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Modeling and Implementation of Hybrid Solar-Wind-Hydro Renewable Energy Systems

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Abstract: One of the major worldwide concerns of the utilities is to reduce the emissions from traditional power plants by using renewable energy and to reduce the high cost of supplying electricity to remote areas. Hybrid power systems can provide a good solution for such problems because they integrate renewable energy along with the traditional power plants. Hybrid systems are characterized by containing two or more technologies of electrical generation, in order to optimize global efficiency of the processes. Basically this system involves the integration of solar, wind, hydroelectric system with battery storage device that will gives continuous power. Solar panels are used for converting solar energy and wind turbines are used for converting wind energy into electricity and hydroelectric system is used for generation of electricity from kinetic energy of the water. The model has designed to provide power quality for hybrid renewable energy systems. In this Paper, the modeling of hybrid solar photovoltaic, wind and hydro energy system with battery storage are done by using MATLAB/SIMULINK software and results are presented.

Keywords: Hybrid Energy System, Solar Photovoltaic System, Wind Energy System, Hydro Energy Systems, Battery Storage, MATLAB/SIMULINK/SIMULIN.

I. INTRODUCTION

Electricity is most needed for our day to day life, with increases in demand for electrical energy, there is a need to search for alternative sources of power generation. There are two ways of electricity generation either by conventional energy resources or by non-conventional energy resources. The conventional energy resources are depleting day by day. Soon it will be completely vanishes from the earth so we have to find another way to generate electricity. The non-conventional energy resources should be good alternative energy resources for the conventional energy resources.

The solution for this problem is the concept of renewable energy source that includes Solar, Wind, and Hydro etc. Sources and the intermittency of the power generated by them create stability, reliability and power quality problems in the main electrical grid. The term hybrid energy system refers to those applications in which multiple energy conversion devices are used together to supply an energy requirement. These systems are often used in isolated applications and normally include at least one renewable energy source in the configuration. In this proposed system solar, wind and hydro power system 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 and it needs low cost. The importance of hybrid systems grown as they appeared to be the right solution for a clean and distributed energy production. In this paper the solar photovoltaic model wind energy and hydro energy system are modeled by MATLAB/SIMULINK.

II. DISCRTPTION OF ENERGY SYSTEM

Hybrid power systems consist on a combination of renewable energy sources such as solar photovoltaic (PV), wind generators, hydro, etc., to charge batteries and provide power to meet the energy demand, considering the local geography and other details of the place of installation. The design process of hybrid energy systems requires the selection and sizing of the most suitable combination of energy sources, power conditioning devices, and energy storage system together with the implementation of an efficient energy dispatch strategy.

The selection of the suitable combination from renewable technology to form a hybrid energy system depends on the availability of the renewable resources in the site where the hybrid system is intended to be installed. In this proposed system solar, wind power and hydroelectric with battery storage system 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 with lower cost.

A. SOLAR ENERGY

Solar energy is that energy which is gets by the radiation of the sun 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 Power is very popular nowadays, because of the high power that can be achieved in an efficient way. Wind energy is the energy which is extracted from wind. For extraction we use wind mill. 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.

C. HYDRO ENERGY

Hydropower is common for many years in countries that have mountains and water. Small hydroelectric power plants harness the falling water kinetic energy to generate electricity. Turbine transform falling water kinetic energy into mechanical energy and then, the alternator transform the mechanical energy into electrical energy.

D. STORAGE DEVICE

The energy storage device/equipments are used basically for three purposes, energy stabilization, ride through capability and dispatch ability. The energy stabilization permits the hybrid system to run at a constant stable level with the help of the energy storage devices, even if load fluctuations rapidly.

The ride through capability is the capability of energy storage devices which provides the proper amount of energy to loads, when the hybrid system generators are unavailable. Since both wind and PVs are intermediate sources of power, it is highly desirable to Incorporate energy storage into such hybrid power systems. Energy storage can smooth out the fluctuation of wind and solar power and improve the load availability For the resources energy sources like photovoltaic or wind energy systems, the power production depends upon the availability of the resources like sunlight or wind.

This makes the nature of power available to loads intermittent, thus making them non-dispatch able sources. However, the energy storage systems with non-dispatch able energy can be deployed as dispatch able energy sources. Batteries are the basic component of an energy storage system.

A battery consists of one or more electrochemical cells that are electrically connected. The basic components of an electrolytic cell like a lead-acid cell are positive electrode, a negative electrode a porous separator and an electrolyte. During cell operation, ions are created and consumed at the two electrodes /electrolyte interface by oxidation/reductions reactions.

The electrolyte, which can either be a solid or liquid chemical, has high conductivity for ions but not for electrons, because if the electrolyte conducts electrons then the battery will self discharge. The hybrid system is shown in Fig. 1. In the following sections, the model of components is discussed.

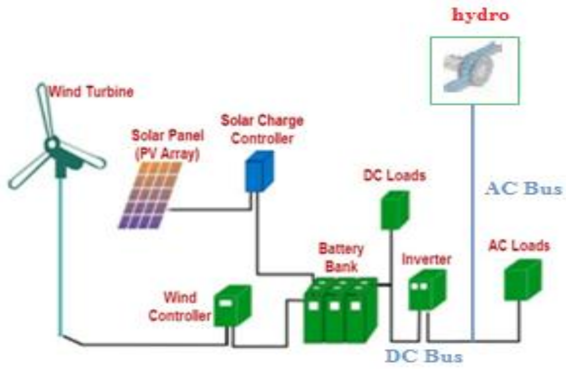

Fig. 1 The hybrid renewable energy system

III. MODELING OF HYBRID SOLAR-WIND-HYDRO ENERGY SYSTEM

A. MODELING THE SOLAR PV SYSTEM

A photovoltaic PV generator consists of an assembly of solar cells, connections, protective parts, supports etc. Solar cells are made up of semiconductor materials (usually silicon),which are specially treated to form an electric field, positive on one diode(backside) and negative on other (towards the sun). When solar energy (photons) solar hits the solar cell, electronics are knocked loose from the atoms in the semiconductor material, creating electron-hole pairs. If the electrical conductors are then attached to the positive and negative sides, forming an electrical circuit, the electrons are captured in the form of electric current (photo current). The model of the solar cell can be realized by an equivalent circuit that consists of a current source in parallel with a diode as shown in Fig.2. For ideal model R_s, R_p and C components can be neglected.

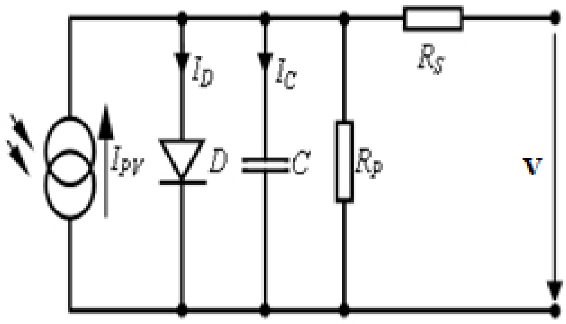

Fig. 2 Equivalent circuit diagram of a solar pv cell

The p-n junction has a certain depletion layer capacitance, which is typically neglected for modeling solar cell. At increased inverse voltage the depletion layer becomes wider so that the capacitance is reduced similar to stretching the electrodes of a plate capacitor. Thus solar cells represent variable capacitance whose magnitude depends on the present voltage. This effect is considered by the capacitor C located in parallel to the diode. Series resistance R_s consists of the contact resistance of the cables as well as of the resistance of the semiconductor material itself. Parallel or shunt resistance R_p includes the ‘leakage current’ at the photovoltaic cell edges at which the ideal shunt reaction of the p-n junction may reduced. This is

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usually within the KΩ region and consequently has almost no effect on the current-voltage characteristics.
The diode is the one which determines the current-voltage characteristic of the cell. The output of the current source is directly proportional to the light falling on the cell. The open circuit voltage increases logarithmically according to the Shockley equation which describes the interdependent of current and voltage in a solar cell.

$$I = I_{PV} - I_0\left(e^{\frac{qU}{kT}} - 1\right) \text{---- (1)}$$

$$V = \frac{kT}{q}\ln\left(1 - \frac{I - I_{PV}}{I_0}\right) \text{----- (2)}$$

Where

k- Boltzmann constant;
T-reference temperature of the solar cell;
q-elementary charge (1.6021 10^{-19} As);
V-solar cell voltage(V);
I_0 – saturation current of the diode (A);
I_{PV} – photovoltaic current (A);
Equations (1) and (2) lead to the development of a Matlab Simulink for the PV module presented in Fig.3.

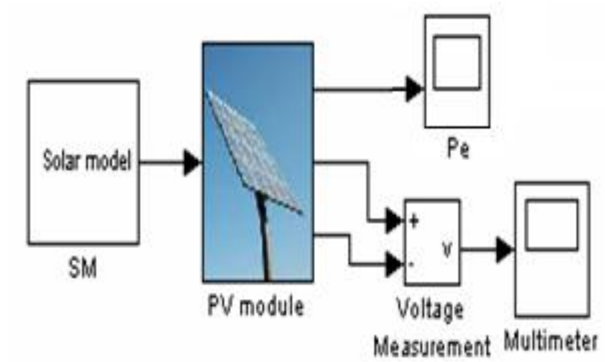

Fig. 3 Matlab/Simulink Library PV module

The solar system model consists of three Simulink blocks: the solar model block, the PV model block and energy conversion modules. The solar model block implements the mathematical model of the solar radiation. This is done by using standard Simulink and Matlab modules and functions. The PV module implements the equivalent circuit of a solar cell, shown Fig.3. The PV array I –V and P–V characteristics is shown in Fig. 4

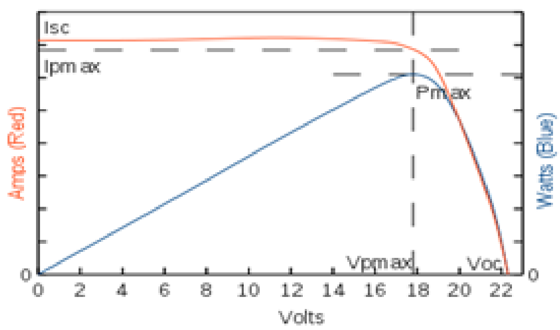

Fig. 4 PV arrays I –V and P–V characteristics.

Standard functions and blocks of Matlab and Simulink were used to obtain this model, Its structure is represented in Fig.5. The output of the PV module is processed by an energy conversion block implemented with an PWM IGBT inverter block from standard Simulink/SimPower Systems library.

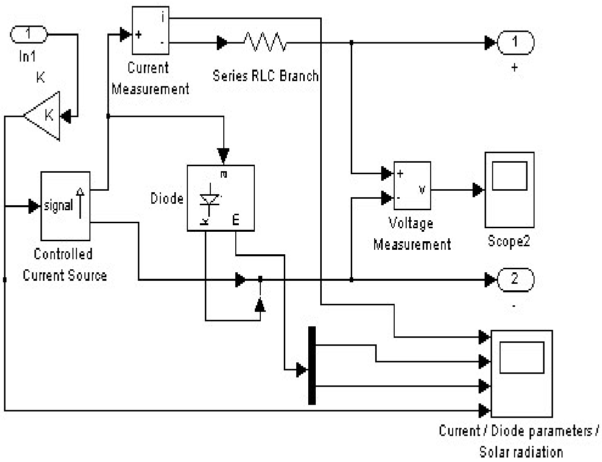

Fig. 5 Matlab/Simulink implemented of the PV module.

B. MODELING THE WIND ENERGY SYSTEM
Modeling the wind energy converter is made considering the following assumptions:
Friction is neglected; Stationary wind flow;
Constant, shear-free wind flow; Rotation-free flow;
Incompressible flow (ρ=1.22 kg/m^3);
Free wind flow around the wind energy converter.
On the above condition the maximum physical achievable wind energy conversion can be derived using theoretical model that is independent of the technical construction of a wind energy converter. The flow air mass has certain energy. This energy is obtained from the air movement on the earth's surface determined by the difference in speed and pressure. This the main source of the energy used by the wind turbines to obtain electric power. The Kinetic energy W taken from the air mass flow m at speed v_1 in front of the wind turbines pales and at the back of the pales at speed v_2 is illustrated by equation (3):

$$W = \frac{1}{2}m({v_1}^2 - {v_2}^2) \text{ ------------- (3)}$$

The resulted theoretical medium power p is determined as the ratio between the kinetic energy and the unit of time and is expressed by equation (4):

$$P = \frac{1}{2}\frac{m}{t}({v_1}^2 - {v_2}^2) = \frac{1}{2}\frac{V\rho}{t}({v_1}^2 - {v_2}^2) \text{ ----- (4)}$$

Where:
V- air mass volume; t- time; ρ - Air density.
Assuming the expression of the mean air speed

$$V_{med} = \frac{1}{2}(v_1 + v_2)$$

The mean air volume transferred per unit time can be determined as follows:

$$V_{med} = \frac{V}{t} = Av_{med} \text{ --------------- } (5)$$

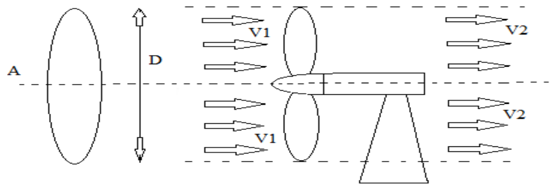

Fig. 6 Flow through a wind energy converter.

The equation for the mean theoretical power is determined using equation (5)

$$P = \frac{1}{4}A\rho(v_1^2 - v_2^2)(v_1 + v_2) = \frac{A}{4}A\rho v_1^3\left(1 - \frac{v_2^2}{v_1^2}\right)\left(1 - \frac{V_2}{V_1}\right) \text{-------} (6)$$

We can conclude that an adequate choice of v_1/v_2 ratio leads to a maximum power value taken by the wind converter from the kinetic energy of the air masses, as shown by equation (7)

$$P_{max} = \frac{8}{27}A\rho v_1^3 \text{------------- } (7)$$

This power represents only a fraction of the incident air flow theoretical power given by

$$P_{wind} = \frac{1}{2}A\rho v_1^3 \text{ -------------- } (8)$$

Equations (7) and (8) lead to:

$$P_{max} = \frac{8}{27}A\rho v_1^3 = \frac{1}{2}A\rho v_1^3 = P_{wind} \,.\, C_P \text{ --- } (9)$$

Where C_p represents the mechanical power coefficient which express that the wind kinetic energy cannot be totally converted in useful energy. This coefficient, meaning the maximum theoretical efficiency of wind power. The electrical power obtained under the assumptions of a wind generator's electrical and mechanical part efficiency is given by:

$$P_{ele} = \frac{1}{2}C_e A\rho v_1^3 \text{ -------------- } (10)$$

Where C_e represents the total net efficiency coefficient at the transformer terminals. A Matlab/simulink model, based on the equations mentioned above, was developed for the wind generator module. This model is shown in fig. 7

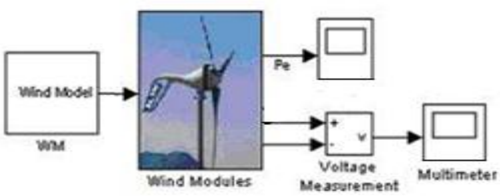

Fig. 7 The Matlab/Simulink model of the wind generator module.

The wind system model consists of three simulink blocks: the wind model block, the wind generator model block and energy conversion modules. The wind model block implements the mathematical model of the air mass flow. This is done by using standard Simulink and Matlab modules and functions. This block allows the selection of different patterns for the air mass flow and the equations mentioned above were used in the design of this model. The wind energy generator model was implemented by a module having configurable parameters based on the equation (10) and using the equivalent model of a generator. This model takes the following form and is shown in fig. 8

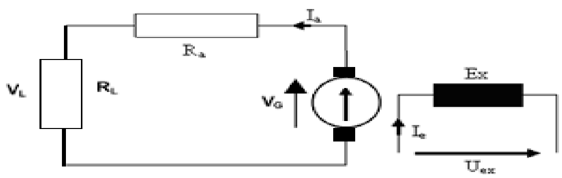

Fig. 8 Equivalent circuit diagram of a wind generator

In the equivalent circuit diagram of a small wind generator the notations are:

R_a – rotor winding resistance
Ex- generator separate excitation winding; current I_e through this winding generates the main field
V_e- induced voltage in the rotor (armature) V- terminal voltage
$V = V_e\text{-}R_a\ I_a$

The resulted Matlab/Simulink model for the wind generator is a particular case of the more general model of an electrical generator, which is presented in figure 9.

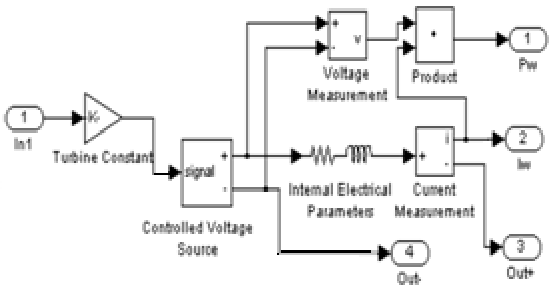

Fig. 9 Matlab/Simulink model of the wind generator

The output of the wind energy generator module is processed by an energy conversion block implemented with a PWM IGBT inverter block from the standard Simulink/Sim Power systems library.

C.MODELING OF HYDROELECTRIC SYSTEM

The hydroelectric system, water flows within a river from a higher geodesic site to a lower geodesic site due to gravitation. This is characterized by different particular kinetic and potential energy at both sides. The correct identification of the resulting energy differences of the out-flowing water can be assumed by considering a stationary

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and friction-free flow with incompressibility. The hydrodynamic Bernoulli pressure equation applied in such conditions is written according to equation (11)

$$p + p_{water}\,gh + \frac{1}{2}p_{water}\,v^2_{water} = constnt \text{ ....(11)}$$

Where: $p - hydrostatic\ pressure;$
P_{water} – water density;
g- acceleration of gravity;
h-the water height;
v_{water} – velocity of the water flow.

Equation (11) can be transformed so that the first term expresses the pressure level, the second term the level of the site and the third term the water velocity level by (12)

$$\frac{p}{p_{water}\,g} + h + \frac{1}{2}\frac{v^2_{water}}{g} = constant \text{ .... (12)}$$

The term $\frac{1}{2}\frac{v^2_{water}}{g}$ refers to the dynamic height and is defined as the height due to the speed of water flow and can be identified by the term of kinetic water energy. The usable head h_{util} of a particular section of river can be determined by considering: the difference in pressure, the geodesic difference in height and the different flow velocities of the water, using equation (13). It must be mentioned that the equation is used to analyse an ideal case and does not consider the losses due to the friction of the individual water molecules among each other and the surrounding matter.

$$h_{util} = \frac{p_{up} - p_{down}}{p_{water}\,g} + \left(h_{up} - h_{down}\right) + \frac{v^2_{water,up} - v^2_{water,down}}{2g} \text{ ....(13)}$$

Where:
$p$up – upstream hydrostatic pressure;
$p$down – downstream hydrostatic pressure;
h up – upstream geodesic water height (headwater);
h down– downstream geodesic water height (tailwater);
v water up , – upstream water velocity;
v water down , – downstream water velocity;

Considering equation (13), the power of a water supply $p$water can be determined using (14).

$$p_{water,th} = p_{water}\,g q_{water}\,h_{util} \text{ ....(14)}$$

where: q_{water} is the volume-related flow rate.

According to equation (14), the power of a water supply is determined by the volume-related flow rate and usable head. The water flow assumes high values in lowland areas, while large heads can be achieved in mountain areas. Considering two specific points of river, the theoretical power of the water $p$water,th, can be calculated based on (15).

$$p_{water,th} = p_{water}\,g q_{water}\,(h_{up} - h_{down}) \text{ ...(15)}$$

where $q$water □represents the volumetric flow rate through a hydroelectric power plant.

In the real case, considering the energy balance between two specific points of a river, and also the energy losses, the hydrodynamic Bernoulli pressure equation can be written according to equation (16)

$$\frac{p_{up}}{p_{water,up}\,g} + h_{up} + \frac{v^2_{water,up}}{2g} = \frac{p_{down}}{p_{water,down}\,g} + h_{av} + \frac{v^2_{water,down}}{2g} + \xi\frac{v^2_{water,down}}{2g} = constant$$

Where:

$\frac{p_{down}}{p_{water,down}\,g}$ - hydrodynamic pressure energy;
h - potential energy of the water;
$\frac{v^2_{water}}{2g}$ - kinetic energy of the water;
$\xi\frac{v^2_{water}}{2g}$ - □ □- energy losses
□ □- loss coefficient

The energy losses are represented by the part of the rated power which is converted into ambient heat by friction and cannot be used technically. In the turbine, pressure energy is converted into mechanical energy. The conversion losses are described by the turbine efficiency ηturbine. Equation (17) describes the part of the usable water power that can be converted into mechanical energy at the turbine shaft $p$turbine□

$$p_{turbine} = \square_{turbine}\,p_{water}\,g q_{water}\,h_{util} \text{ .....(17)}$$

h_{util} □is the usable head at the turbine, and the term ($p_{water}\,g q_{water}\,h_{util}$ □ □ □represents the actual usable water power. The water model described by the equations mentioned above was introduced in a Matlab/Simulink model of the hydroelectric system. This model is shown in Fig. 10 and it encapsulates the model of the hydroelectric plant connected to the water model. Measurement of power and voltage is also provided by this model. The model of the hydroelectric plant (generator) has the same form as the one of the wind generator and also an equivalent diagram as the one we considered for the wind generator can be assumed Fig. 8

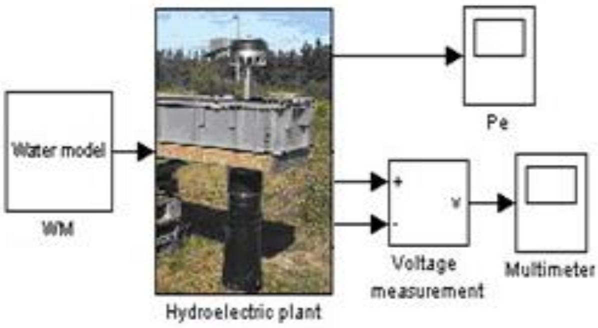

Fig. 10 The Matlab/Simulink model of the hydroelectric system

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D. MODELING OF STORAGE DEVICE

The parameters associated with battery modeling are internal resistance, discharging type, discharging mode rate of charge and discharge In fig.11 The venin equivalent battery model is presented.

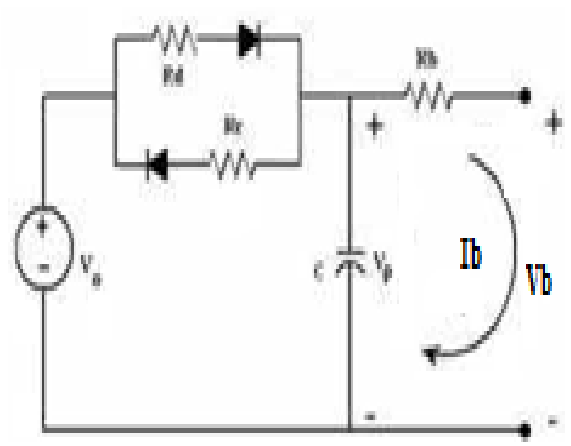

Fig. 11 The venin equivalent battery model

The open circuit voltage, internal capacitor voltage and the terminal voltage are represented by $V_{0,}$ V_P and $V_{b.}$ The charging, discharging and the internal resistance of the battery are represented by $R_{c,}$ R_d and R_b and the polarization capacitance of the battery is represented by C. The current I_b is taken as positive if discharging and negative.

The equation model for the circuit model is

$$\frac{1}{C}\left(\frac{V_0-V_P}{R_d}\right)-\frac{1}{C}I_b \quad .... (18)$$

$$V_b = V_P - I_b R I_b \; ....(19)$$

Based on this model and the equation above Matalb/Simulink model was developed for the battery storage device. This model is shown in fig. 12

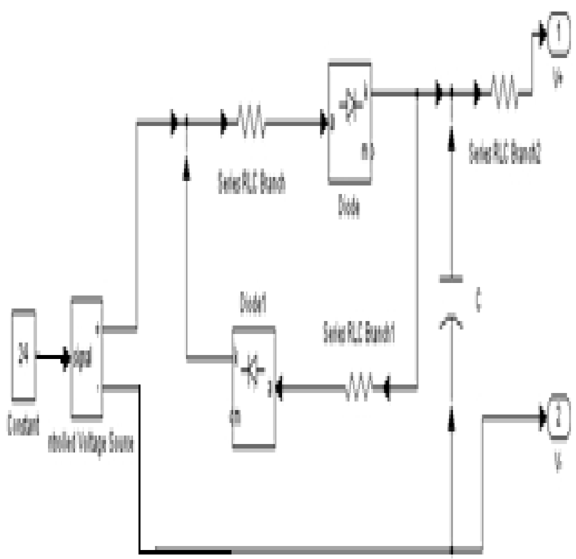

Fig. 12 The Matlab/Simulink model of the battery storage device

IV. MODELING AND SIMULATION OF THE HYBRID RENEWABLE ENERGY SYSTEM

Considering the above models, by using Matlab/Simulink an application useful for study of hybrid renewable energy system connected to a local grid was developed. The purposes of the application reside in scientific studies and, also didactical ones, concerning renewable hybrid solar-wind-hydro systems. Simulation model of a hybrid renewable energy system with battery storage is shown in Fig. 13.

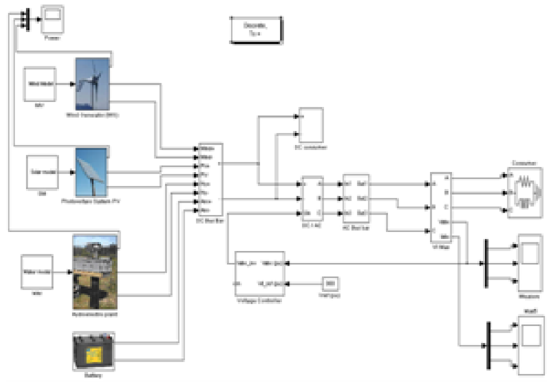

Fig. 13 Simulation model of a hybrid renewable energy system.

By using the presented simulation several functioning studies of solar-wind hybrid system can be performed. Different patterns of solar, wind models and also different type of loads can be selected. Fig. 14 illustrates the voltage waveform measured at the bus bar. It can be seen a voltage waveform distortion caused by electronic devices inverters used for energy conversion.

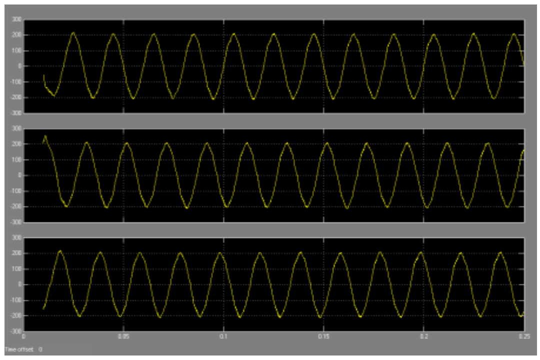

Fig. 14 Voltage waveform at the AC three-phased bus bar

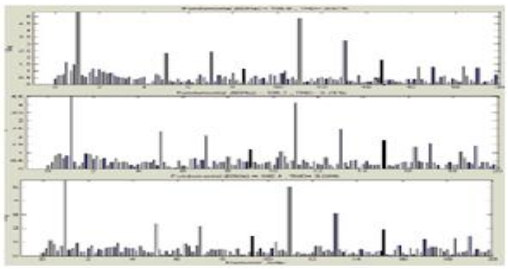

Fig. 15 Harmonic analysis of the voltage waveform corresponding to three phases A, B and C

V. CONCLUSION

This paper presented the analysis and modeling of a hybrid solar-wind-hydro energy system with battery storage using Matlab/Simulink. This application is useful for analyse and simulate a real hybrid solar-wind energy system connected to a local grid. The blocks like wind model, solar model, and hydroelectric energy conversion and load are implemented and the results of simulation are also presented. Hybrid power generation system is good and effective solution for power generation. People should motivate to use the non conventional energy resources. It is highly safe for the environment as it doesn't produce any emission and harmful waste product like conventional energy resources. It is cost effective solution for generation. It only need initial investment. It has also long life span. Overall it good, reliable and affordable solution for electricity generation.

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