Modeling and Simulation of Utility Interfaced PV/Hydro Hybrid Electric Power System

P. V. V. Rama Rao, B. Kali Prasanna, Y. T. R. Palleswari

Abstract**—**Renewable energy is derived from natural processes that are replenished constantly. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and bio-fuels and hydrogen derived from renewable resources. Each of these sources has unique characteristics which influence how and where they are used. This paper presents the modeling the simulation of solar and hydro hybrid energy sources in MATLAB/SIMULINK environment. It simulates all quantities of Hybrid Electrical Power system (HEPS) such as AC output current of the inverter that injected to the load/grid, load current, grid current. It also simulates power output from PV and Hydraulic Turbine Generator (HTG), power delivered to or from grid and finally power factor of the inverter for PV, HTG and grid. The proposed circuit uses instantaneous p-q (real-imaginary) power theory.

Keywords**—**Photovoltaic Array, Hydraulic Turbine Generator, Electrical Utility (EU), Hybrid Electrical Power Supply.

I. Introduction

THE energy crisis during 1970s created a pertinent need to find and develop alternative energy sources, such as fossil fuels; coal, gas, nuclear energy and renewable energy resources. Renewable resources replenish faster than humans consume them. Renewable energy sources currently supply somewhere between 15% and 20% of total world energy demand.

H. H. El.Tamaly [1] focused in modeling and simulation of PV/Wind Hybrid Electric Power System interconnected to the electrical utility. A computer simulation program has been designed to simulate all quantities of HEPS. But water is also another renewable resource, and after usage, it gets cycled back into nature through many ways. Hydroelectric power will play a vital role in the global energy supply in future. Optimizing and improvising existing hydroelectric power plants would also offer the potential to run larger plants in consonance with the environment.

Delimustafic D. [2] explains that a combination of one or more resources of renewable energy, called hybrid, will improve load factors and help saving on maintenance and replacement costs as the renewable can complement each other. High initial capital of the hybrid is a barrier to adopt the system thus the needs for long lasting, reliable and cost-effective system. The design of HRES specifies the operation of a pumped-storage hydro power plant, a wind power plant and a solar power plant.

Solar energy, radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Hang-Seok Choi, Y. J. Cho [3] proposes a transformer-less PV inverter employing zero current switching (ZCS) PWM switch cell. By using these techniques, ZCS of the main switches and the auxiliary switches are achieved. Since the proposed inverter operates as an alternating buck converter, the switching loss and the output current ripple can be minimized. It is controlled to extract maximum power from the solar array and to provide sinusoidal current into the mains.

Nowadays the installation of hybrid systems generally requires electronic power controllers, batteries and an inverter. Arulampalam et al. [4] describes that a microgrid is a combination of generation sources, loads and energy storage, which is interfaced through fast acting power electronics? This combination of units is connected to the distribution network through a single PCC and appears to the power network as a single unit. Kusakana et al. [5] simulated using the hybrid optimization model for electric renewable (HOMER) with the stream flow, the solar radiation and the system components costs as inputs; and then compared with those of other supply options such as grid extension and diesel generation.

Mohibullah et al. [6] presented the conceptual design and development of a micro hydro power plant. The overall estimation and calculation of a 50 kW power plant has been carried out. Gagan Singh and D.S. Chauhan [7] performed the computer based simulations and analyzed by comparing different models through simulation in MATLAB/Simulink. The results obtained provide an insight into the interaction between electrical and hydraulic system of hydro power plant governed by different governor settings, so that the system may remain unaffected during any disturbance.

Blaabjerg et al. [8] gives an overview of the structures for the DPGS based on fuel cell, photovoltaic, and wind turbines. In addition, control structures of the grid-side converter are presented, and the possibility of compensation for low-order harmonics is also discussed. Nehrir, M. H. et al. [9] highlights some important issues and challenges in the design and energy management of hybrid RE/AE systems. System configurations, generation unit sizing, storage needs, and energy management and control are addressed.

Dr. Rama Rao P.V.V., member IEEE is with the Shri Vishnu Engineering College for Women, Bhimavaram, Andhra Pradesh, India (phone: +91-7569508112; e-mail: pvvmadhuram@gmail.com).

Ms. B. Kali Prasanna and Mrs. Y.T.R. Palleswari are with the Shri Vishnu Engineering College for Women, Bhimavaram, Andhra Pradesh, India (e-mail: prasanna.bandi@svecw.edu.in, tulsiadabala@svecw.edu.in).

II. The Proposed System Model

The system model shown represents PV/HYDRO HEPS connected to a 50 Hz, 11 kV EU. PV system connected to EU through a DC/DC boost converter, DC/AC inverter, LC filter and step-up transformer. HTG connected to EU through back to back converter, LC filter and step-up transformer. The load connected to 11kV Bus through a step-down transformer. The power obtained from PV system is applied to an IGBT's inverter. The task of the boost DC/DC converter drains the power from the PV system and feed the DC link capacitor.

The variables which will be sensed for the controller of PV system are PV solar cell array current, I_{PV}, DC link voltage, V_{dcpv}, inverter filter output current, $I_{fpva}, I_{fpvb}, I_{fpvc}$, load phase currents, I_{La}, I_{Lb}, I_{Lc}, and load phase voltages V_a, V_b, V_c.

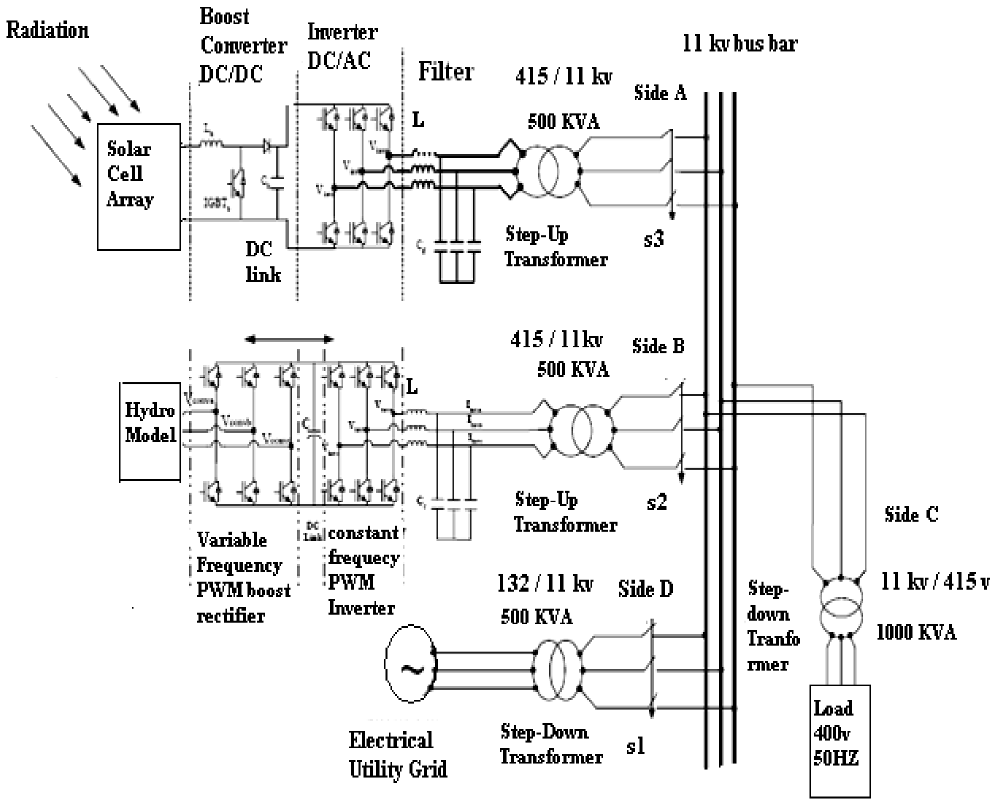

Fig. 1 Power and control circuit of PV/HTG HEPS Interconnected with EU to Feed the Load

III. System Configuration

A. Modeling of Photovoltaic Array

The electrical power generated and terminal voltage of PV module depends on solar radiation and ambient temperature. The equivalent electrical circuit describing the solar cells array used in the analysis is shown in Fig. 2.

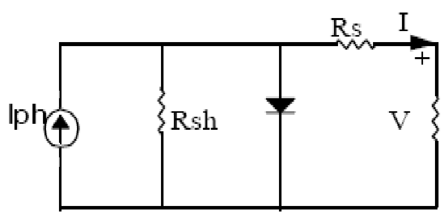

Fig. 2 Equivalent circuit of PV cell

The mathematical equation describing the I-V characteristics of PV solar cells array is given by (1):

$$I = I_{ph} - I_0\left(\exp\left(q\left(V + I^*R_s\right)/AKT\right) - 1\right) - \left(V + I^*R_s\right)/R_{sh} \quad (1)$$

where, I is the output current, Amp, V is the output voltage, Volt, A is the ideality factor for p-n junction, T is the temperature, Kelvin, K is the Boltzmann's constant in Joules per Kelvin, and, q is the charge of the electron in Coulombs. the electron in Coulombs. I_o is the reverse saturation current and the generated current I_{ph} of solar cell array vary with temperature.

B. Modeling of Hydraulic Turbine

A synchronous machine can be described by a system of n+ 1 equation, n of which are electrical and one of which is mechanical. The number n of electrical equations is equal to the number of independent electrical variables necessary to describe the machine. These variables can be either currents or flux linkages.

The machine's q axis is placed at 90 electrical degrees (in a counterclockwise direction) with respect to the machine's d axis. Then, the rotor position can be expressed by means of an angle, named θ, between the magnetic axis of the armature's phase a and the rotor's q axis.

The model takes into account the dynamics of the stator, field, and damper windings. The equivalent circuit of the model is represented in the rotor reference frame (qd frame). All rotor parameters and electrical quantities are viewed from the stator.

They are identified by primed variables. The subscripts used are defined as follows:

d,q: d and q axis quantity

R,s: Rotor and stator quantity

l,m: Leakage and magnetizing inductance

$$V_d = R_s i_d + \frac{d}{dt} j_d - \omega_R j_q \tag{2}$$

$$V_q = R_s i_q + \frac{d}{dt} j_q + \omega_R j_d \tag{3}$$

$$j_d = L_s i_d + L_{md}\left(i'_{fd} + i'_{kd}\right) \tag{4}$$

$$j_q = L_q i_q + L_{mq} i'_{kq} \tag{5}$$

C. Instantaneous Reactive Power Theory

Transformation from the abc to the dq reference frame is given by the following transformation matrix:

$$T=\sqrt{2/3}\begin{bmatrix} \sin\theta & \sin\left(\theta-\left(2\pi/3\right)\right) & \sin\left(\theta+\left(2\pi/3\right)\right) \\ \cos\theta & \cos\left(\theta-\left(2\pi/3\right)\right) & \cos\left(\theta+\left(2\pi/3\right)\right) \end{bmatrix} \tag{6}$$

The proposed system control scheme for the system under study usually uses the Instantaneous Reactive Power Theory, IRPT. The load currents and load voltages are sampled and transformed into the two-axis αβ-coordinate system and then into the rotating dq-coordinate system. IRPT uses the park transformation, as in (7) to generate two orthogonal rotating vectors α and β from the three-phase vectors a, b and c. This transformation is applied to the voltages and currents and so the symbol x is used to represent volt or current. IRPT assumes balanced three-phase loads and does not use the x_0 term.

$$\begin{bmatrix} X_O \\ X_\alpha \\ X_\beta \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \tag{7}$$

The instantaneous active and reactive powers p and q are calculated from the transformed voltage and current. Then the reference compensating currents have been determined as in (8):

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = 1/\left(V_\alpha^2 + V_\beta^2\right)\begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix}\begin{bmatrix} P_{pv} + P_h \\ q_{pv} + q_h \end{bmatrix} \tag{8}$$

In a balanced three-phase system with linear loads, the instantaneous real power p and imaginary power q are constant and equal to the three-phase conventional active power and reactive power respectively. So, the inverse park transformation is applied to and this gives the output currents in standard three-phase form, as in (9):

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3/2} \end{bmatrix}\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \tag{9}$$

There are two modes of operation:

Mode 1: When the generated power from PV/HYDRO HEPS is lower than the load demand then the deficit power will be supplied from the EU. Presumably, the power factor will be within the allowed limits.

Mode 2: When the generated power from PV/HYDRO greater than the load demand then the surplus power will be transmitted to the EU. In this condition, the power factor of the ac source will deteriorate.

IV. Simulink Model for Utility Interfaced PV/ Hydro HEPS

The power and control circuit of the proposed PV/HTG interconnected with EU of Fig. has been simulated using MATLAB/Simulink as shown in Fig. 3.

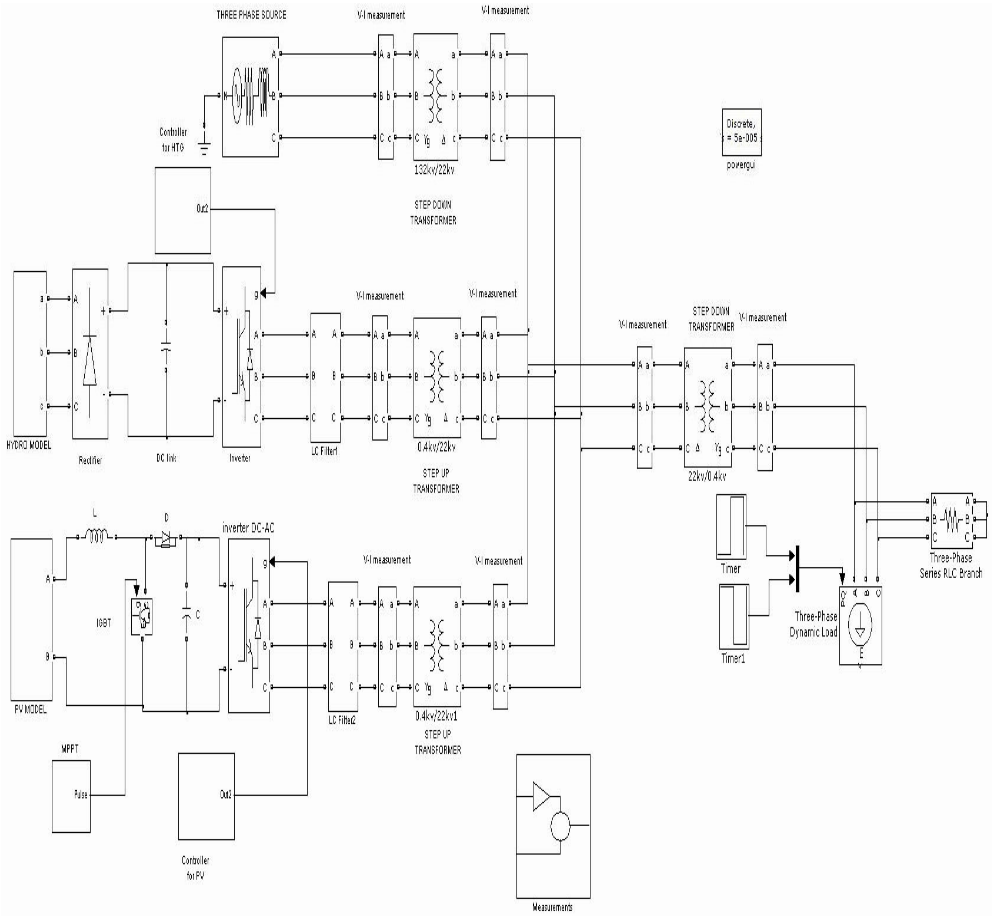

Fig. 3 Matlab/Simulink Model for Power and control circuit of PV/HTG HEPS Interconnected with EU

V. Results and Discussions

The total power load level is 500 kW with 721.68A per phase load current for duration 0.2 sec. After 0.2sec the load has been changed from 500 kW to 900 kW with 1299.03A per phase load current for duration from 0.2sec to 0.4sec. Finally the load is suddenly changed to 500 kW with 721.68A per phase load current for duration from 0.4 to 0.5sec.

VI. Conclusion

The design and manufacture of highly reliable equipment made integration of HEPS easier nowadays. In this paper PV/HYDRO HEPS interface with EU for solving power crisis problems are simulated by using Matlab/Simulink environment. The control circuit for the converter for all radiation and hydraulic turbine speed has been successfully simulated. The total harmonic distortion (THD) at the local bus is within acceptable limits and reached to 0.14% for the inverter current from HTG, 0.15% for the inverter current from PV and 0.20% for the grid current.

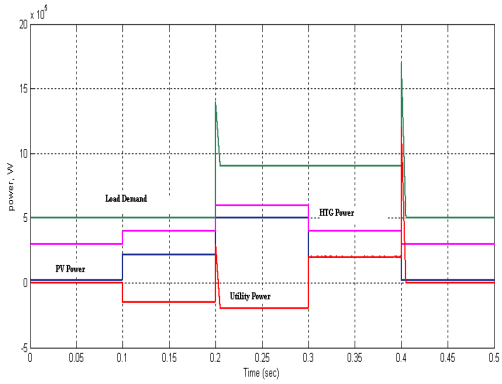

Fig. 4 Generated Powers from PV/HTG, Load Demand Grid Power

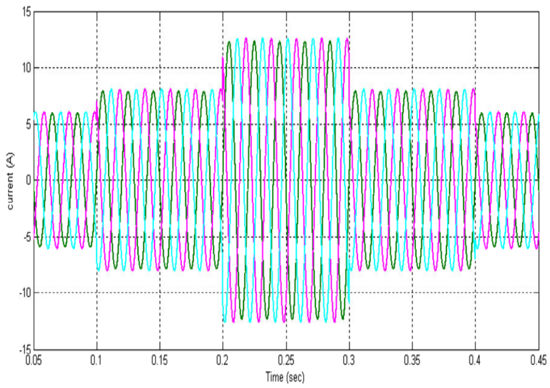

Fig. 5 Inverter Line current from HTG to the Load/Grid in the side (B)

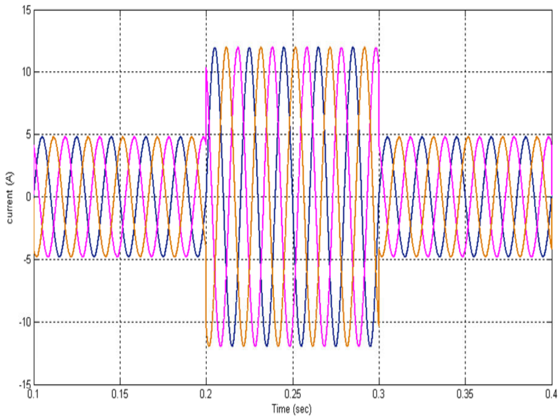

Fig. 6 Inverter Line current from PV to the Load/Grid in the side (A)

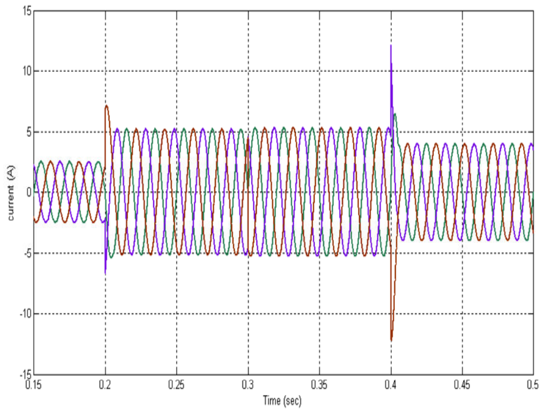

Fig. 7 Grid Line Current in the side (D)

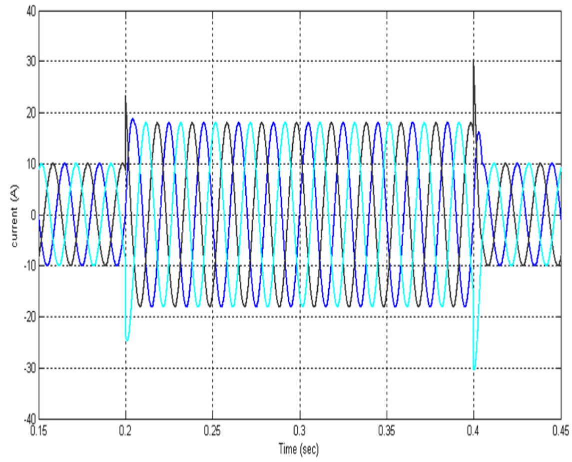

Fig. 8 Load Line Current in the side (C)

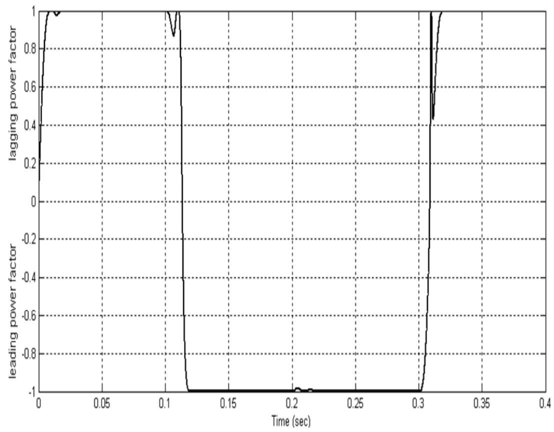

Fig. 9 Power Factor of the Grid for the Hybrid PV/HTG system

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