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Optimal Modeling of Grid Connected DC Coupled PV/Hydro Hybrid Power System

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ABSTRACT

The sustainable power source systems (RESs) are an appealing alternative to energize the group as they are condition amicable, free of cost, and all-overrunning. The effectiveness of these vitality systems is low and can be enhanced by coordinating them in parallel. In this paper, hydro (7.5 kW) and PV (10 kW) are taken as RESs and associated with the utility grid. Because of the discontinuous idea of both the hydro and photovoltaic energy sources, utility grid is associated with the system for guaranteeing the ceaseless power stream. The hydro power generation system uses the 3-phase synchronous machine and converters. The AC/DC/AC converter is used as interface to connect the hydro turbine to the utility grid to adjust the generated voltage to the utility grid voltage. The solar generation system is the combination of PV array, boost converter, and solar inverter. The control of both the hydro and solar power plants is provided through the constant current controller. The analysis has been done to verify the existence of the proposed system. Results demonstrate that the proposed system is able to be put into service and can feed the community.

I. INTRODUCTION

India supervision has up-scaled the goal of renewable power capacity near 175 GW by the year 2022 which incorporates 100 GW as of , 60 GW as of hydro, 10 GW from bio-power and 5 GW from small hydro-power. The capacity goal of 100 GW put in the National Solar Mission (JNNSM) want mainly comprise of 40 GW Rooftop and 60 GW due to Large and Medium Scale Grid Connected Solar Power Projects. With this ambitious goal, India will develop into one of the largest Green Energy producers in the world, surpassing several developed countries. The total investment in setting up 100 GW will be around Rs.6, 00,000 crore. India encourages The Research and Development efforts of the Ministry are directed towards technology development and demonstration, leading to commercialization, apart from strengthening the capacity of R&D/Academic Institutions and Industry for taking up advanced research for technology development. The ultimate goal is to reduce the cost and improve efficiency in the near future. The prominent projects taken up include advanced research and demonstration of higher efficiency solar cells, solar thermal power generation, hydrogen energy storage and fuel cells development, development and deployment of improved biomass cook stoves, etc. Research & development activities have been taken up with national laboratories, universities, scientific & educational institutions & industry for improvements in the renewable energy systems and products. The focus is on improved efficiency, cost reduction and technology transfer and demonstration for their commercialization [1-2].

In this paper, a system is proposed in which hydro and solar based hybrid power generation system is connected with the utility grid. In the peak summer, solar energy is abundantly available, but in rainy days it is difficult to generate the electrical power using the solar energy.

Similarly the power generation using the hydro energy gives better efficiency in rainy seasons. Hence, the parallel combination of these two energy systems has been adopted, and for the continuous power flow grid is also connected. In the summer, the grid connected solar system supplies the power to the load, and hydro system will be disconnected. In rainy days the grid connected hydro system supplies the power to the load, and solar system will be disconnected. In other seasons, grid connected the solar and hydro systems are able to deliver the power to the consumer. Hence, it is good option to adopt the proposed system for supplying continuous power to the consumer. The solar power generation system contributes power of about 10 kW. It consists of PV array and solar inverter controlled by constant current controller. The hydro system has the 3-phase synchronous generator (SG) and back to back converter (combination of Rectifier and inverter) as an interfacing device for integrating the hydro system into the utility grid. The hydro power generation system contributes 7.5 kW power.

II. SYSTEM DESCRIPTION

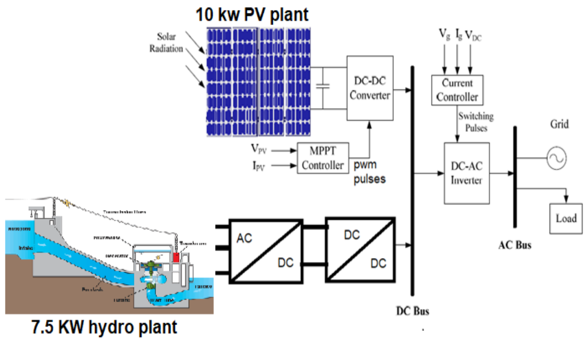


Figure 1. Schematic diagram of grid integrated hydro and solar based hybrid energy system.

Figure 1 shows the circuit diagram of the grid connected solar and hydro based hybrid energy systems. A 10 kW PV array and a 7.5 kW 3-phase synchronous generator are connected to the 25 kV, 100 MVA utility grid. The detailed description is given as follows.

A. SOLAR SYSTEM

The solar system consists of PV array, solar inverter with a harmonic reduction LC filter. The PV array is delivering 10 kW at 1000 W/m^2 solar irradiation. The DC power generated by the PV array charges the DC link capacitor. The PV array can be mathematically modeled as

$$Ppv = Ipv\,Vpv = NpIph\left[\left(\frac{q}{kAT} * \frac{Vpv}{Ns}\right) - 1\right] \text{ ------- (1)}$$

Where Ppv is generated DC power of the PV array (kW) are generated DC Voltage (in V) and current (in A) of the PV array, respectively. is photocurrent of the PV cell (8.96 A), is charge of an electron, that is, C, is ideality factor, that is, 2.46, is cell temperature (K), 5 is number of series connected PV modules. 6 are number of parallel connected PV modules.

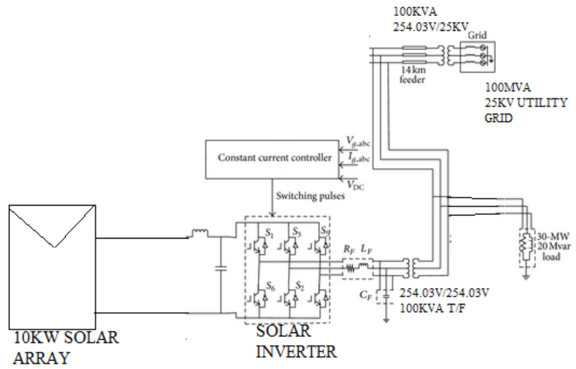


Figure 2. Schematic diagram of grid integrated solar energy system.

The voltage source converter inverts the DC voltage to the sinusoidal AC voltage keeping the unity power factor. The control of the solar inverter is provided through the constant current controller. The harmonics produced by the VSC is filtered by the LC filter. To integrate the PV system with the utility grid, the AC voltage level has been stepped up to the grid voltage level using a 100 kVA transformer. This transformer also performs as an isolation transformer.

B. HYDRO SYSTEM

The hydro system consists of 3-phase synchronous generator (SG), back to back converter (combination of rectifier and inverter), and LC filter.

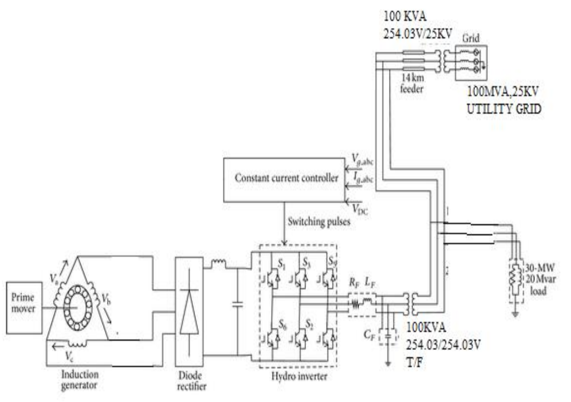


Figure 3. Schematic diagram of grid integrated solar energy system.

The generator side converter acts as a rectifier and used to convert variable magnitude and variable frequency voltage at SG terminals to the DC voltage. The grid side converter works as a PWM inverter.

The DC power available at the rectifier output is filtered using the LC filter and converted to AC power using a PWM inverter. The hydro PWM inverter is also controlled using the current controller.

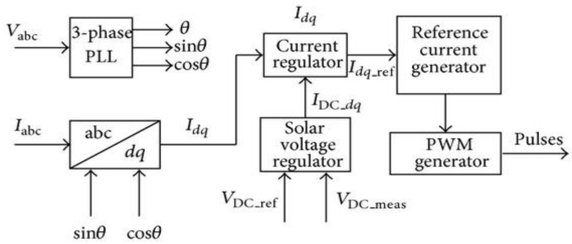
The output of the PWM inverter contains the harmonics and is filtered using the LC filter. For connecting the hydro system to the grid, the voltage level of the hydro system is increased from 220 V to 254.03 V using the 100 kVA three-phase transformer.

III. CONTROLLER FOR THE INVERTER

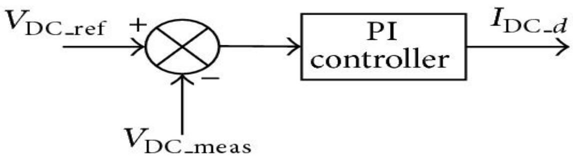
The In the proposed grid connected hydro and solar systems, the 3- inverter is interfacing the utility grid and also converts the variable direct current output of a photovoltaic (PV) panel into a utility frequency alternating current that can be fed into a commercial electrical grid. It is a critical component in the system, and its control should be such that its output can interface the voltage of the utility grid. For connecting the solar and hydro system in parallel with the grid, it is essential that the voltage magnitude, frequency, and phase sequences of both the energy system and power grid must be same. This feature is provided through the constant current controller (CCC). CCC generates the switching pulses for solar and hydro side interfacing inverter such that the frequency and phase sequences of output voltages of the inverters are the same as of the grid voltage.

In this proposed system, two inverters are used: one is for integrating solar system into grid, that is, solar inverter, and another is for integrating the hydro system, that is, hydro inverter. There are two basic control modes for the grid connected inverters. One constant current control and the other is constant power control. In this proposed model, the control of the solar inverter is provided through the constant current controller using the 3- phase locked loop (PLL). In constant current control, the inverter output currents are regulated to the reference grid current.

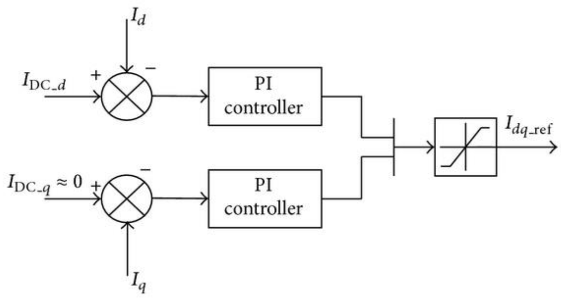
Figure 4 shows the detailed block diagram of the constant current controller for generating the controlled switching pulses for the solar inverter such that the output voltage should be able to interface the grid. The 3-phase locked loop calculates the phase angle of the utility grid and also gives the information about the frequency variation. According to the phase angle of the utility grid voltage, the constant current controller is modeled such that the controller is able to generate the switching pulses for solar and hydro inverter for tracking the phase of the grid voltage. The 3- grid current is converted into α β variable using the Clarke transformation. The α β variables are transformed into the dq variables. The current, and are compared with the and for processing in the PI controller to minimize the errors. These signals are transformed into 3- signal using the inverse park's transform and then compared with the triangular waveform for generating the PWM switching pulse for the solar inverter. The and are the DC link voltage of the PV array for the solar system or DC link voltage of rectifier for the hydro system and expected DC voltage of the PV array or the rectifier for solar or hydro systems respectively.



(a) Control unit



(b)Voltage regulator



(c)Current regulator

Figure 4. Block diagram of constant current controller.

IV. MODELLING OF SYSTEM

The 25 kV, 100 MVA utility grid is connected to 10 kW PV system and also with the 7.5 kW hydro system. Figure.5 shows the MATLAB simulink model for the grid integrated hydro and solar based hybrid systems. The array consists of 6 strings of 5 series connected PV modules connected in parallel. One PV module has 96 PV cells. The PV array is delivering the 10 kW at 1000 W/m2 at maximum power. The open circuit voltage (Voc) of the one module is 45 V, and voltage at the maximum power point (Vmp) is 37 V. The short circuit current (Isc) of the one module is 8.96 A, and current at the maximum power point is 8.64 A. The three-phase voltage source inverter converts 220 V DC voltages to the 254.03 V AC voltages. The switching frequency of the solar inverter is 1650 Hz. The obtained AC voltage is in stepped waveform. Hence, the 3- LC filter is used for converting the stepped waveform into the pure sinusoidal waveform. The filtering inductance has been chosen as 200 mH and filtering capacitor bank of 5 kVAr is used. To avoid resonance problem, the damping resistor is used in series with the filtering capacitor bank , which can absorb the switching frequency ripple and is valued as 2 Ω .A 100 kVA transformer is used to increase the AC voltage level from 220 V to the grid voltage level 254.03 kV.

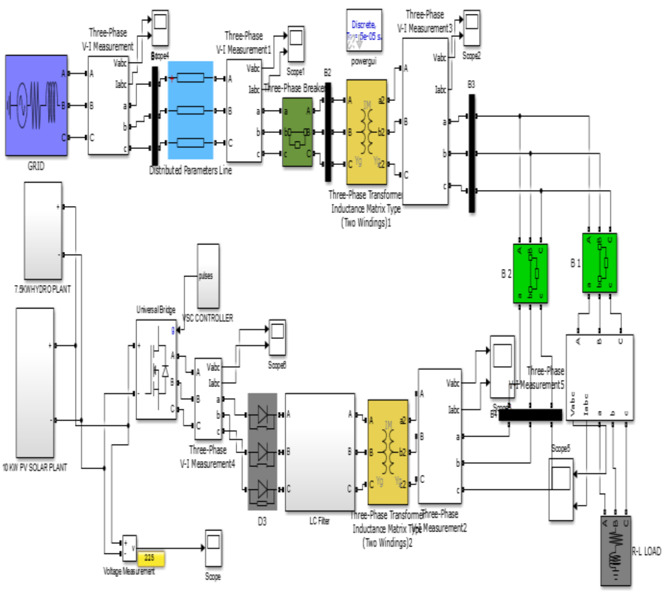


Figure 5. Shows the MATLAB simulink model for the grid integrated hydro and solar based hybrid systems.

The 7.5 kW induction machine is used as 3-phase synchronous generator (SG).For feeding the AC power to the utility grid, the back to back (AC-DC-AC) converter is used. The AC voltage generated by the induction generator is converted to the DC voltage using the uncontrolled rectifier. The output of the rectifier contains the ripples. For obtaining the ripple free DC voltage LC filter is used with the value of 200 mH and 5mF. The grid side converter acts as a PWM inverter, whose control is provided through the CCC. The 3- LC filter is sinusoidal AC voltage. For the isolation as well as increasing the voltage level from 220 V to 254.03 V AC voltage a 100 kVA three-phase transformer is used. The grid connected hydro and solar systems are able to feed the static resistive and R-L load.

V. SIMULATION RESULTS

A. RESULTS OF SOLAR SYSTEM

The solar system consists of PV array, solar inverter with a harmonic reduction LC filter. The PV array is delivering 10 kW at 1000 W/m^2 solar irradiation. The voltage source converter inverts the DC voltage to the sinusoidal AC voltage keeping the unity power factor. The harmonics produced by the VSC is filtered by the LC filter. To integrate the PV system with the utility grid, the AC voltage level has been stepped up to the grid voltage level using a 100 kVA transformer.figure.6 shows the output voltage, current and power of the solar array.

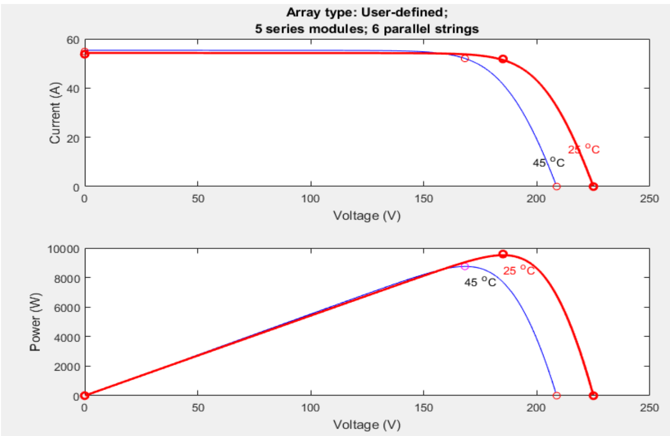


Figure 6. PV array output voltage (V) ,current (I) and power(W).

The 200 V constant DC voltage is converted into 254.03 V, 50 Hz AC voltage using bridge inverter. Figure 7 shows the output voltage (254.03V) of the inverter and current .

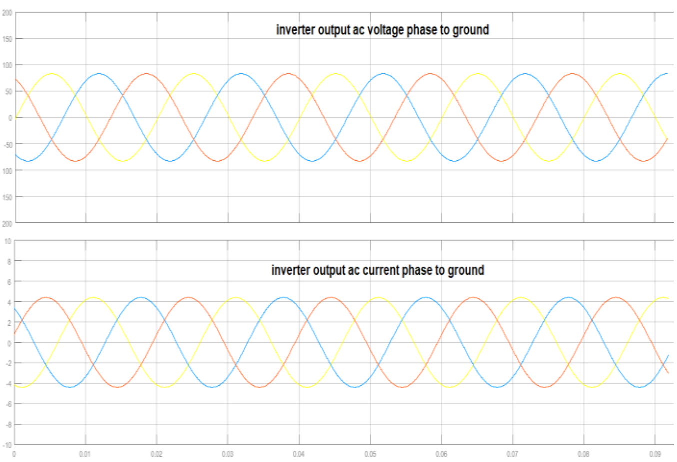


Figure 7. Inverter output AC voltage and current.

B. RESULTS OF HYDRO SYSTEM

The SG is generating the 415 V AC voltages. The SG is taking 1.0 sec for generating the AC power.

Figure 8: the output DC voltage (Vhdc after filter).The uncontrolled rectifier is connected at the SEIG terminals to convert the AC voltage into 220V DC voltage. Figure 6 shows the hydro power system output DC voltage after conversion (Vhdc after filter).

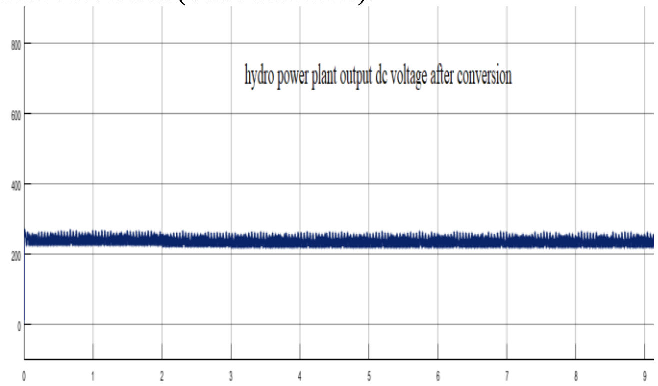


Figure 8. The output DC voltage (Vhdc after filter).

The DC voltage is converted into AC using the PWM inverter. Figure.9 shows the output AC voltage (Vh1) of the hydro inverter after filtering.

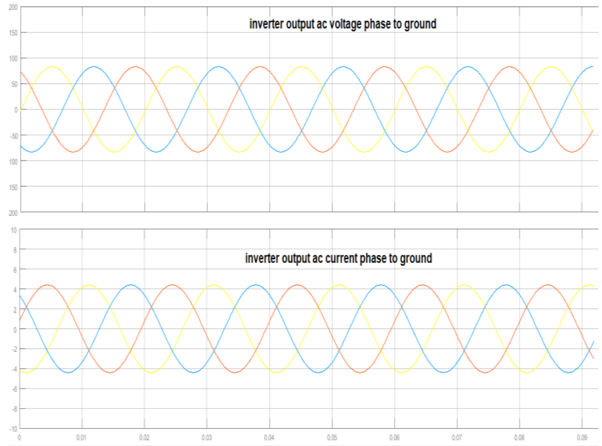


Figure 9. Output AC voltage and current of the hydro inverter after filtering.

C. RESULTS OF HYBRID SOLAR AND HYDRO SYSTEM

Figure .10(a) shows the Hybrid power system inverter output voltage and currents. Figure 10(b) shows the 100MVA, 25KV utility grid voltage and current .The solar and hydro system is integrated into a 25 kV, 100 MVA utility. A 100 KVA, 25 kV/254.03 V step-down transformer is used for bringing the AC voltage level to the level of hydro and solar system voltage for connecting in parallel.

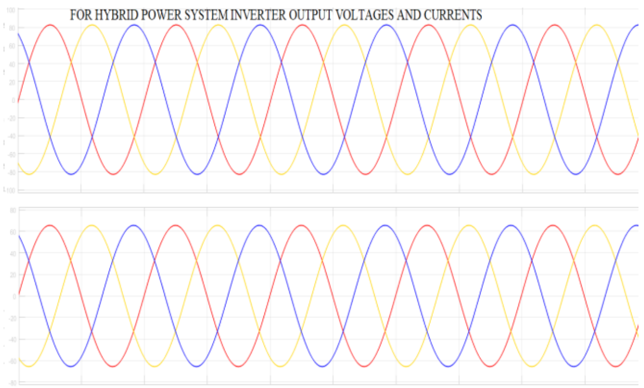


Figure 10(a). Hybrid power system inverter output voltage and currents.

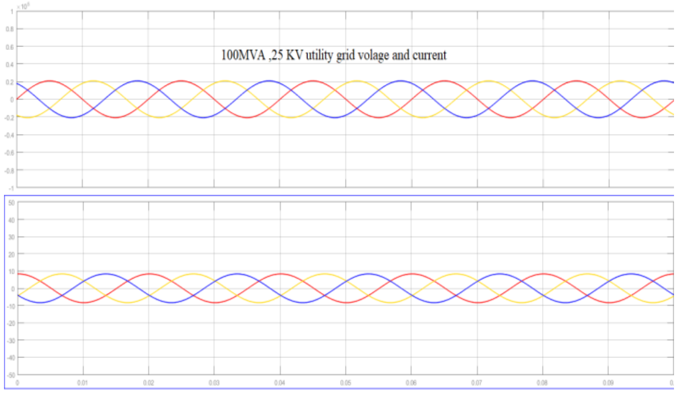


Figure 10(b). 100MVA, 25KV utility grid voltage and current.

D. RESULTS OF 30 MW RL LOAD

RL load of 30 MW (0.8 lagging power factor) are supplied through the proposed model. Figures 11 show the load current and load voltage waveforms (IL_R and VL_RL in Amp) for the RL load..

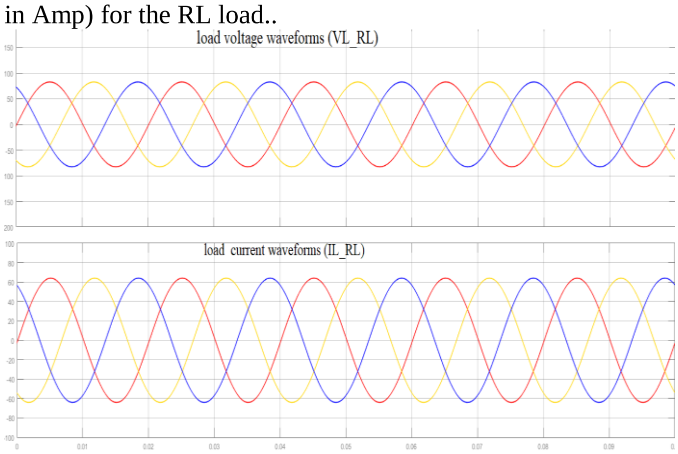


Figure 11. Load voltage and current through RL load.

VI. CONCLUSION

In this paper, analysis of grid interactive solar and hydro systems has been done. The proposed system is implementable to those areas where the solar and hydro energies are available at moderate nature such as Indian circumstance. The nature of the solar and hydro energies is intermittent. Hence, using the individual system the continuous power generation is not possible, and it will also increase burden to the grid. The proposed system is able to supply the community in all seasons. In rainy season, the grid connected hydro system will feed the AC power to the consumers and in summer grid connected solar system will supply power. In other season both systems will supply the power to the consumer. The proposed system reduces the complexity of the electrical system, having less cost as compared to other RESs and reliable operation. The control of interfacing solar and hydro inverters is provided through the constant current controller. As compared to phase and amplitude control, constant current controller offers reduced cross-coupling between the real and reactive power control loops, greater immunity to phase measurement errors, better transient response, reduced current harmonics, and inherent over current protection. The obtained results show that the proposed system has the potential to supply the local community.

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