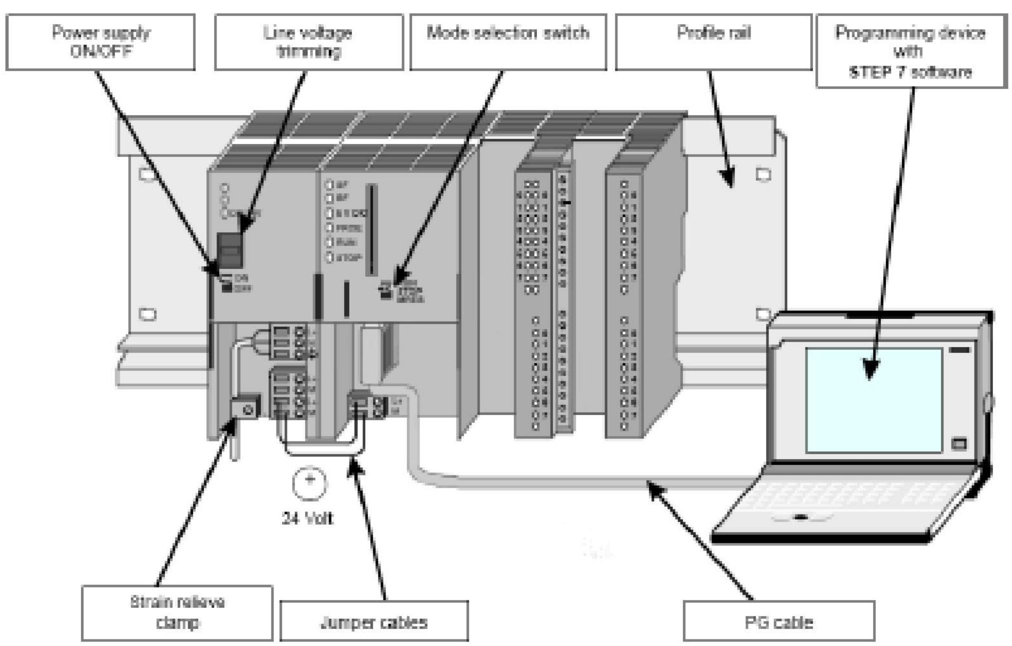


Figure (1-4) The structure of Siemens automation system S7-300

2-9- Review of system reliability

Because of the characteristics of solar radiation and non-continuous wind speed, and discontinuous features of fuel cell systems that affect production of energy so much, analysis of power reliability are considered as an important step in the design of hybrid systems. In this episode two techniques of DPSP and LPSP reliability are used and finally, the results of these two techniques are compared with each other.

An reliable electric power system is a system that has enough electric power to supply load demand during a particular period, or in other words, it is a system that has less deficit possibility of power supply (DPSP).

An reliable electric power system is a system that has enough electric power to supply load demand during a particular period, or in other words, it is a system that offers less loss possibility of power supply (LPSP).

LPSP is a probability for when the inadequate supply of power occurs and hybrid system fails to provide the load demand. LPSP value is calculated from the following formula from zero to T time.

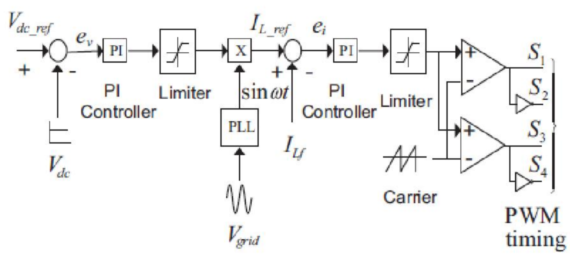


Figure (1-5) Block diagram of the proposed inverter controller

Figure 4-2 shows the difference of electric output power of 4 energy source and the total generated power. Figure 4-2 (a) shows that the PV system should be first 0.5 kW and then due to the sudden rise in radiation levels from 0.7 to 0.10.1 kW/m^2 in 0.5s is increased to 0.75 kW. Figure 4-2 (b) shows that the output of WT at first generate 0.1 kW and then due to the sudden increase in wind speed from 15.6 to 2.5 m/s in 0.2 s, is reduced to 0.5 kW. It is clear that in both Figure 4-2 (a) and (b) the PV curves of existed maximum and wind power are simultaneous with the generated output power, this indicates that the controller forces the system to extract maximum power and transfers it to dc-link bus as an useful electrical energy.

$$LPSP = \frac{\sum_{i=1}^{T} \text{power failure time}}{\tau} \quad (3\text{-}7)$$

$$= \frac{\sum_{t=0}^{T} \text{Time}(P_{available}(t) < p_{needed}(t))}{\tau}$$

That in this relation, T is the number of hours with hourly weather data input. Time of power error is defined as when it is not the time of load supply. When the power produced by both of wind turbine and photovoltaic array is insufficient and storage of battery is also finished. Power required by the load can be expressed as follows.

$$P_{needed}(t) = \frac{p_{ac\ load}(t)}{\eta_{inverter}(t)} + P_{needed}(t) \quad (3\text{-}8)$$

Available power through a hybrid photovoltaic and wind system with battery storage system can be expressed as follows:

$$P_{available}(t) - P_{PV} + P_{WEC} + P_{FC} + C.V_{bat}.\mathrm{Min}\left[i_{bat.max} = \frac{0.2\,C_{bat}}{5\,t}, \frac{C_{bat}(SOC(t) - SOC(\min))}{\Delta t}\right] \quad (3\text{-}9)$$

In this relation, C is a constant and its value in the process of battery charge is zero and in the process of battery discharge is equal to 1.

3- Simulation results and review of performance Plants

In order to evaluate the performance of the proposed hybrid system with its every controllers, the whole system is simulated using MATLAB software. All four energy sources are controlled accurately and effectively. Specifications and size of the components of the system are shown. Hybrid systems are measured to electrification a loading (load) telecommunications of 2 kW/200Vdc or permanent continuously electrical applications (residential) throughout the year in remote areas or outlying islands. Load is simulated like a fixed resistance load connected to a fixed dc bus line voltage, because it can simulate ac load by inverter connected to it as a current source at high power factor.

Reference power command from FC is determined as the difference between the load power of 2.0 kW and the generated power of PV and WT. This reference power can play the role of a output in look-up tables which calculates the reference voltage of the boost converter that connects FC to the dc bus line voltage. The power output of FC system is shown in Figure 4-2 (c) that changes with the changing in output power of PV and WT. FC output power changes from 0.5 kW to 1.0 kW and then to 0.75 kW in 0.2 and 0.5 seconds, respectively. Figure 4-2 shows the mast of power generated from hybrid systems. From Figure 4-2 (d) it is clear that should be noted that the system's output power in load demand, rather than emergence the volatility in the power output of PV and WT, remains unchanged always.

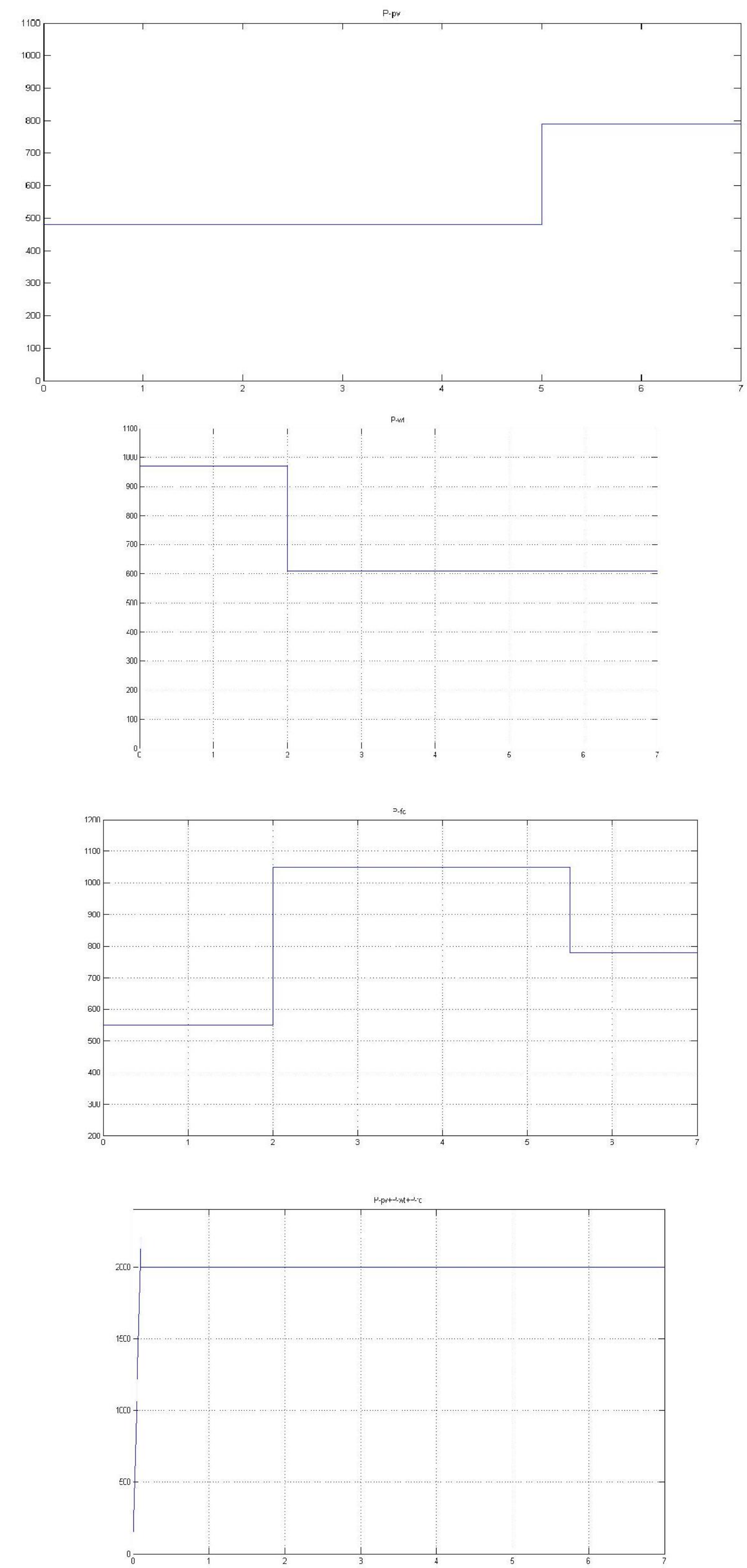
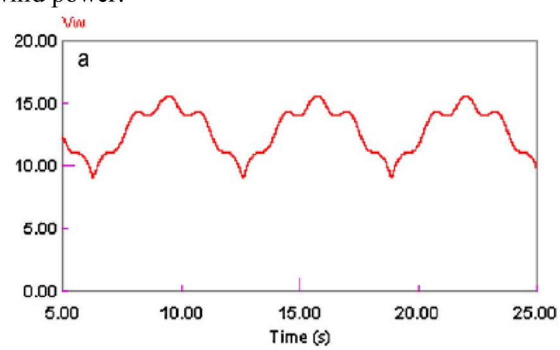


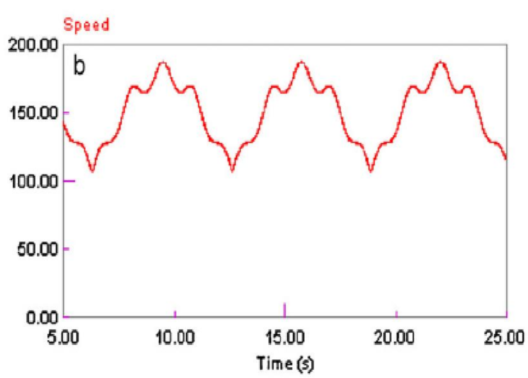
Figure (1-6) Power generated by PV, WT and FC and a total output power

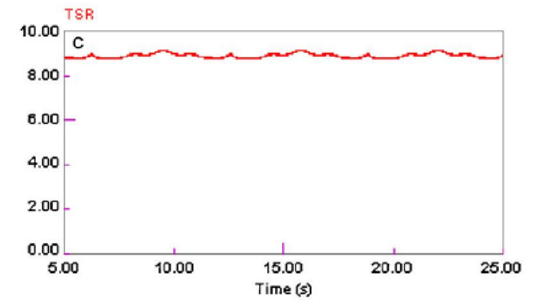
The results in Figure 4-2 show that the reaction and response of proposed system is similar to the expected performance under the step of changing circumstances and is consistent with the results of previous research [132].

In order to evaluate the dynamic performance of the proposed hybrid system, an example of the rapid and continuous changes of wind speed and solar radiation was created. The results shown in this section, as shown in Figure 4-3 (a) and 4-3 (b), have changed based on simulations of 150 s with a wind speed of 7 to 16 m/s (average wind speed of 12 m/s) and irradiation varies from 600 to 1000 W/m^2 range. Simulations is better over a longer time frame but simulation time is limited to run the simulation with the amount of memory on the used computer.

Figure 4-3 shows the simulation results of the dynamic performance that evaluate the effective MPPT of WEC System. The first image of Figure 4-3 (a) shows a time series of wind speed and the corresponding rotational speed (in rad/s) is shown in Figure 4-3 (b). As we can see, WEC system controller is operated depending on successful wind speed at control the rotational speed. Figure 4-3 (c) shows the corresponding ratio of velocity peak. As you see in the picture, WEC system controller is designed to maintain the ratio of velocity peak within a reasonable area of the optimal ratio of velocity peak of Figure 4-9. Figure 4-3 (d) shows the total wind power and the extracted wind power.







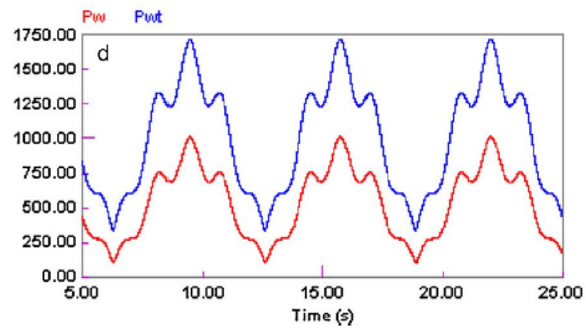
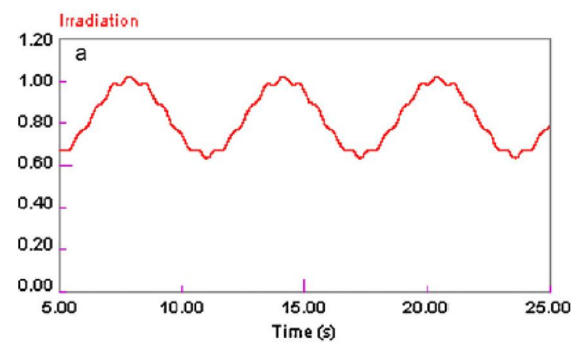


Figure (1-7) WEC system under the proposed MPPT



It is well known that the mode of control the voltage-centered of PV and wind systems takes a second to make the transition to MPPT. Results of PV and WEC systems can be observed in [133-136] such as work cycle of controller for controlled voltage and reference voltage. Wind and PV generated electricity is not constant and depends on wind speed and solar radiation conditions. Figure 4-5 shows the total electricity produced from wind and PV systems. By comparing Figure 4-3 (d) and 4-4 (b), it must be noted that the output power of the primary system is still not fixed and depends on the conditions of wind speed and solar radiation. But this case is better than the power output obtained individually from each source.

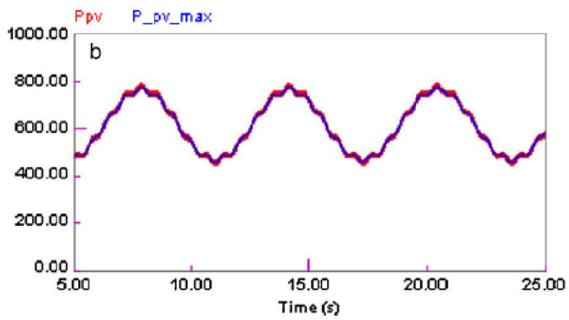


Figure (1-8) Properties of a PV system under MPPT

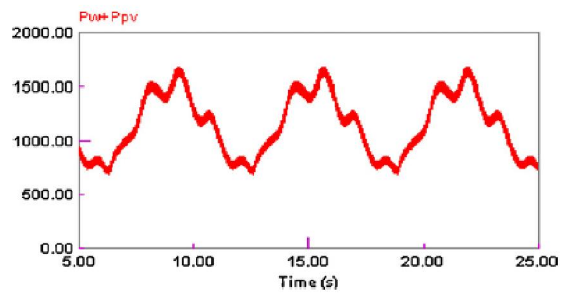


Figure (1-9) Output power produced of the primary system

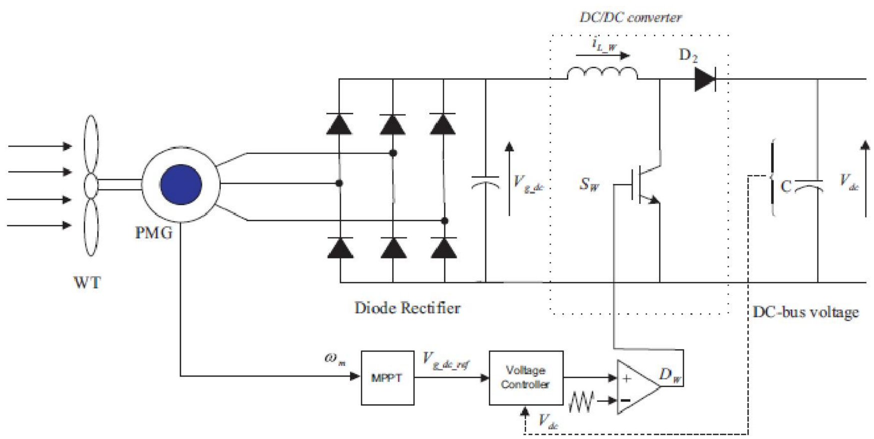


Figure (1-10) WEC system with dc-dc boost converter connected to dc bus line.

1-2- Co-ordination between the resources by the help of PLC

The concept of controlling a process is very simple and easy and needs to do the following principles: identifying the order of machine work and selection of PLC model.

By examining the process duty cycle that we want to control, specifying the number and type of input-output systems and with respect to the accuracy required, we select the appropriate PLC. We must set the following characteristics about selection of a PLC:

- Number of inputs
- Number of outputs
- Type of input and output of a device
- The number of auxiliary registers and bits
- The number of required timers and counters
- Memory size
- Speed of program execution and responsiveness of the Scan Time device

1-2-2- Block WEC

In the above figure (Figure (1-10) that was also brought in the previous chapter) wind turbine and PMG is considered as follows:

1-2-3- PV Block

For PV plant along with MPPT will be also as follows:

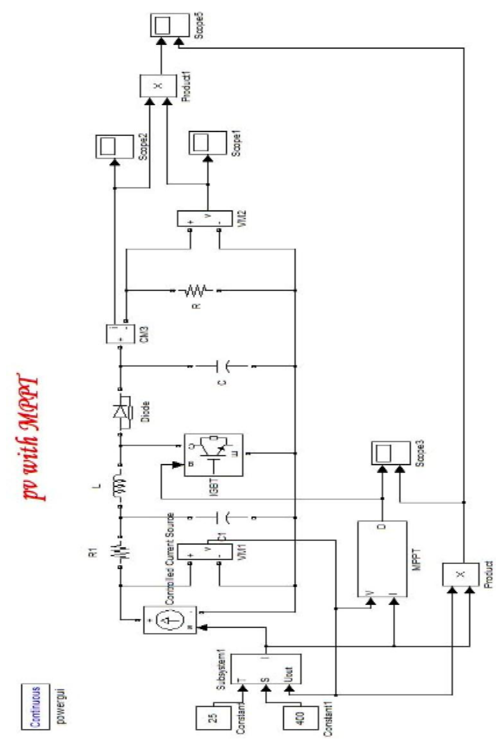


Figure (1-11) Depicted circuit of PV diagram in MATLAB Simulink.

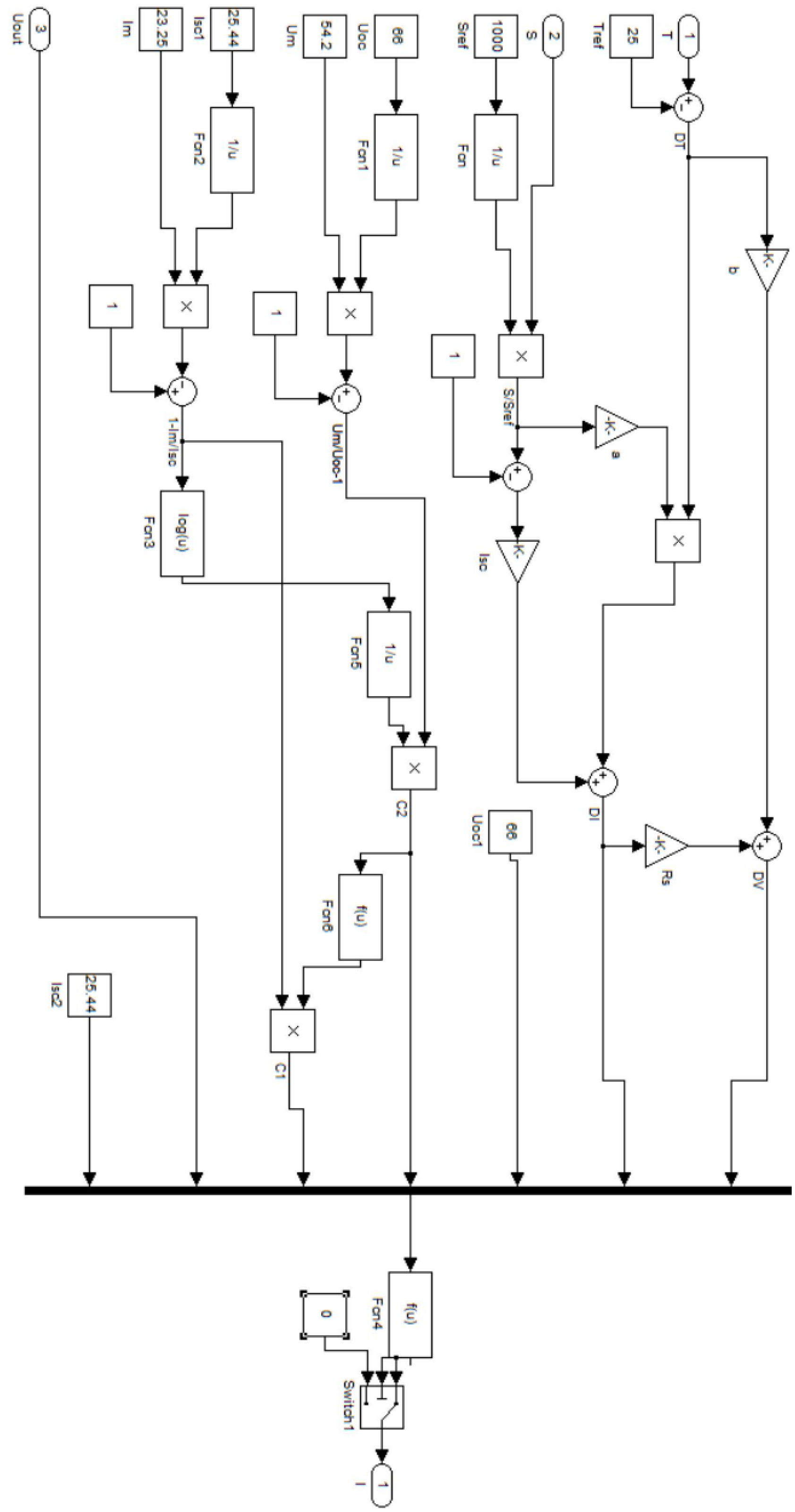


Figure (1-12) Block PV

Output flow rate is specified with regard to temperature, radiation intensity, number of cells and other conditions. The figure below is MPPT for PV that its input and output is voltage and current:

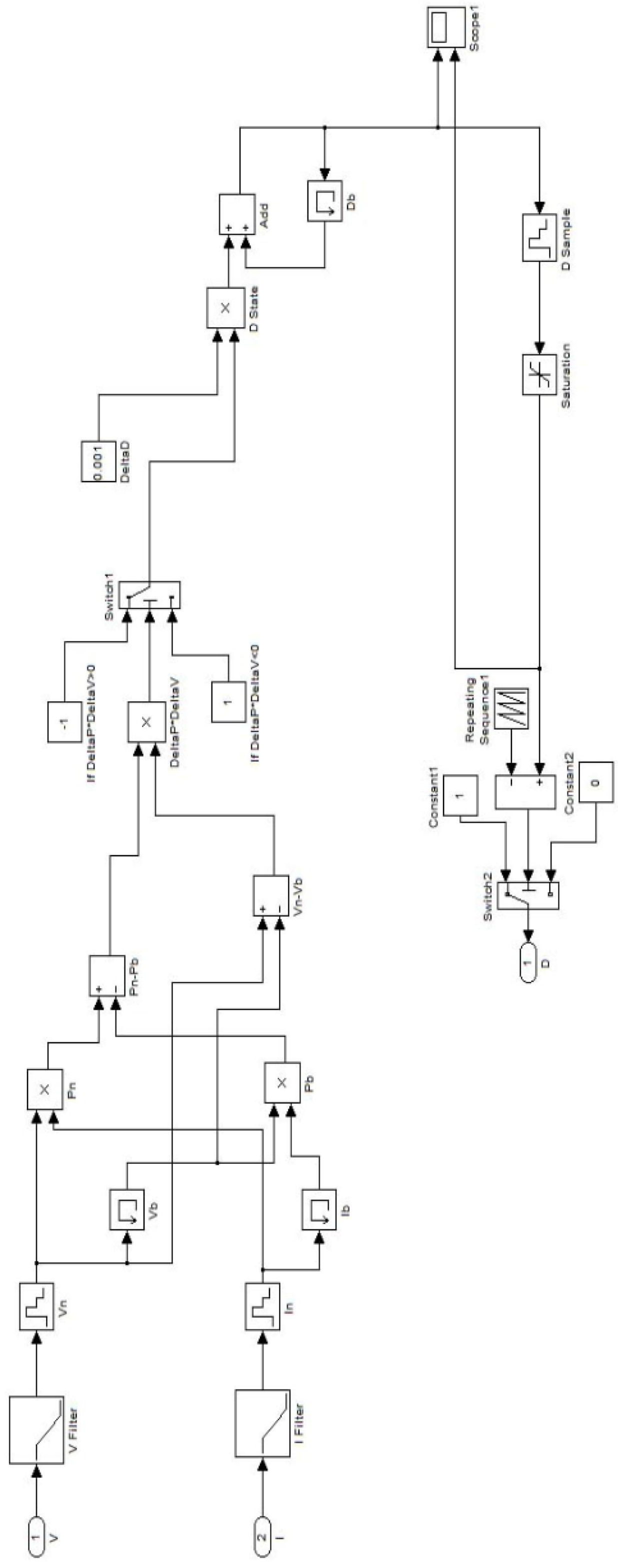


Figure (1-13) MPPT diagram for PV.

1-2-4- Block FC

The figure below is related to the fuel cell:

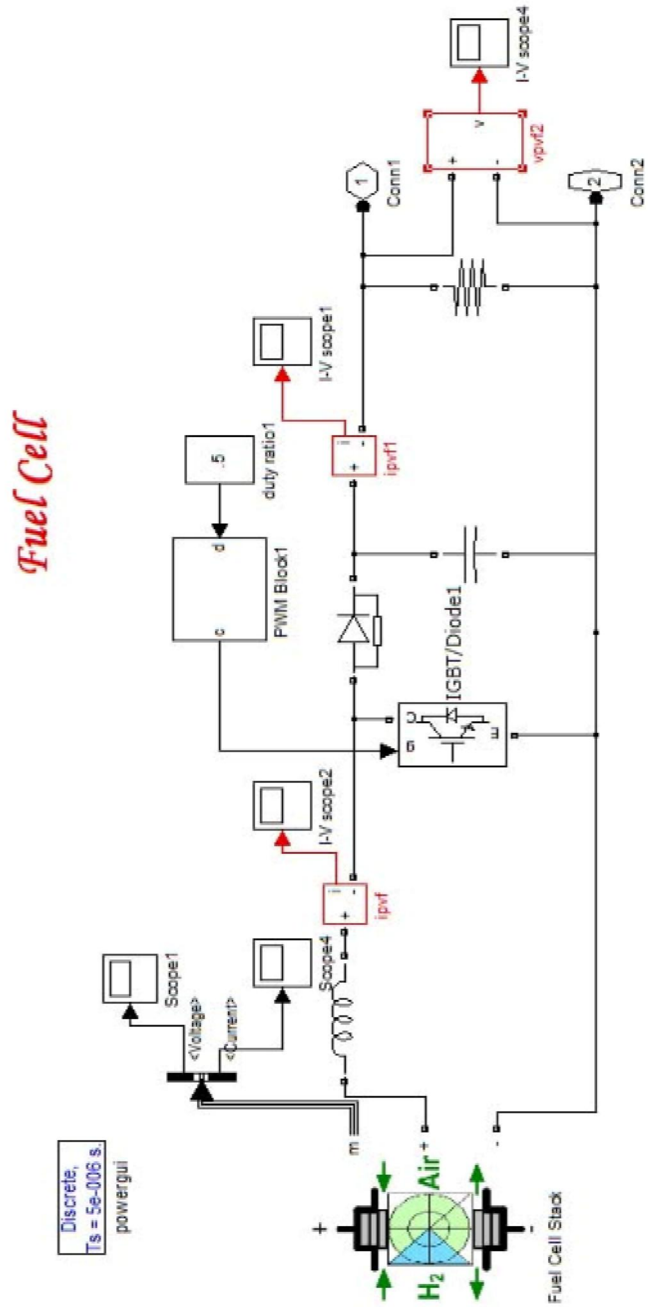


Figure (1-14) Depicted diagram of FC Plant in MATLAB Simulink.

1-3- Summing up

In this study, a hybrid renewable energy system was modeled and implemented. Simulation results show that the presence of REGS can reduce the effects of serious problems of power quality, such as frequency and voltage of fluctuation, voltage drop, harmonic distortion and power coefficient. The proposed system's output power at load power demand, instead of emergence fluctuations in the output power of PV and WT, remains unchanged always. To evaluate the dynamic performance of the proposed model, an example of rapid changes in wind speed and solar radiation was generated. Results demonstrate the ability to achieve maximum power corresponding to any irradiation conditions with the proposed controlled simple-voltage of MPPT. Output power of the primary system depends on the conditions of wind speed and solar radiation, however, in this model the performance is better than the output power obtained individually from each source. The results of this section illustrate the concept of controlling any of three energy sources:

• Effective control of the output voltage of PV in order to track its MPP

• Control of the rectified voltage of PM generator in order to follow (track) MPP of WEC systems

• Control of FC voltage to produce a deficit of electricity in order to guarantee the continuous power current of network

Thus, the ability of system to meet the minimum required constant electric of grid with FC rated capacity was evaluated under the worst environmental conditions when there is no electric output of PV and WEC sources.

Conclusions

In this paper, a hybrid power system WEC/PV/FC/ESS with dc bus voltage regulations and MPPT was proposed. The proposed hybrid system can make almost continuous electrical power with greater confidence rate in compared with a single power supply. Wind and PV controller has MPPT control function, while FC controller has the compensation (balanced) function of load power fluctuation. t is suggested that a simple control method that track the MPP of wind and PV with no measure of wind speed and solar radiation (radiation), is very useful in small real wind turbines and PV systems. As a result, ESS is controlled in order to produce and provide electricity deficit, at a time when wind energy resources and primary PV and combined FC cannot supply net network or load power demand. The detailed description of the hybrid system with a detailed description of the control design and simulation results that guarantee its possibility, are given. Power swing of the hybrid system is reduced in compared to swing of every systems and is suppressed completely using the FC system. Further research and work about the design of whole system and its pilot implementation is underway.

References

Omit.

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