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Study and Design of AC and Hybrid AC-DC Microgrid

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ABSTRACT: This paper highlights the modeling and the simulation of a micro-grid renewable power system. It comprises a wind turbine (WT) doubly fed induction generators (DFIG), photovoltaic generator (PV), a proton exchange membrane (PEM) Fuel Cell (FC) generator, a water Electrolyzer, a Hydrogen tank, and a battery bank (BBs). The system configuration and the characteristics of the main components in the proposed system are given; and the overall control and power management strategy for this latter are presented. In addition, the dynamic models of a boost DC-DC converter and a bidirectional DC-DC (Buck-Boost) converter are considered. A battery bank (BB) is used for short-term energy storage and an electrolyzer is used for long-term energy storage. The excess power from the WT-DFIGs and PV generators is then used for charging BB and for water electrolyzer to produce hydrogen. The (FC) and the (BB) work as a backup generator to supply the demand required power, when the WT-DFIGs and the PV energy are deficient. All the work is undertaken under MATLAB/Simulink environment.

KEYWORDS: Doubly fed induction generator, wind and solar energy, hybrid micro-grid, hydrogen production, hybrid energy storage system.

I.INTRODUCTION

In the last years, the renewable energy sources (RESs) based on micro-grid system applications have attracted more interest. The RESs are non-polluting, free in their availability and continuous. This fact makes this kind of energy attractive for micro-grid applications [1]. Many AESs including wind turbine (WT), photovoltaic panels (PV) and micro-turbines are reported in the literature for hybrid power sources system based on micro-grid applications [2]. As known, the drawback of these structures is the seasonal and daily climatic variations (solar radiation, wind speed, temperature) and geographical conditions as well as the profiles of the required power. This requires adopting other measures as solutions. However, Energy Storage Systems (ESSs) are necessary to mitigate the effects of wind or solar fluctuations and to maintain the power and energy balance as well as to improve the power quality. Hence, they must have a high-power density in order to face fast power variations, and at the same time they must have a high energy density to give autonomy to the micro-grid. For these reasons, it is necessary to associate more than one storage technology creating a Hybrid Energy Storage Systems (HESSs) [3,4].

The ESS as BBs is very important for an efficient and economic utilization of these hybrid systems [2]. However, the charge and discharge cycles decrease the life time of batteries [5, 6]. To improve the energy supply reliability of WT and PV hybrid system, a third energy source is needed. The fuel cell (FC) can be combined with an electrolyzer system to ensure the need for any backups the supply power system [7]. The energy management strategies of a micro-grid combined WT, PV and FC containing electrolyzer and battery are the most efficient procedures to produce very high energy quality. In this case, the micro-grid can be associated with distributed generation and decentralized management and that are normally connected to the grid. In addition, the micro-grid based renewable energy can be reduced the transmission losses [8].

Due to the increasing of DC loads in residential, electric vehicles, industrial and commercial buildings the power system loads may be DC dominated in the near future [8]. If these latter are supplied by means of AC grid, then it requires embedded AC/DC converters and DC/DC converters. The multiple reverse conversions associated with an individual AC or DC grid leads to additional costs and losses. Hence, reduces the overall efficiency of the system. A hybrid AC/DC micro-grid normally associated with individual AC grids or DC grids can overcome the fact that AC loads must be connected to AC grid [7, 9, 10], whereas DC loads are

connected to DC grid [5, 6, 8, 10-13], and the AC and DC grids are connected through a bidirectional converter[14].

Several studies and a various configurations of micro-grid applications based on the hybrid energy generations have been proposed [7, 9-12, 14]. However, a little attention has been reserved to the integration of a DFIG on the micro-grid system.

In [14], a hybrid micro-grid consists a WT-DFIG and a FC is proposed, to reduce the process of multiple AC-DC-AC and DC-AC-DC conversions which are commonly seen in an individual AC grid or DC grid. The drawback of this paper is that there is no power management and no battery to support the FC operations. In addition to linear vector control handicap, regarding to the robustness, the advantages provided by DFIG were not reported particularly its operations modes, such as Sub, Super and synchronous modes, which is the case of reference [7], as well as the impact of the over-speeds area (pitch angle control) was not discussed. In the [9], the reactive power required is provided by a synchronous compensator, while the active power is provided by a wind turbine generator. The lacks of this topology is that the cost and the complexity of control have been increased.

The main contribution of this paper is that the proposed micro-grid based on WT-DFIG/PV hybrid power sources system is designed in a new topology. The advantage of this topology is an easier accessibility of AC and DC grid. However, the AC/DC and DC/DC converters required for supplying the DC loads are not needed. This configuration of the micro-grid permits an achieving of optimal and efficient control of the different sources, ensuring better power quality for AC and DC grid, regulating the voltage level and the frequency of AC grid, ensuring continuity of the service and supplying the local reactive power compensation. In addition, a micro-grid based on a multiple source topology can increase the flexibility of power management for the micro-grid into the grid and vice versa. Finally, the simulation of applied management algorithm of the whole system in very severe situations such as: change in power demand, random variations and sudden meteorological conditions, are presented and the results are discussed.

Thus, before presenting the obtained results and their comments, we will describe the proposed system and the control techniques used.

II. DESCRIPTION OF THE PROPOSED MICRO-GRID

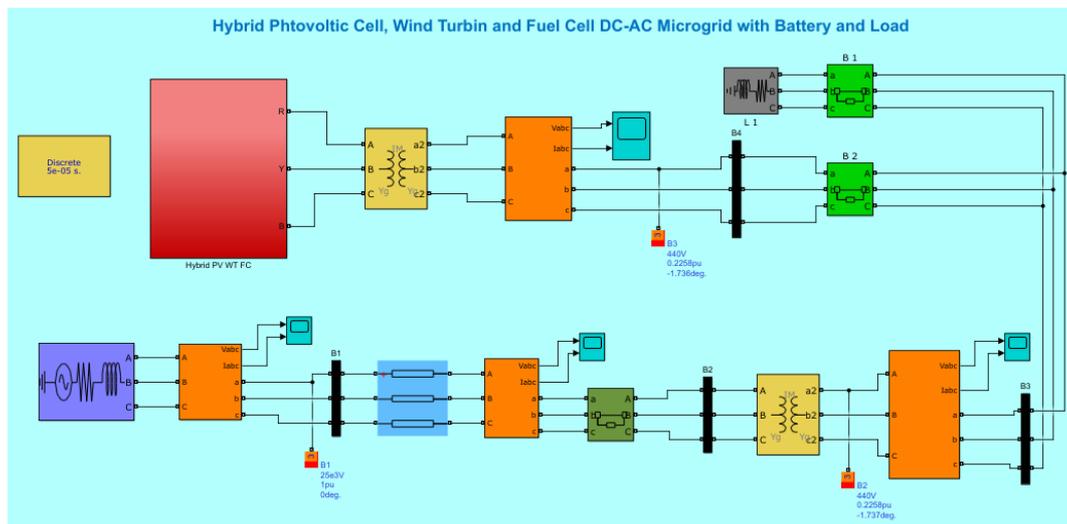


Figure 1. Hybrid PV/WT and FC system with transmission line and load

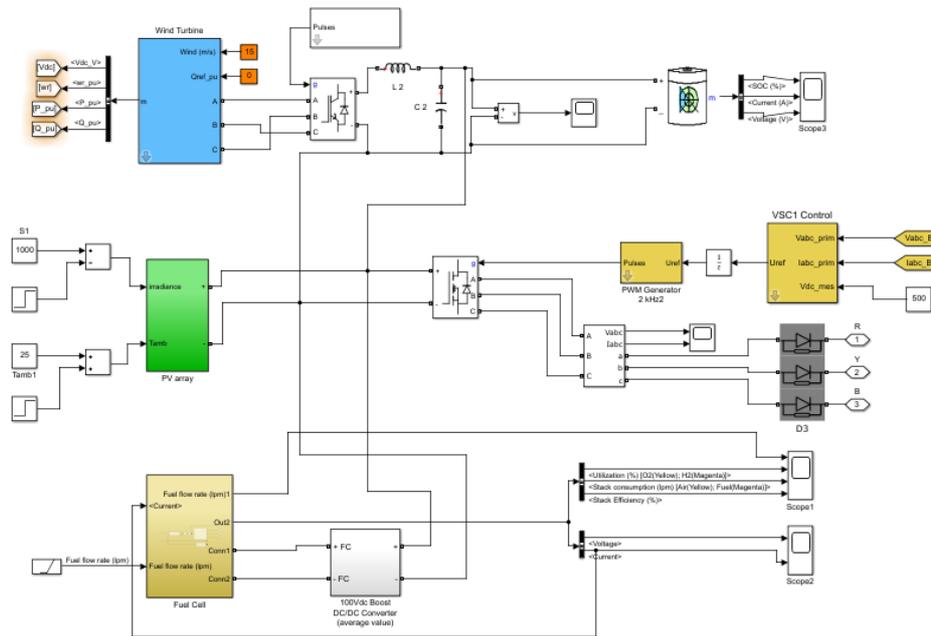


Figure2. PV/WT and FC to DC-DC bus and DC-AC Bus

The proposed hybrid energy system, shown in Fig. 2 consists of a DFIG based variable speed wind energy conversion, PV array, battery, fuel cell and electrolyzer. WT and PV energy sources are managed with maximum power point tracking (MPPT) algorithms and connected to the common DC bus. Where, in the WT case, the MPPT algorithm is applied at below nominal turbine speed. Beyond the nominal speed, we will be acting on the pitch angle control, whereas the power extraction maximization amounts to regulate the power produced at its rate value. The Battery is used as a storage device and is connected to the DC bus through DC/DC Buck-Boost bidirectional converter (BBDC). Wind and solar power depend on weather conditions and during night hours solar power is zero. Therefore, under the situation of long term no-wind and solar or low-wind and solar condition, battery alone cannot cater the load demand. Hence, fuel cell (FC) is integrated to make the system more sustainable. In case of high-power generation from wind and solar for a long time and the battery reached its upper limit of charge storage, the electrolyzer comes into effect and consumes the surplus power. The hydrogen generated from the electrolyzer can be stored and used as input by FC.

System Modeling and Control

A. Photovoltaic Cell

The PV cell mathematical model is represented in [11, 12]. The typical PV module power characteristic is given in [1]. In order to extract the maximum available power from a PV array, it is necessary to operate the PV array at its maximum power point. The MPPT device is a high-frequency boost dc-dc converter inserted between the PV array and the dc bus, and it takes the dc input from the PV array, convert it to a different dc voltage and current to exactly match the PV array to the dc bus.

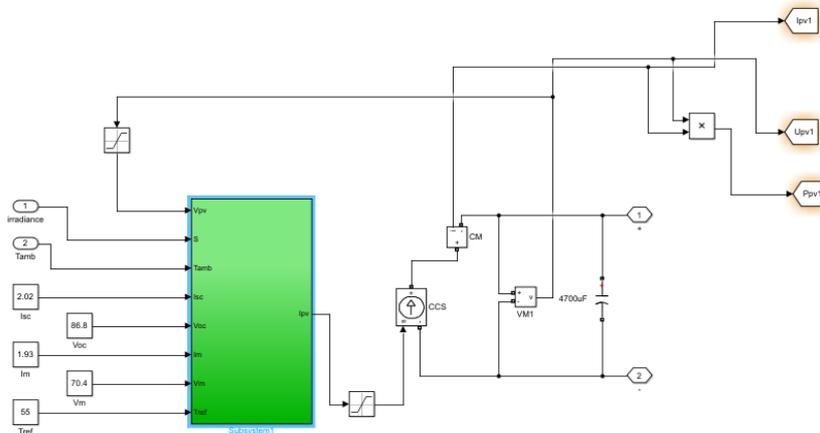


Figure3. Modelling of PV with irradiance and temperature.

Fig.3 shows that the output power is directly proportional to the irradiance. As such, a smaller irradiance will result in reduced power output from the PV module. However, it is also observed that only the output current is affected by the irradiance. This is expected, because the generated current is proportional to the flux of photons. According to V_{mpp} they result 4 arrays are connected in parallel; each array consists of 27 modules connected in series. each of them delivers 108 W peaks.

B. Wind Energy Conversion

The aerodynamic power at the rotor of the turbine is given by the following equation:

$$P_{wind} = \frac{1}{2} \rho A v^3 C_p(\lambda, \theta) \quad (1)$$

Where ρ is the air density in kilogram per cubic meter, A is the area swept by the rotor blades in square meter, and v is the wind velocity in meters per second. C_p is called the power coefficient or the rotor efficiency and is a function of tip speed ratio (λ) and pitch angle (β) [15].

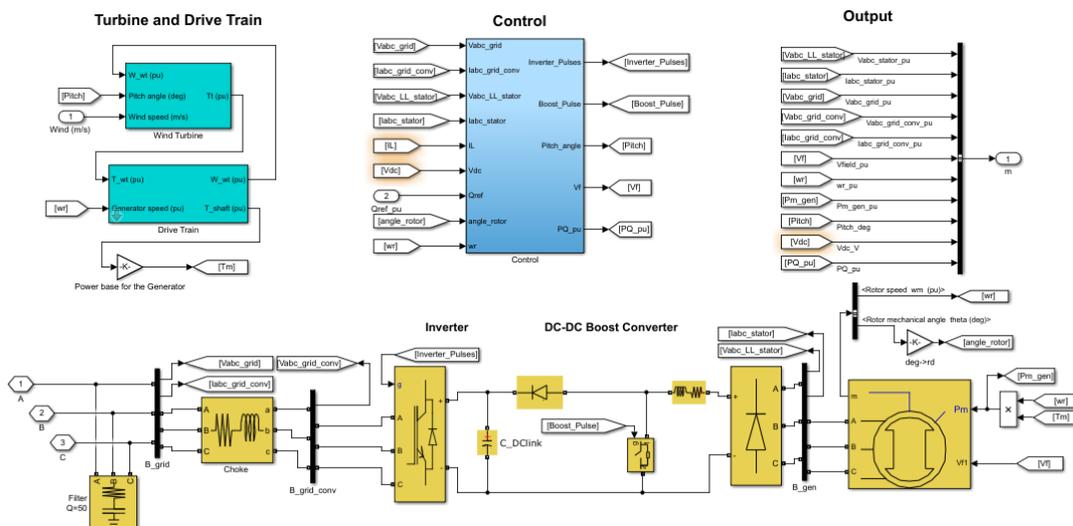


Figure4. Modelling of WT with converters

The proposed WT-DFIGs control strategy is illustrated in Fig. 1. This latter is based on DTC combined with a fuzzy logic control technique, called a direct torque reactive power control (DTRPC). So, the reactive and active powers are controlled respectively with the rotor flux and electromagnetic torque. These latter are considered to be the outputs of the fuzzy controllers established for regulating the reactive power and the mechanical speed of DFIG.

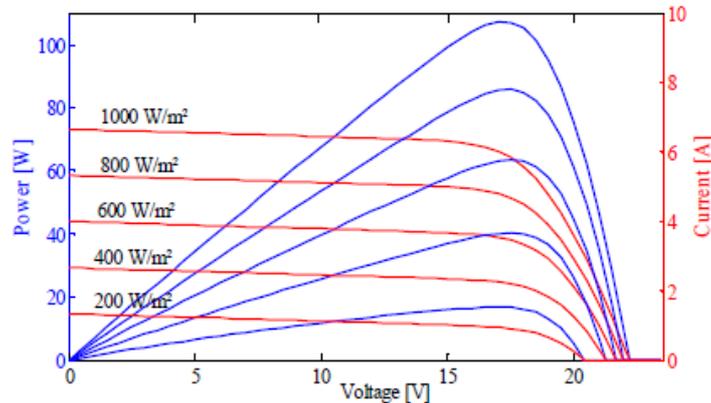


Figure 5. Typical PV module unit I-V and P-V characteristic showing the effects of irradiance.

C. Fuel Cell

The FC is a device for directly converting the chemical energy of a fuel, into electrical energy. The output voltage of a single cell given in [10-12] can be defined as in (2):

$$E_{cell} = E_{Nernst} - E_{Act} - E_{Con} - E_{Ohm} \tag{2}$$

Where E_{Nernst} is the reversible voltage, E_{Act} is the activation voltage drop, E_{Con} is the concentration voltage drop, and E_{Ohm} is the Ohmic voltage drop. The terminal voltage of PEM fuel cell stacks is defined as in (3).

$$V_{FC} = N_s E_{Cell} \tag{3}$$

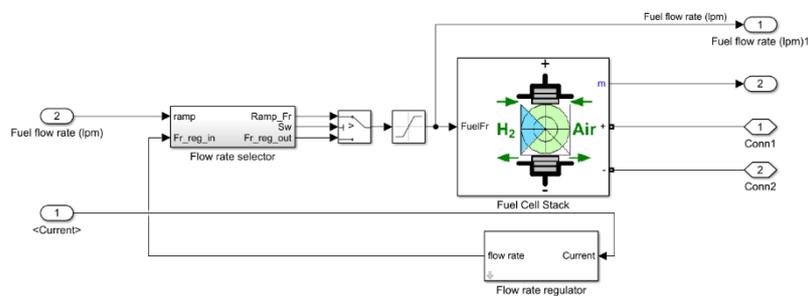


Figure6. Modelling of FC

Fig. 7 shows voltage and power versus current polarization curves of a PEM FC. It is shown that the activation voltage drop dominates at low current, the Ohmic drop voltage dominates at mid-range current, and the concentration drop voltage dominates at high current. The voltage deviates further as the current is increased, illustrating the effects of drop voltages. In concentration voltage drop region, the FC output power occurs near the FC rated power.

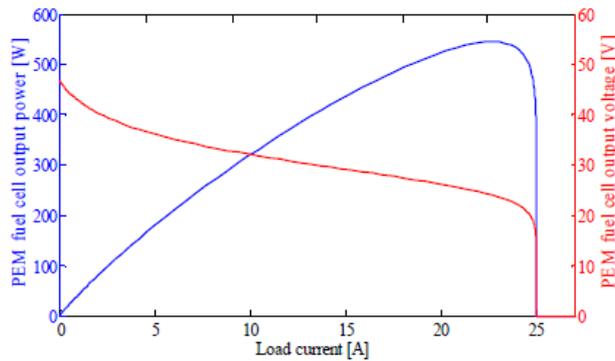


Figure 7. Power and voltage versus current polarization curves of PEM FC

The FC controller through which the boost converter switch is controlled. Controllers associated with the battery and FC are developed in such a fashion that when there is a sudden required power change, the battery provides the power instantaneously and as FC power goes on increasing, battery power should go on decreasing. In order to make the proper coordination between battery and FC, boost converter controller associated with fuel cell is developed based on and assuming battery current is ideally zero. Moreover, when the battery state of charge (SOC) is below 20 %, the fuel cell should give power to the battery.

The PEM fuel cell is composed of 2x6 stacks with the power rating of 10 kW.

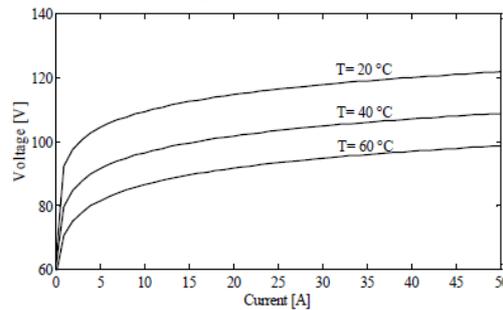


Figure 8. Typical U-I characteristic of an electrolyzer under different Temperatures

D. Electrolyzer

The description of the water electrolyzer is developed in [11, 12]. The U–I characteristics of the electrolyzer model used in this study at different cell temperatures. At a given current, the higher the operating temperature, the lower is the terminal voltage needed. The excess energy produced is first pushed into the battery until it reaches its upper limit of charge carrying capacity and then the excess power is fed to the electrolyzer and is regulated via the buck DC/DC converter. The decision about switching on the control action is carried out by comparing the upper limit of the state of charge (SOC) of the battery and the present status of SOC. When the SOC becomes higher than its limit, 80 %, the controller will increase the duty cycle as a function of over voltage in the dc bus voltage.

III.SIMULATION RESULT AND DISCUSSION

Using the component models, a simulation system test for the proposed WTDFIGs/PV/FC-Electrolyzer energy system has been developed using MATLAB/Simulink, the WT-DFIGs and the PV parameters are given in [1, 15], but those of the Electrolyzer, BB and FC are given in [11, 12]. In order to verify the system performance under different situations, simulation studies have been carried out using variable load demand data and random weather data (wind speed, solar irradiance, and air temperature).

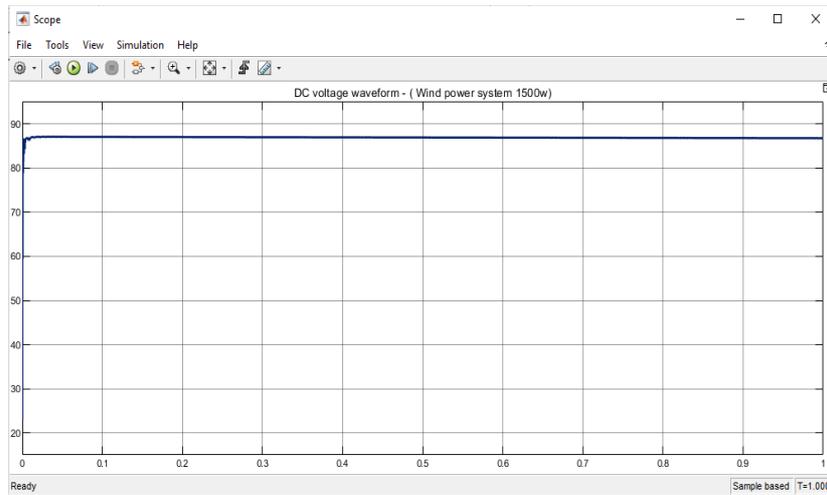


Figure 9. DC-DC microgrid voltage

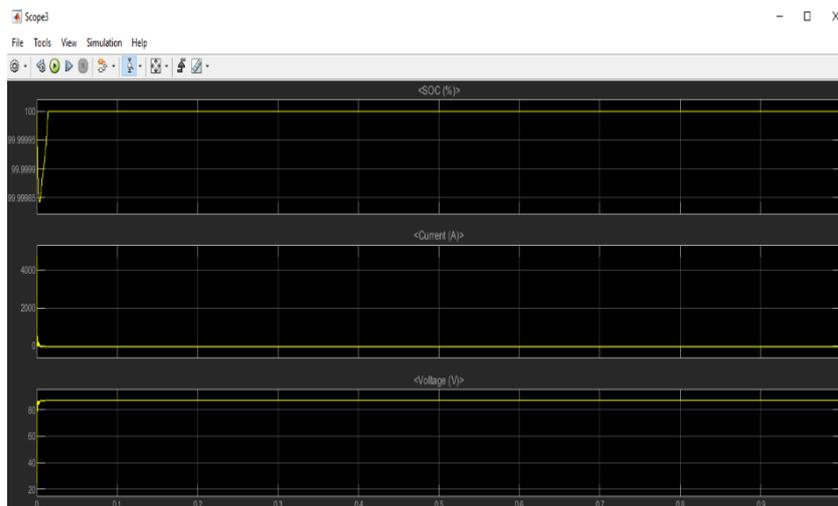


Figure10. SOC, Current and Voltage of Battery

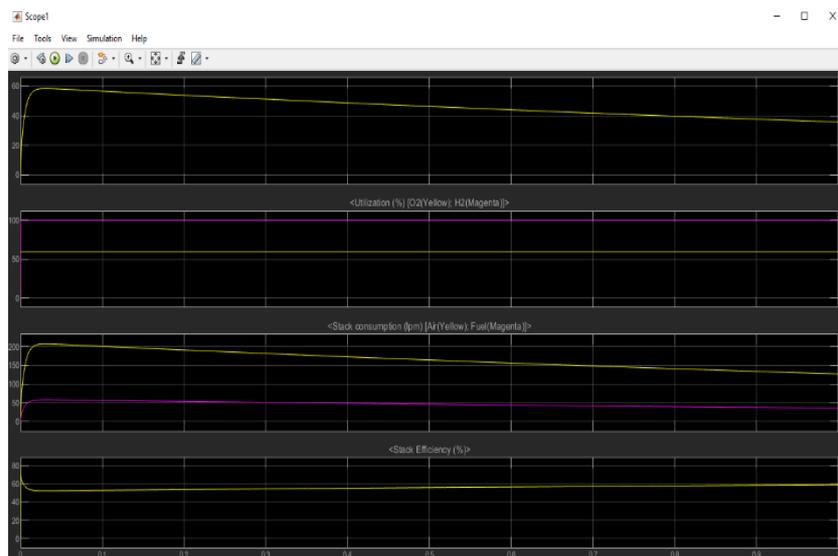


Figure11. Characteristic of FC

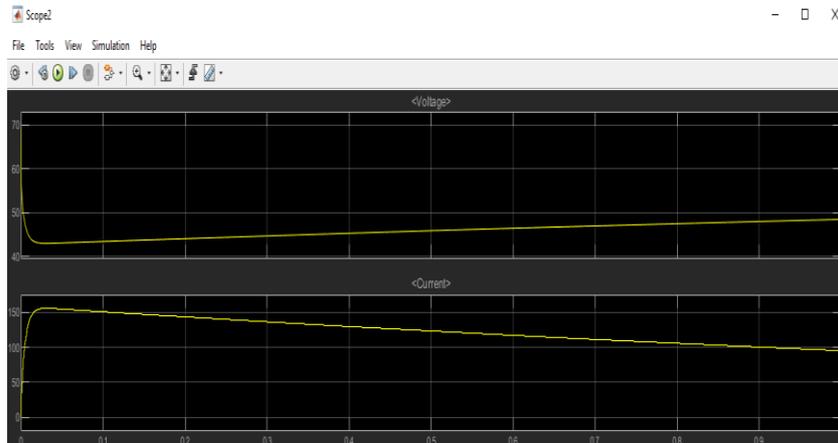


Figure12. Voltage and Current of FC

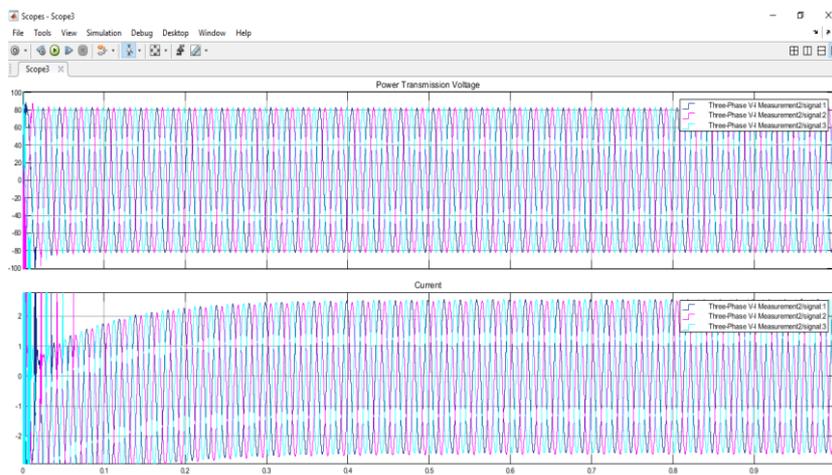


Figure13. Voltage and Current of DC-AC Converter

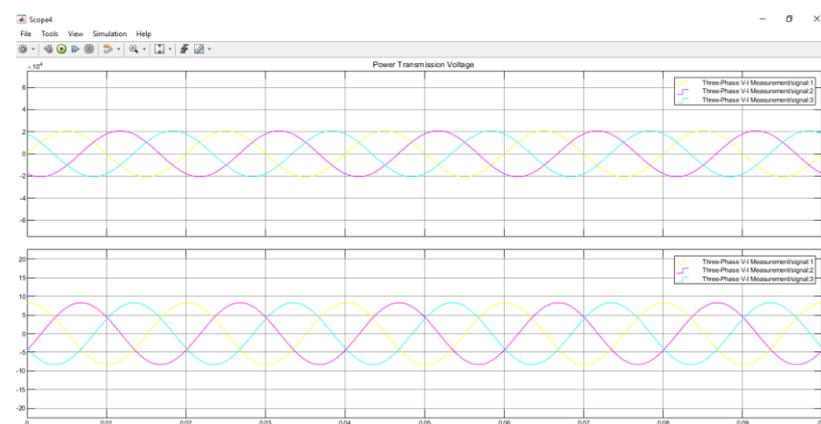


Figure14. Voltage and Current of Load

IV.CONCLUSIONS

In this paper, a Hybrid micro-grid system associated to generating system using WT-DFIGs/PV/FC combined with a hybrid energy storage system is proposed. The system configuration and the characteristics of the main components in the system are given, and the overall control and power management strategy for the proposed hybrid energy system is presented. The WT-DFIGs and PV generation systems are the main power generation devices and the electrolyzer-BB acts as a dump load using any excess power available to BB charging and produce H₂. The FC and BB system are the

backup generation and supply power to the system when there is a power deficit. Simulation studies have been carried out to verify the system performances and the results obtained which show the effectiveness of the adopted control strategy. This latter justifies the usefulness of the DFIG in the possibility of management and the active-reactive power control, especially, operating as a local reactive power compensator.

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