HYBRID POWER SYSTEM GRID CONNECTION WITH POWER QUALITY IMPROVEMENT FEATURES

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ABSTRACT:
Micro grid systems consisting of several alternative energy sources that include solar cells, wind turbine, fuel cells and storage batteries are capable of balancing generated supply and demand resources to maintain stable service within a defined boundary. Wind and solar energy plays an important role in ensuring an environmental friendly and clean energy generation for remote and isolated areas. In this paper, a grid connected wind and PV hybrid generating system was developed with improved power quality features. A unified control strategy that enables both islanded and grid tied operation of three phase inverter in distributed generation was developed. Furthermore, the wave forms of the current in grid tied mode and load voltage in the islanding mode are distorted under non-linear load is mitigated by the proposed unified control strategy and the results are verified using MATLAB/SIMULINK software.
KEYWORDS: wind generator, Photovoltaic, unified control strategy, hybrid power generating system, power quality.

1. INTRODUCTION

As generation and distribution companies in the market have been seeing an increasing interest in the renewable energy sources and also seeing demands from customers for higher quality and cleaner electricity, we are in need to switch over for renewable energy generation methods.

In order to reduce the greenhouse gas emission and to meet the demand of electricity, the trend converges to the use of renewable energy sources. Wind and PV energy technologies have a significant share in the use in hybrid power generating systems, because of emission free and no cost of energy. Hybrid wind and PV systems is one of the most efficient solution to supply power directly to a utility grid or to an isolated load [7].

Wind turbine converts kinetic energy of the wind into the mechanical energy and the mechanical energy is further converted into electrical energy by the wind generator. Solar is an non – linear power source, whose radiation changes frequently, where the output power of the panel varies with temperature and isolation. A single solar cell produce low voltage therefore several cells are combined to form modules to produce the desired voltage [1].

DC/AC inverter transfers the energy drawn from the wind turbine and PV into the grid as well as load by keeping common DC link constant. The inverter serves a dual role, to integrate hybrid systems to the grid and also to mitigate the harmonics and to improve the power quality problems due to non-linear load.

The proposed control strategy composes of an inner inductor current loop and a voltage loop in synchronous reference frame. The inverter is regulated as the current source just by the inner inductor current loop in grid tied operation and the voltage controller is used to regulate the load voltage upon the occurrence of Islanding. The proposed control strategy is enhanced by introducing a unified load current feed forward, in order to deal with issues caused by non-linear local load and implemented by adding the load current is given to the reference of inner current loop. In grid tied mode, DG injects harmonic current and therefore the harmonic component of the grid current will be mitigated [2],[3].

The entire paper is organized as follows: Section II discusses the wind and solar system. Section III discusses the structure of the proposed Hybrid system. Section IV presents an overview of Boost converters for hybrid system. Sections V discuss Inverter model and its purposes. Section VI discusses the unified control strategy for the inverter. Finally, the simulation results and conclusions are discussed in Section VII and VIII.

2. WIND AND SOLAR HYBRID SYSTEM

A. Wind Power Generating System

A hybrid energy system consists of two or more renewable energy sources to enhance system efficiency as well as greater balance in energy supply. Wind turbine is a device that converts kinetic energy of the wind into mechanical energy and the mechanical energy is again converted into electrical power. The power from the wind depends upon aerodynamically designed blades and rotor construction [6],[9]. The power in the wind is given by the kinetic energy of the flowing air mass per unit time and is expressed as,

$$P_{air} = \frac{1}{2}\,(\text{air mass per unit volume})^2 \quad (2.1)$$

$$= \frac{1}{2}\,(\rho A V_\infty)\,(V_\infty)^2 \quad (2.2)$$

$$= \frac{1}{2}\rho A V_\infty^3 \quad (2.3)$$

P air - power contained in wind(in watts)
A - swept area in (square meter)
V_∞ - wind velocity without rotor interference

Although Equation (2.1) gives the power available in the wind, the power transferred to the wind turbine rotor is reduced by the power coefficient, C_p

$$C_p = \frac{P_{wind\ turbine}}{P_{air}} \quad (2.4)$$

$$P_{wind\ turbine} = C_p * P_{air}$$

$$S = \frac{1}{2}\,\rho A V_\infty \quad (2.5)$$

A maximum value of C_p is defined by the Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum Cp values in the range 25-45%.

Variable speed wind turbine driving a Permanent Magnet Synchronous Generator (PMSG) is considered in this paper. PMSG is opted over other generators due to its advantages like, self-excitation property, which allows operation at high power factor and efficiency. PMSG also operates at low speed and thus the gearbox can be removed [4],[6].

B. PV Power Generating System

The building block of PV arrays is the solar cell and it is basically a p-n junction diode that directly converts light energy into electricity. The cells are made of semiconductor materials, such as silicon, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. A single PV cell generates 0.5V therefore several PV cells are connected in series and in parallel to form a PV module for desired output. The modules in PV array are usually first connected in series to obtain desired voltages; the individual modules are then connected in parallel to allow the system to produce more current [9],[11].The PV mathematical model is represented by the following equation:

$$I = n_p I_{ph} - n_p I_{rs} \left[exp^{\frac{q}{KTA} \times \frac{V}{ns}} - 1 \right]$$

Iph - cell photo current
T - cell temperature(k)
Np - number of cells in parallel
Ns - number of cells in series
A - p-n junction ideality factor

3. STRUCTURE OF HYBRID POWER SYSTEM

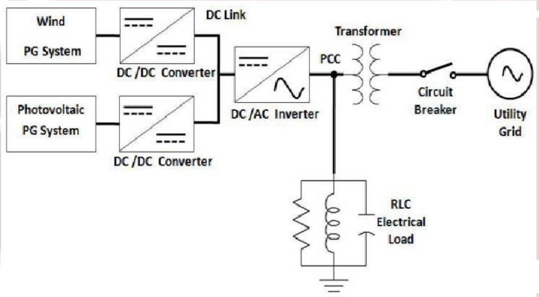

Figure 1. General Structure of the Proposed Model

The proposed hybrid system consists of a wind and a photovoltaic system as shown in Fig 1.Wind and solar systems are connected to the grid through inverter which serves as a dual purpose. The inverter is designed in such way to integrate the hybrid systems to the grid and also to eliminate the harmonics and to improve the power quality problems, which increases system efficiency. The system supplies the load and when there is excess generation, the power is delivered to the grid. Manual switch is used to connect the sources with grid. Converters were designed in order to meet the constant dc bus voltage.

4. DC/DC CONVERTER MODEL

DC-DC converters can be used to convert an uncontrolled dc voltage to a controlled dc output voltage. The regulation is normally achieved by PWM at a set frequency and the switching device is generally BJT, MOSFET or IGBT. Due to the variable characteristics of the wind the output voltage from PMSG is also varied. Therefore an uncontrolled rectifier with boost converter is used in order to meet constant DC bus voltage. Similarly, a converter is designed with solar panel to meet the constant DC bus voltage [5].

5. DC/AC INVERTER MODEL

Wind and solar systems are connected to the grid through an inverter which serves as a dual purpose. The inverter is designed in such a way to integrate the hybrid systems to the grid and also to eliminate the harmonics and to improve the power quality problems. The inverter is regulated as the current source just by the inner inductor current loop in grid connected operation and the voltage controller is used to regulate the load voltage during Islanding operation. The proposed control strategy is discussed in the next section.

6. PROPOSED UNIFIED CONTROLLER FOR INVERTER MODEL

The proposed control strategy consists of an inner inductor current loop and a voltage loop in the synchronous reference frame. The inverter is regulated as a current source just by the inner inductor current loop in grid-tied operation, and the voltage controller is to regulate voltage during islanding mode [8]. The grid current in the grid-tied mode and the load voltage in the islanding mode are distorted under nonlinear load. A unified control strategy is designed to perform two operations. First, the traditional inductor current loop is used to control the three-phase inverter in DG to act as a current source with a given reference in the Synchronous Reference Frame (SRF) [2]. Second, voltage controller is presented to supply reference for the inner inductor current loop, where a proportional-plus-integral (PI) compensator and a proportional (P) compensator are employed in *d*-axis and *q*-axis. The block diagram of unified controller is shown in the Fig 2.

The proposed control strategy is enhanced by introducing a unified load current feed forward, in order to deal with the issue caused by the nonlinear local load, and this scheme is implemented by adding the load current into the reference of the inner current loop. In the grid-tied mode, the DG injects harmonic current into the grid for compensating the harmonic component of the grid current, and thus, the harmonic component of the grid current and the load voltage will be mitigated, and improved quality of the load voltage[2],[3].

7. SIMULATION RESULTS

The overall proposed system is implemented in MATLAB as shown in Fig 3. The proposed system employs PMSG based wind turbine, solar system and inverter with unified control strategy. The wind turbine converts the power of the wind to mechanical power in the rotor shaft. This is then converted to electricity using a permanent magnet synchronous generator (PMSG). The output voltage is rectified using a three-phase diode bridge rectifier. The boost converter is used to increase the rectified dc voltage.

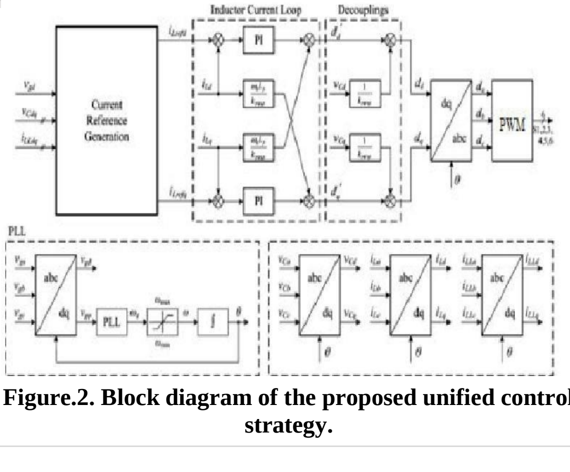

Figure.2. Block diagram of the proposed unified control strategy.

Due to the variable characteristics of the wind, the output voltage from PMSG is varying as shown in Fig.4(a). An uncontrolled rectifier with boost converter is used in order to get constant DC voltage as shown in Fig.4(b).

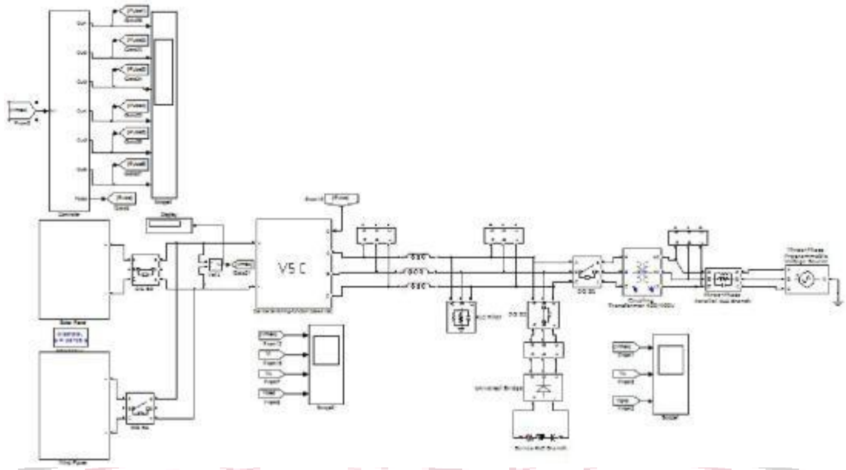

Figure 3. Grid Interconnected Hybrid Wind and Solar System

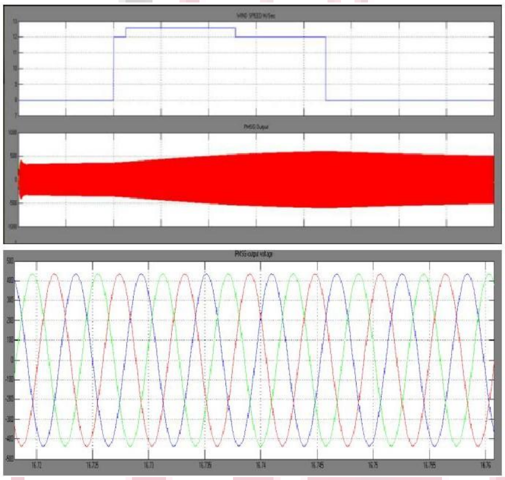

Figure.4. Varying Wind Speed and Corresponding PMSG Output

In similar manner, solar energy is converted into electrical energy with the help of solar cells, the produced solar output voltage is not sufficient to support the DC bus so that dc –to- dc converter used to enhance the voltage.

The PV module design depends upon the irradiance, temperature, number of PV cells connected in series and parallel. The detailed block of PV module is shown in Fig.5.The boost converter is used in order to meet the desired DC bus voltage. The output voltage of boost converter is shown in the Fig.7. The output waveform shows that 180V of PV panel is boosted into 400V and fed into the common DC bus.

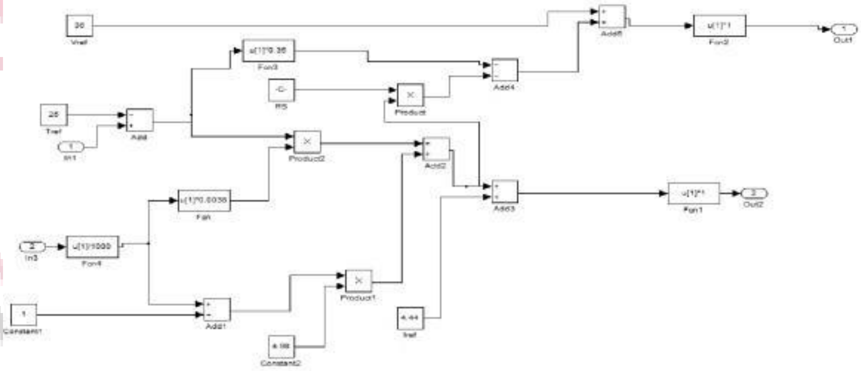

Figure 5. Simulink diagram of solar model

Fig.6. Output Voltage of Single PV module

The dual role inverter regulates dc-link voltage and injects the generated power into the grid as well as to the non- linear load. In addition to this, the inverter also eliminates harmonics generated by non-linear loads, thus the proposed strategy helps to achieve improved power quality at PCC. The corresponding inverter model is shown in Fig .8.

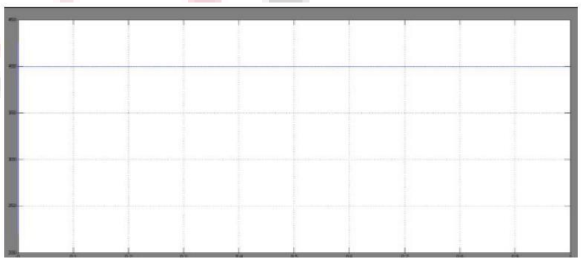

Fig .7.Output Voltage of Boost Converter (PV)

The Fig .9 shows that the load voltage is distorted due to the non-linear load and harmonic component is presented. The Fig.10 shows the waveforms when DG feeds nonlinear load in the islanded mode with control circuit. It can be seen that the distortion of the load voltage is improved by proposed unified control strategy. Fig.11 shows the output voltage of grid and inverter.

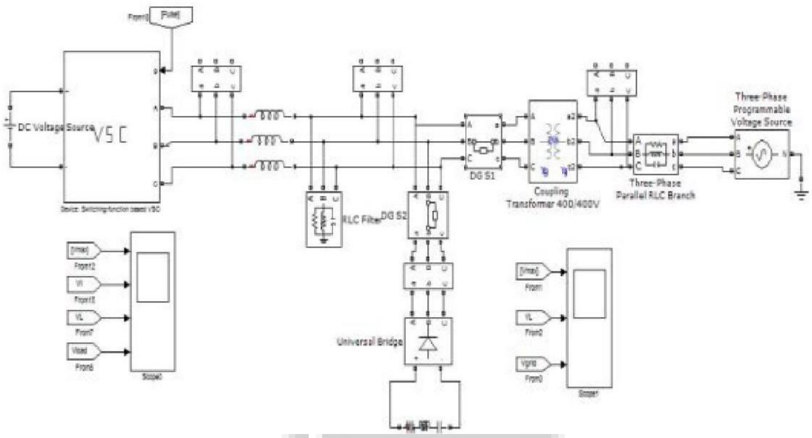

Figure 8. Inverter model with islanding and grid tied mode

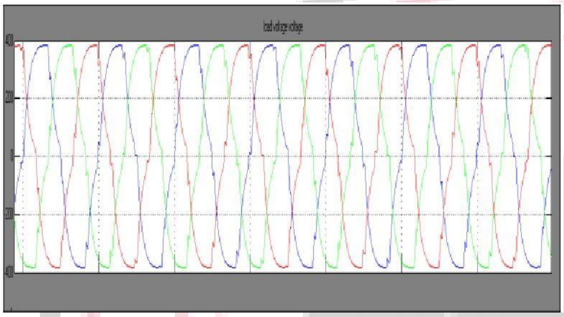

Figure 9. Distortion Waveform of Inverter without controller

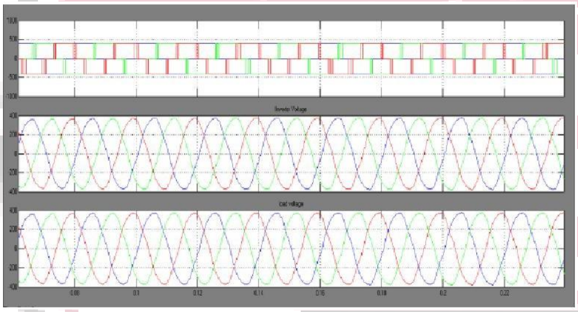

Figure 10. Waveform of Improved Inverter voltages with controller

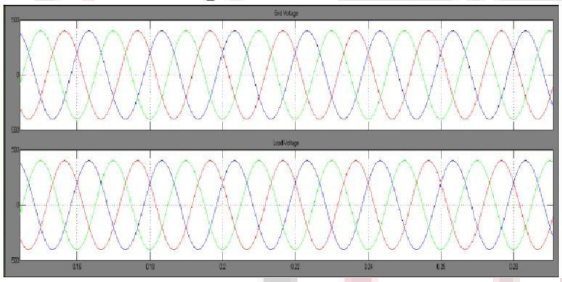

Figure 11. Output Voltage Waveform of Grid and inverter

Fig.12 shows THD of the load voltage is reduced from 7.63% to 3.45%. The proposed strategy helps to achieve IEEE standard requirements with improved power quality at PCC.

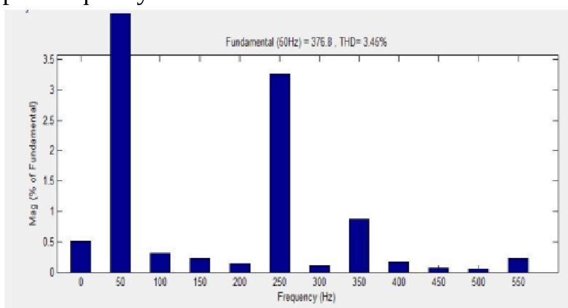

Fig .12. THD Analysis of load voltage

8. CONCLUSION

In this paper, grid connected solar and wind hybrid power system was developed in MATLAB/SIMULINK software. Corresponding converters are modeled for solar and wind energy system. The hybrid system is connected to the load and also to the grid through a manual switch. Dual purpose inverter was designed with an unified control strategy in order to improve the power quality problem and to integrate hybrid power generating system to grid. The THD analysis shows that the controller very well improves the power quality as well as connects the renewable sources to the grid.

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