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Smart Grid Integration of Solar/Wind Energy Conversion System

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Abstract:

Performance optimization, system reliability and operational efficiency are key characteristics of smart grid systems. In this paper a novel model of smart grid-connected PV/WT hybrid system is developed. It comprises photovoltaic array, wind turbine, asynchronous (induction) generator, controller and converters. The model is implemented using MATLAB/SIMULINK software package. Maximizing the generated power based on maximum power point tracker (MPPT) implementation. The dynamic behavior of the proposed model is examined under different operating conditions. Real-time measured parameters are used as inputs for the developed system. One of the primary needs for socio-economic development in any nation in the world is the provision of reliable electricity supply systems. This work is a development of an indigenous technology hybrid Solar -Wind Power system that harnesses the renewable energies in Sun and Wind to generate electricity. Here, electric DC energies produced from photovoltaic and wind turbine systems are transported to a DC disconnect energy Mix controller. The controller is bidirectional connected to a DC-AC float charging-inverter system that provides charging current to a heavy duty storage bank of Battery and at the same time produces inverted AC power to AC loads.

Keywords: Control systems, Hybrid power systems, MATLAB, Modeling, Photovoltaic systems, Power electronics, Smart grids, Wind power generation.

1. INTRODUCTION:

One of the primary needs for socio-economic development in any nation in the world is the provision of reliable electricity supply systems. In Nigeria, the low level of electricity generation in Nigeria from conventional fossil fuel, has been the major constraint to rapid socio-economic development especially in rural communities. Moreso, about sixty-five percent(65%) of 140million Nigeria populace are rural dwellers with majority of them living far-off grid areas [1]. These rural dwellers are mostly farmers whose socio-economic lives can only be improved when provisions are made to preserve their wasting agricultural products and provide energy for their household equipment such as refrigerator, fan, lighting etc. There is also such a need to provide electricity for e-information infrastructures in our rural communities to service school, rural hospital, rural banking and rural e-library. Hence, there is the need to develop an indigenous technology to harness the renewable energies in Sun and Wind to generate electricity.

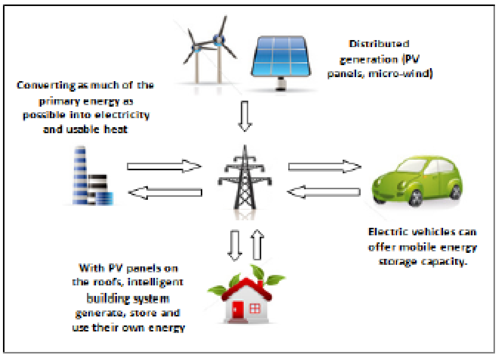

Fig. 1. General layout of the smart grid

1.1 Importance of Renewable energy The global search and the rise in the cost of conventional fossil fuel is making supply-demand of electricity product almost impossible especially in some remote areas. Generators which are often used as an alternative to conventional power supply systems are known to be run only during certain hours of the day, and the cost of fueling them is increasingly becoming difficult if they are to be used for commercial purposes. There is a growing awareness that renewable energy such as photovoltaic system and Wind power have an important role to play in order to save the situation. Figure 1 is the schematic layout of Solar-Wind Hybrid system that can supply either dc or ac energy or both.

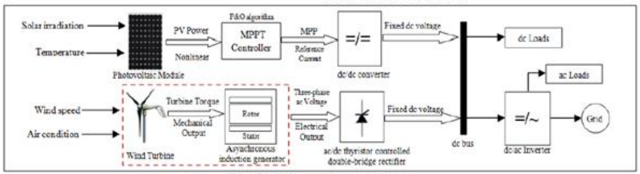

Fig. 2. Block diagram of the proposed system

2. SOLAR ENERGY:

Solar energy is energy from the Sun. It is renewable, inexhaustible and environmental pollution free. Nigeria, like most other countries is blessed with large amount of sunshine all the year with an average sun power of 490W/m2/day [2]. Solar charged battery systems provide power supply for complete 24hours a day irrespective of bad weather. Moreso, power failures or power fluctuations due to service part of repair as the case may be is nonexistent.

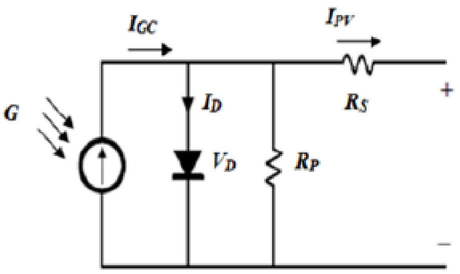

Fig. 3. Single diode PV cell equivalent circuit

2.1 Solar Systems:

There are two types of solar systems; those that convert solar energy to D.C power, and those that convert solar energy to heat.

2.2 Solar-generated Electricity – Photovoltaic

The Solar-generated electricity is called Photovoltaic (or PV). Photovoltaics are solar cells that convert sunlight to D.C electricity. These solar cells in PV module are made from semiconductor materials. When light energy strikes the cell, electrons are emitted. The electrical conductor attached to the positive and negative scales of the material allow the electrons to be captured in the form of a D.C current. The generated electricity can be used to power a load or can be stored in a battery. Photovoltaic system is classified into two major types: the off-grid (stand alone) systems and inter-tied system. The off-grid (stand alone) system are mostly used where there is no utility grid service. It is very economical in providing electricity at remote locations especially rural banking, hospital and ICT in rural environments. PV systems generally can be much cheaper than installing power lines and step-down transformers especially to remote areas. Solar modules produce electricity devoid of pollution, without odour, combustion, noise and vibration. Hence, unwanted nuisance is completely eliminated. Also, unlike the other power supply systems which require professional training for installation expertise, there are no moving parts or special repairs that require such expertise [3].

2.3 Basic Components of Solar Power

The major components include P.V modules, battery and inverter. The most efficient way to determine the capacities of these components is to estimate the load to be supplied. The size of the battery bank required will depend on the storage required, the maximum discharge rate, and the minimum temperature at which the batteries will be used [4]. When designing a solar power system, all of these factors are to be taken into consideration when battery size is to be chosen. Lead-acid batteries are the most common in P.V systems because their initial cost is lower and also they are readily available nearly everywhere in the world. Deep cycle batteries are designed to be repeatedly discharged as much as 80 percent of their capacity and so they are a good choice for power systems.

Figure 2 is a schematic diagram of a typical Photovoltaic System.

2.4 Photovoltaic (P.V) Solar Modules

The photovoltaic cell is also referred to as photocell or solar cell. The common photocell is made of silicon, which is one of the most abundant elements on earth, being a primary constituent of sand. A Solar Module is made up of several solar cells designed in weather proof unit. The solar cell is a diode that allows incident light to be absorbed and consequently converted to electricity. The assembling of several modules will give rise to arrays of solar panels whose forms are electrically and physically connected together. To determine the size of PV modules, the required energy consumption must be estimated. Therefore, the PV module size in Wp is calculated as[5]: Daily energy Consumption (1) Isolation x efficiency Where Isolation is in KWh/m2/day and the energy consumption is in watts or kilowatts. Batteries and Batteries Sizes of the Solar System As mentioned above, the batteries in use for solar systems are the storage batteries, otherwise deep cycle motive type.

Various storage are available for use in photovoltaic power system, The batteries are meant to provide backups and when the radiance are low especially in the night hours and cloudy weather. The battery to be used: (a) must be able to withstand several charge and discharge cycle (b) must be low self-discharge rate (c) must be able to operate with the specified limits. The battery capacities are dependent on several factors which includes age and temperature. Batteries are rated in Ampere-hour (Ah) and the sizing depends on the required energy consumption. If the average value of the battery is known, and the average energy consumption per hour is determined. The battery capacity is determined by the equations 2a and 2b[3]

$BC = 2*f*W/Vbatt$ (2a)
Where BC – Battery Capacity
f – Factor for reserve
W – Daily energy
Vbatt – System DC voltage
The Ah rating of the battery is calculated as[3]:
Daily energy Consumption (KW) (2b)
Battery rating in (Amp-hr) at a specified voltage

III. DESIGN OF HYBRID ENERGY SYSTEM

For designing of the hybrid energy system we need to find the data as follows

A. Data required for Solar System:

1. Annual mean daily duration of Sunshine hours
2. Daily Solar Radiation horizontal (KWH/m2/day)

B. Data required for Wind System:

1. Mean Annual Hourly Wind Speed (m/sec)
2. Wind Power that can be generated from the wind turbine

3. WIND POWER:

Wind Power is energy extracted from the wind, passing through a machine known as the windmill. Electrical energy can be generated from the wind energy. This is done by using the energy from wind to run a windmill, which in turn drives a generator to produce electricity [6]. The windmill in this case is usually called a wind turbine. This turbine transforms the wind energy to mechanical energy, which in a generator is converted to electrical power. An integration of wind generator, wind turbine, aero generators is known as a wind energy conversion system (WECS)[7]

3.1 Component of a wind energy project Modern wind energy systems consist of the following components A tower on which the wind turbine is mounted; A rotor that is turned by the wind; The nacelle which houses the equipment, including the generator that converts the mechanical energy in the spinning rotor into electricity. The tower supporting the rotor and generator must be strong. Rotor blades need to be light and strong in order to be aerodynamically efficient and to withstand prolonged used in high winds[8].

In addition to these, the wind speed data, air density, air temperature need to be known amongst others.

3.2 Wind Turbine A wind turbine is a machine for converting the kinetic energy in wind into mechanical energy. Wind turbines can be separated into two basic types based on the axis about which the turbine rotates. Turbines that rotate around a horizontal axis are more common. Vertical-axis turbines are less frequently used [8,9]. Wind turbines can also be classified by the location in which they are used as Onshore, Offshore, and aerial wind turbines [9] To increase the controller's robustness against variations in the operating conditions when the microgrid operates in the grid-connected or islanded mode of operation as well as its capability to handle constraints, a model-based model predictive control (MPC) design is proposed in this paper for controlling the inverters. As the microgrid is required to operate stably in different operating conditions, the deployment of MPC for the control of the inverters offers better transient response with respect to the changes in the operating conditions and ensures a more robust microgrid operation. There are some research works on the implementation of MPC for the control of inverters. In [16], a finite control set MPC scheme which allows for the control of different converters without the need of additional modulation techniques or internal cascade control loops is presented but there search work does not consider parallel operation of power converters. In [17], an investigation on the usefulness of the MPC in the control of parallel-connected inverters is conducted. The research work is, however, focused mainly on the control of inverters for uninterruptible power supplies in standalone operation. The MPC algorithm will operate the inverters close to their operating limits to achieve a more superior performance as compared to other control methods which are usually conservative in handling constraints [18], [19]. In this paper, the inverters are controlled to track periodic current and voltage references and the control signals have a limited operating range. Under such operating condition, the MPC algorithm is operating close to its operating limits where the constraints will be triggered repetitively. In conventional practices, the control signals are clipped to stay within the constraints, thus the system will operate at the sub-optimal point. This results in inferior performance and increases the steady-state loss. MPC, on the contrary, tends to make the closed-loop system operate near its limits and hence produces far better performance. MPC has also been receiving increased research attention for its applications in energy management of microgrids because it is a multi-input, multi-output control method and allows for the implementation of control actions that predict future events such as variations in power generation by intermittent DERs, energy prices and load demands [20]–[22]. In these research works, the management of energy is formulated into different m1ulti-objective optimization problems and different MPC strategies are proposed to solve these optimization problems. The scope of this paper is however focused on the application of MPC for the control of inverters. In what follows, a comprehensive solution for the operation of a dc grid based wind power generation system in a microgrid is proposed for a poultry farm and the effectiveness of the proposed system is verified by simulation studies under different operating conditions.

II. HYBRID ENERGY SYSTEM:

Hybrid energy system is the combination of two energy sources for giving power to the load. In other word it can defined as “Energy system which is fabricated or designed to extract power by using two energy sources is called as the hybrid energy system.” Hybrid energy system has good reliability, efficiency, less emission, and lower cost. In this proposed system solar and wind power is used for generating power. Solar and wind has good advantages than other than any other non-conventional energy sources. Both the energy sources have greater availability in all areas. It needs lower cost. There is no need to find special location to install this system.

A. Solar Energy

Solar energy is that energy which is gets by the radiation of the sun. Solar energy is present on the earth continuously and in abundant manner. Solar energy is freely available. It doesn't produce any gases that mean it is pollution free. It is affordable in cost. It has low maintenance cost. Only problem with solar system it cannot produce energy in bad weather condition. But it has greater efficiency than other energy sources. It only need initial investment. It has long life span and has lower emission.

B. Wind Energy

Wind energy is the energy which is extracted from wind. For extraction we use wind mill. Ii is renewable energy sources. The wind energy needs less cost for generation of electricity. Maintenance cost is also less for wind energy system. Wind energy is present almost 24 hours of the day. It has less emission. Initial cost is also less of the system. Generation of electricity from wind is depend upon the speed of wind flowing. The major disadvantages of using independent renewable energy resources are that unavailability of power for all time. For overcoming this we use solar and wind energy together. So that any one source of power fails other will take care of the generation. In this proposed system we can use both sources combine. Another way is that we can use any one source and keep another source as a stand by unit. This will leads to continuity of generation. This will make system reliable. The main disadvantages of this system are that it needs high initial cost. Except that it is reliable, it has less emission. Maintance cost is less. Life span of this system is more. Efficiency is more.

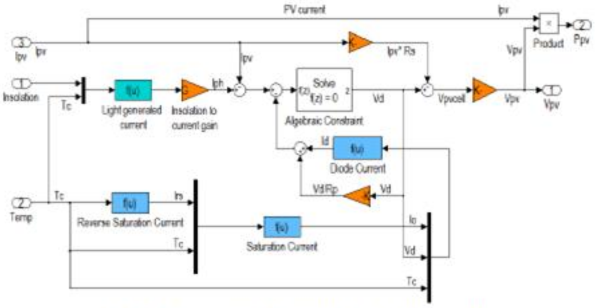

Fig. 4. Subsystem implementation of the PV model

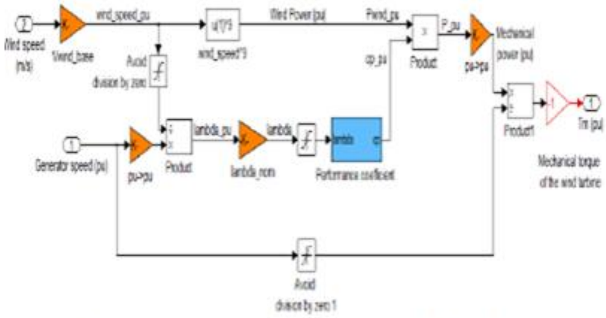

Fig. 5. Subsystem implementation of the WT model

2.6 Charging Electronics (Controllers) The need for Charging Controllers is very important so that overcharging of the batteries can be prevented and controlled.. The controllers to be used required the following features[4]: Prevent feedback from the batteries to PV modules It should have also a connector for DC loads It should have a work mode indicator.

Power Control Systems

1) Photovoltaic Control System

The output characteristics of the PV model with different solar irradiance and cell temperature are nonlinear. Furthermore, the solar irradiation is unpredictable, which makes the maximum power point (MPP) of the PV module changes continuously. Therefore, a maximum power point tracker (MPPT) technique is needed to operate the PV module at its maximum power point (MPP). Perturb and observe (P&O) algorithm is the maximum power point tracker (MPPT) control algorithm that will be adapted in this model. The P&O algorithm operates by periodically incrementing or decrementing the PV array operating current, and comparing the PV output power with the previous one. If it's positive the control system moves the PV array operating point in the same direction, otherwise, it's moved in the opposite direction. A MPPT controller model is built and implemented using MATLAB, to operate the PV module at its maximum power point. The P&O algorithm requires two measurements: measurement of the current (Ipv) and measurement of the voltage (Vpv). The proposed model is implemented as shown in Fig. 6.

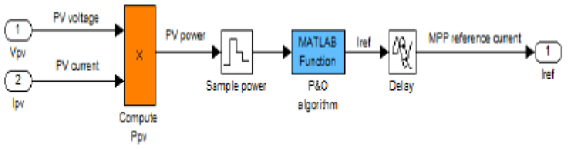

Fig. 6. Subsystem implementation of the MPPT controller model

2.7 Solar Inverters The Solar inverters are electrical device meant to perform the operation of converting D.C from array or battery to single or three phase A.C signals. For P.V Solar Systems, the inverters are incorporated with some inbuilt protective devices. These include[3]: Automatic switch off if the array output is too high or too low. Automatic re-start Protecting scheme to take care of short circuit and overloading. Generally the inverter to be used that would produce the quality output must have the following features[3,4,5]: Overload protections Miniature Circuit Breaker Trip Indicator(MCB) Low - battery protection Constant and trickle charging system Load status indicator

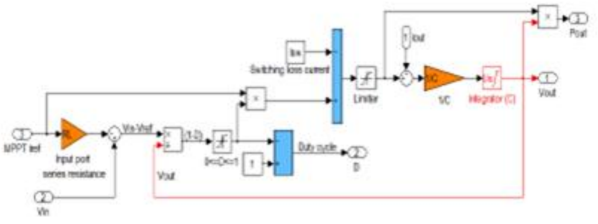

Fig. 7. Subsystem implementation of the dc/dc converter model

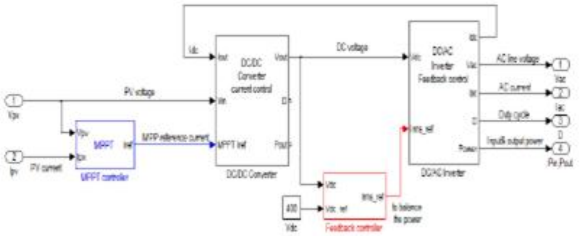

Fig. 8(a) Implementation of the PV control system model

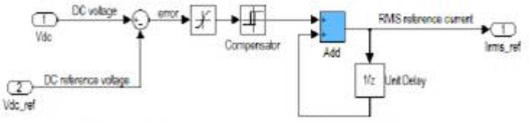

Fig. 8(b) Subsystem implementation of the feedback controller model

2) Wind Turbine Control System

Due to the variations in wind speed, the output power of the wind turbine induction generator experiences variations in frequency and amplitude. Therefore, a controllable ac/dc converter is used to smooth the wind turbine output power before being supplied to other electronic devices. Fig. 9, shows the schematic of the double-bridge rectifier One of the advantages of the double-bridge rectifier is the controllable dc output voltage, by tuning the firing angle (α) of the 12-pulse synchronized PWM generator, and the narrowed commutation periods, which causes less harmonic distortion effects on the source side. In this model a three-phase two winding transformer is used to obtain six input ports with appropriate phase angles for the double-bridge rectifier.

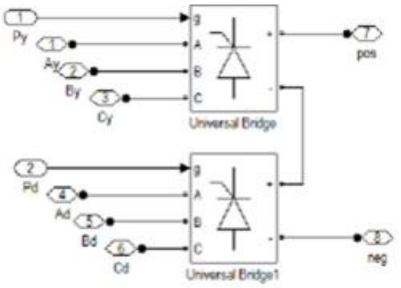

Fig. 9. The double-bridge rectifier

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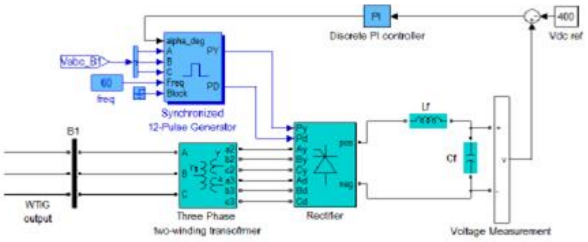

Fig. 10. The double-bridge rectifier, filters elements and control system model

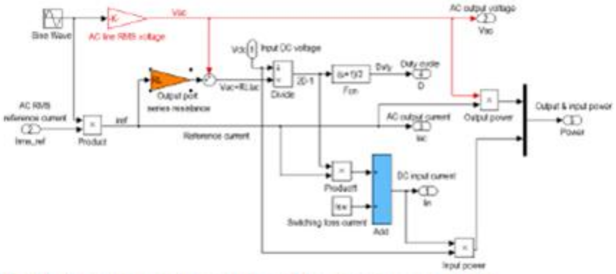

Fig. 11. Subsystem implementation of the dc/ac inverter model

3) dc/ac inverter for load side

An ac averaged switched model inverter is built and implemented using MATLAB/SIMULINK, to convert the direct current (dc) into alternating current (ac), at a switching frequency (fs) greater than the AC line frequency (50Hz - 60Hz). Losses are included due to output-port series resistance (ROP) and input-port switching loss current (IIP).The proposed model is implemented

Table I
Astronergy CHSM6610P specifications (1kW/m^2, 25° C)

Parameter	Value
Maximum power (P_m)	225 (W)
Open circuit voltage (V_{oc})	36.88 (V)
Voltage at P_m (V_{amp})	29.76 (V)
Short circuit current (I_{sc})	8.27 (A)
Current at P_m (I_{amp})	7.55 (A)
Temp coefficient for P_m	-0.46 (% / °C)
Temp coefficient for V_{oc}	-0.129 (V / °C)
Temp coefficient for I_{sc}	+ 0.052 (% / °C)
No. of cells and connections	60 in series

Table II
Wind Turbine Induction generator parameters

Parameter	Value
Turbine data	
Base wind speed (W_{base})	9 (m/s)
Maximum power at W_{base} (k_p)	1 (p.u.)
Coefficient (c_1-c_6)	[0.5176, 116, 0.4, 5, 21,0.0068]
Nominal performance coefficient	0.48 (p.u.) for [β =0°, λ=8.1]
Generator data	
Rotor type	Squirrel cage
Nominal power ($P_{mechanic}$)	200 (HP)
Nominal voltage (line-to-line)	460 (V)
Nominal frequency	60 (Hz)
Nominal revolutions per minute	1785 (rpm)
Stator resistance	0.01282 (p.u.)
Stator inductance	0.05051 (p.u.)
Rotor resistance	0.00702 (p.u.)
Rotor inductance	0.05051 (p.u.)
Magnetizing inductance	6.77 (p.u)
Inertia constant	0.3096 (s)
Friction factor	0.0114 (p.u.)
Pairs of poles	2

Table III
dc/dc converter model parameters

Parameter	Value
Input port series resistance	0.5
Switching loss current	0.03
Capacitance	200 (µF)
Initial capacitor voltage	400 (V)

Table IV
Double-bridge rectifier model parameters

Parameter	Value
Pulse width of synchronized 12-pulse generator	80 (°)
Proportional gain of PI voltage control system	2
Integral gain of PI voltage control system	20
Snubber resistance of one thyristor	2 (kΩ)
Snubber capacitance of one thyristor	0.1 (µF)
Internal resistance of one thyristor	1 (mΩ)
Filter inductance	66 (mH)
Filter capacitance	3300 (µF)
Reference voltage	400 (V)

Table V
Transformer parameters

Parameter	Value
Nominal power	120 (kW)
Nominal frequency	60 (Hz)
Input winding parameters (Yg) [V1 R1 L1]	[460 (V) 0.00025 (p.u.) 0 (p.u.)]
Output winding parameters (Y) [V2 R2 L2]	[230 (V) 0.00025 (p.u.) 0.0024 (p.u.)]
Output winding parameters (Delta) [V3 R3 L3]	[230 (V) 0.00025 (p.u.) 0.0024 (p.u.)]
Magnetization resistance	368.62 (p.u.)
Magnetization inductance	368.62 (p.u.)

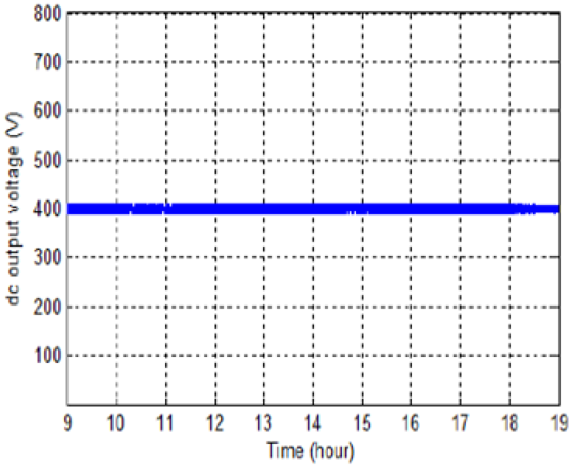

Fig. 15. Output voltage of the dc/dc converter

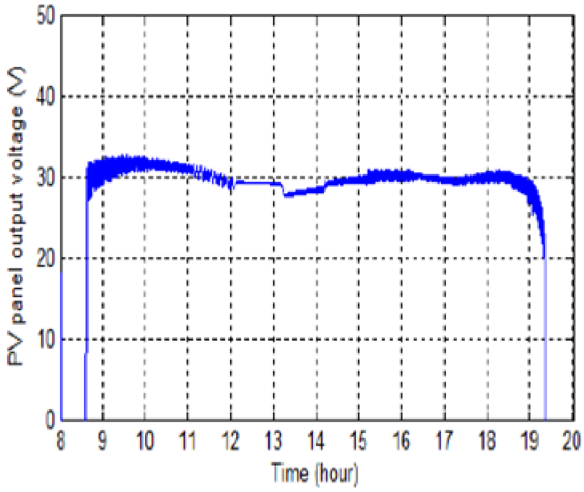

Fig. 16. Output voltage of the PV panel

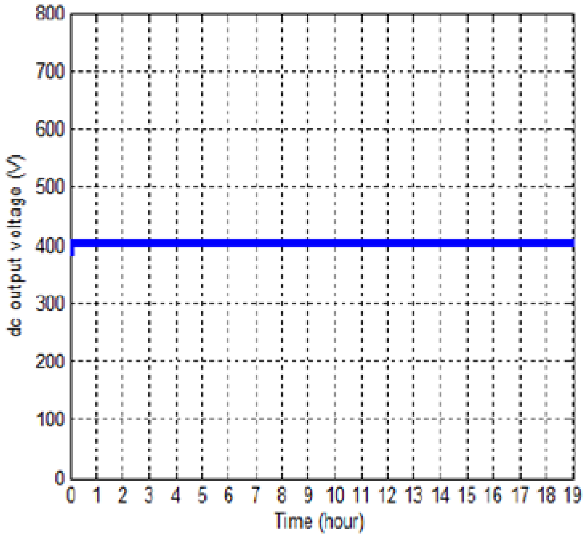

Fig. 20. Output voltage of the double-bridge ac/dc converter

V. CONCLUSION:

In this paper, a novel PV/WT hybrid power system is designed and modelled for smart grid applications. The developed algorithm comprises system components and an appropriate power flow controller. The model has been implemented using the MATLAB/SIMULINK software package, and designed with a dialog box like those used in the SIMULINK block libraries. The available power from the PV system is highly dependent on solar radiation. To overcome this deficiency of the PV system, the PV module was integrated with the wind turbine system. The dynamic behavior of the proposed model is examined under different operating conditions. Solar irradiance, temperature and wind speed data is gathered from a 28.8kW grid connected solar power system located in central Manchester. The developed system and its control strategy exhibit excellent performance for the simulation of a complete day. The proposed model offers a proper tool for smart grid performance optimization. The design concept has been verified through various test scenarios to demonstrate the operational capability of the proposed microgrid and the simulation results has shown that the proposed design concept is able to offer increased flexibility and reliability to the operation of the microgrid.

However, the proposed control design still requires further experimental validation because measurement errors due to inaccuracies of the voltage and current sensors, and modeling errors due to variations in actual system parameters such as distribution line and transformer impedances will affect the performance of the controller in practical implementation. In addition, MPC relies on the accuracy of model establishment, hence further research on improving the controller robustness to modeling inaccuracy is required. The simulation results obtained and the analysis performed in this paper serve as a basis for the design of a dc grid based wind power generation system in a microgrid.

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