Design and Control of Hybrid Power System for Stand-Alone Applications

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Abstract: This work presents design and controlling of photovoltaic fuel cell and super capacitor based hybrid system in standalone applications. It uses solar PV array with fuel cell as the major power sources. The sources will share their energy efficiently to supply the load connected. During transients in loads, the supercapacitor will be used to supply/absorb the power. The major control part consists of controller to maximize the power tracking with PV system, buck converter, fuel cell controller arrangement to manage power and controller for inverter to regulate frequency and voltage. The aim of hybrid standalone system is to supply quality power to the users with a sustained frequency and voltage along with efficient power management with simple control methods. The designing and control techniques of hybrid standalone system are analyzed in MATLAB/Simulink.

IndexTerms - **PV system, fuel cell, MPPT, Controller for inverter**

I. Introduction

At present the energy demand for world is majorly met with the energy from fossil fuels like coal which will be depleted in few years. This will necessitate the conservation of fossil fuels for further uses as energy demand increasing day by day. Due to increased emission of greenhouse gases from the power plants and industries etc. that use conventional fuels the environment conditions are worsened, This necessitate the use of renewable sources of energy to meet the increase in power demand which will cause low pollution. Photovoltaic cells are semiconductor p-n junction devices which generates DC energy directly from sunlight. The Photovoltaic system operates with less maintenance and noise free when compared with other sources of renewable energy. Since the irradiation from solar on earth is irregular PV systems with other sources are necessary to provide consumer with reliable and continuous supply of power. Fuel cells supply constant DC power by chemical energy conversion. Wind energy has profiles which are complementary with energy from solar but it cannot be extracted effectively in some regions where sufficient wind is not available and the installation cost is also high. Storage system with battery is less reliable when used in combination with solar system. Hence the FC is the alternative energy source to backup energy when the standalone loads are used. As long as the oxygen and fuel hydrogen is available fuel cell keeps generating DC energy with efficiency of about 60%.

The detailed modelling of fuel cell FC is given in [1]. Proton Exchange Membrane cell model is given in [3 2]. design and operation of a Photovoltaic array is given by many researchers [5 8]. A hybrid standalone system with a major source of energy as fuel cell and the storage system with supercapacitors is given in [3]. The proposed method is not used source side DC - DC converters. Due to the high power density, the phase angle and voltage control method is implemented to inverter control. The compensation can be done by supercapacitor bank for source and load side transients and variations. The sensors will track the load and control of fuel rate within the model of fuel cell In [4 6]. Fuel cell and PV array system were connected with supercapacitor bank to give uninterrupted supply The fuel cell types and the comparison is given in [1], which shows that PEMFC is suitable for standalone power applications and levels of power considered. In [6] a different control method for the same type hybrid power system is given in which hydrogen electrolyzer and ultracapacitor store extra power and variable dump load receives excess power.

Lot of work done and published on comparison of MPPT methods for PV systems and from available methods efficient and accurate is incremental conductance algorithm is given In[10 9]. The output voltage of inverter consists of harmonics. To get a sinusoidal voltage, a filter must be used. Many filters types are given in [11 13]. In a system of standalone application when the load power changes suddenly the source voltage falls at the source and disturbance in frequency occur. Hence a control method has to be developed for regulating frequency and voltage of the system to maintain the system safe and stable [1 14 16]. Many techniques are discussed by researchers to manage the power in a hybrid power system. In this paper the system uses PV array and supercapacitor bank along with fuel cell to absorb or supply transients in load. In this, DC bus is connected directly with the supercapacitor bank [1]. This work aims to design and develop simple control methods for power management, compares to methods given in existing works. The control method consists of MPPT controller for Photovoltaic system fuel cell controller to manage power and controller to regulate inverter voltage.

II. Configuration of Hybrid System and Modelling

Figure 1 shows the circuit of a PV fuel cell and SC system, which majorly consists of a solar source of energy with controller like MPPT FC system with DC-DC converter controller for single phase inverter and load. Both fuel cell and PV system is connected with common DC link and the super capacitors are connected with DC bus to absorb or supply transients in load. The capacity of fuel cell and PV system are 4.9 kW and 5 6 kW. The DC voltage is 370 V. The rating of set of super capacitors are taken as 400 V. 150 super capacitors of 2.7V each and 3 Farads capacity is chosen, which is charged to 92.5% of its total capacity. The generated DC supply will be converted into AC by single phase H type bridge inverter. The LCL filter in the design removes harmonics in AC output. The control system operates and regulates the hybrid system which uses current control for power balance on DC side and frequency and voltage controller on the AC side of hybrid system

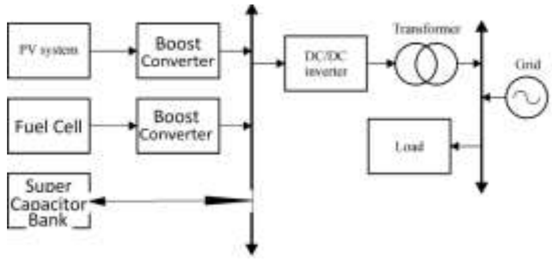

Fig. 1. The PV, FC and SC hybrid system representation

2.1. PV Array

A Photovoltaic cell is a semiconductor diode, which generates current when higher energy of photons higher than the band gap energy of semiconductor material. The PV module is formed by proper combination of photovoltaic cells in parallel and series combination. Many mathematical models were proposed by researchers for power generation from PV system and a diode model with single diode is used in this work. Figure 2 shows the circuit of diode model of a solar cell with single diode.

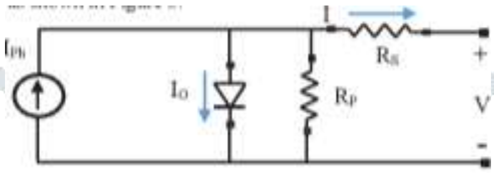

Fig. 2. PV cell equivalent circuit

2.2. PEM Fuel Cell System

In this work PEMFC is taken in which electricity generated using Hydrogen fuel. Figure 3 represents PEMFC system The model is is designed and analysed in MATLAB/Simulink

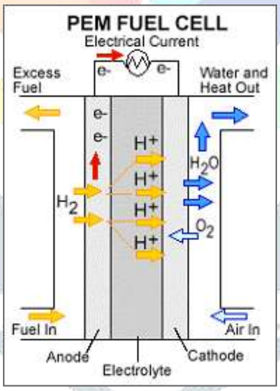

Fig. 3. Proton Exchange Membrane Fuel cell system

III. CONTROL STRATEGIES FOR POWER ELECTRONIC CONVERTERS

3.1. Photovoltaic MPPT Control

For delivering maximum power to load connected, PV system use MPPT controller under varied temperature and insolation conditions. Maximum power point tracking controller is necessary for the solar PV systems, as conversion efficiency of photovoltaic modules is relatively less. Hence MPPT control is implemented with DC-DC boost converter.

Incremental conductance IC algorithm is used among the available MPPT methods proposed by the researchers and compared two algorithms and found that implementing PO algorithm is easy. But the output fluctuates about the maximum power point and hence efficiency is less when compared to the IC algorithm [10 9]. According to this IC method dl/dV = I/V at maximum power point as shown in Figure 4. Also when compared with perturb and observe method this algorithm can track power quickly for varying irradiance conditions with better accuracy [9]. The Figure 5 shows flow chart of Incremental conductance method. This method shows the fact that the rate of change in conductance output is equal to the negative of the output conductance. At maximum power point Figure 6 shows MATLAB/Simulink block diagram for implementing IC algorithm.

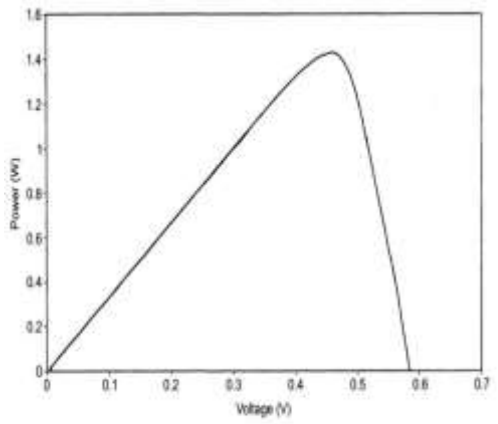

Fig. 4. P-V curve of a Photovoltaic cell

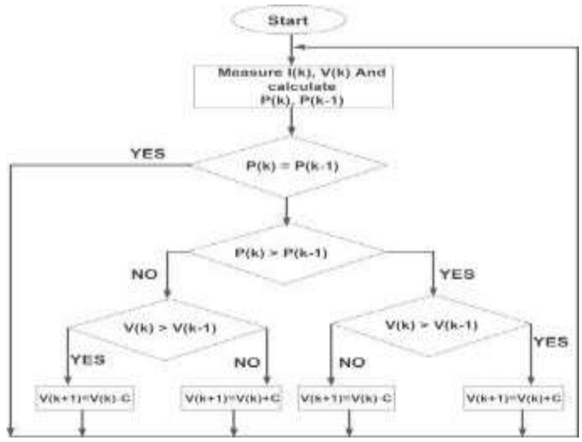

Fig. 5. IC method flow chart

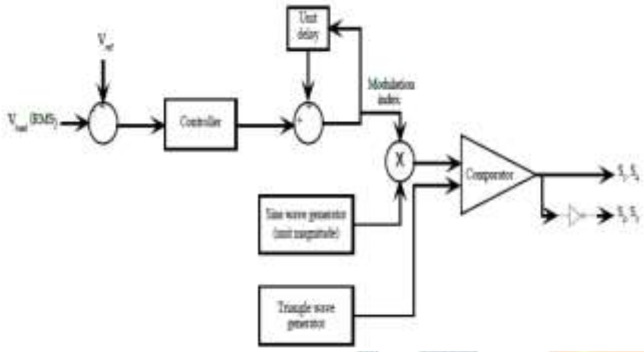

Fig. 6. MATLAB/Simulink model of IC algorithm

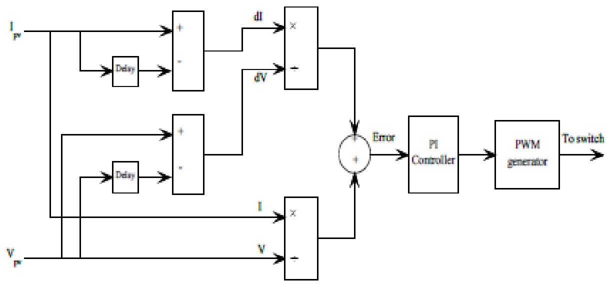

Fig. 7. Frequency and Voltage control method

3.2. Inverter controller

The frequency and voltage changes when load demand changes. Loads require constant frequency and voltage for their satisfactory operation [15]. So it is necessary to maintain the frequency and voltage on the AC side of the system. Figure 7 represents the frequency and voltage controller used. The RMS value of fundamental load voltage component is taken and compared with the 230 V reference voltage. The error is given to the PI controller. The unit delay update the modulation index value for every period. The controller output is modulation index, which value ranges from 0 to 1. This modulation value is multiplied with a sine wave unit magnitude, which is compared with a triangular wave. The pulses generated are given to four switches of inverter as shown in Figure 7. By adjusting modulation index, voltage variations across load are controlled. This controls the voltage and frequency.

3.3. Current Control Strategy for Power Balance

Solar energy being intermittent in nature, cannot meet the load demand alone. So when it is not able to supply the entire load demand, the additional power has to be supplied by the fuel cell system. The control strategy using current control technique for boost converter of fuel cell is shown in Fig. 8. The RMS value of load current is taken as the reference and the total current generated from fuel cell and PV source is compared with the reference. The PI controller functions as current controller generating the duty cycle to compensate the mismatch in demand and generation. The PWM generator produces gate pulses depending on the duty cycle and the output power of fuel cell is controlled.

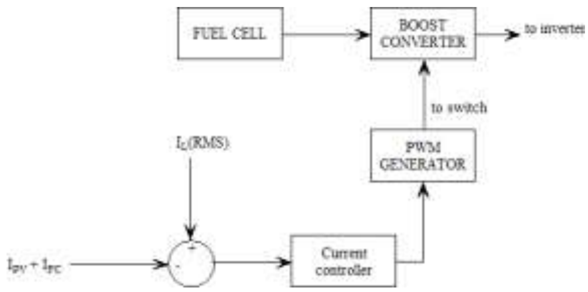

Fig. 8. Current control method for power balance

The sudden variations of load are common in stand-alone systems. In this paper, supercapacitor is used to supply or absorb transient power due to load variations. Supercapacitor is a device with high power density, small time constants and can absorb or supply high power within a short interval of time. Here supercapacitor bank is connected to the DC bus directly, as it can respond to transients without converter [1]. When the transients in the load appear, the supercapacitor supplies the power to match the load and to keep the system safe. When the PV power exceeds the load demand; supercapacitor absorbs the additional power from the PV system.

IV. Results and Discussions

In this section, the simulation results of the PV/FC/SC hybrid system for different source and load conditions in MATLAB/Simulink environment are presented. A simulation period of 2 sec has been considered for the study. The simulation parameters of PV cell are given in Table 1 [11]. The details of the parameters used for the fuel cell model are considered from [1]. The PV system generates 5.6 kW for irradiation of 1000 W/m^2. The current generated by a PV array, is a direct function of irradiance. The output power of PV array reduces with the reduction in irradiance. The irradiation profile of PV array is shown in Fig. 9. The irradiance data is collected from the sun rise to sun set in the interval of 30 minutes in a sunny day and is scaled down to 2 sec. The corresponding output power variation of PV system is shown in Fig. 10.

Table 1. Parameters of PV system

Module	Waree WS-290
Technology	Multi crystalin silicon
Number of cells in series	72
Voc (V)	44.8
Imp (A)	7.99
Vmp (V)	36.3
Temperature coefficient of current	0.0681
Temperature coefficient of voltage	-0.2941
Temperature coefficient of power	-0.3845

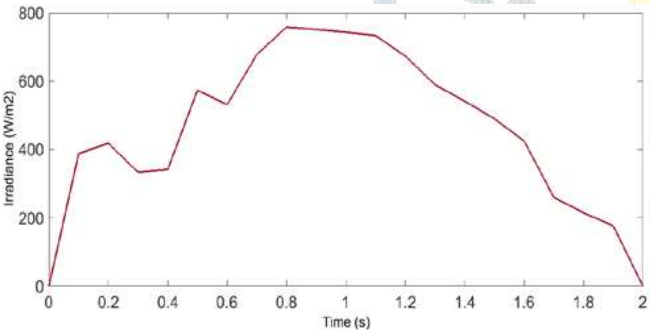

Fig. 9. Profile of Irradiation

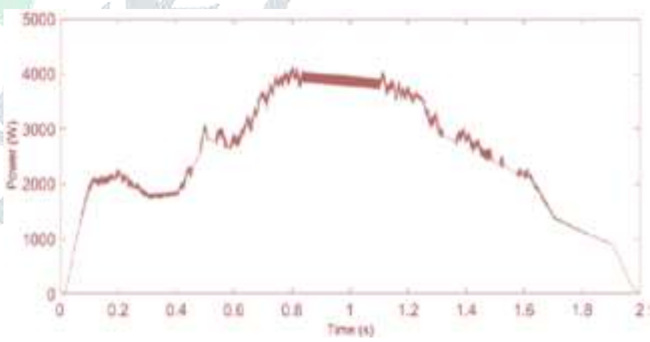

Fig. 10. PV Power output

Figure 11 shows the variations in the load demand considered for the simulation. So as to show the effect of supercapacitor, the sudden load changes are considered at time instants 0.35sec and 1.15sec. Figure 12 depicts the output power of fuel cell system. It follows the load demand of the system. But whenever PV generation is sufficient to meet the demand, its output power is zero. Figure 13 illustrates variations of load power and supercapacitor power. Whenever sudden load change occurs, supercapacitor bank responds immediately to the transients. In the time interval from 0.6 to 1.2 sec, the supercapacitor output power is negative. In this interval generation from PV system is higher than the demand and supercapacitor bank is charged.

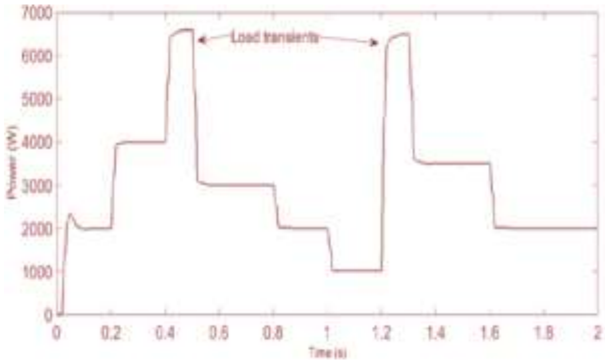

Fig. 11. Load power

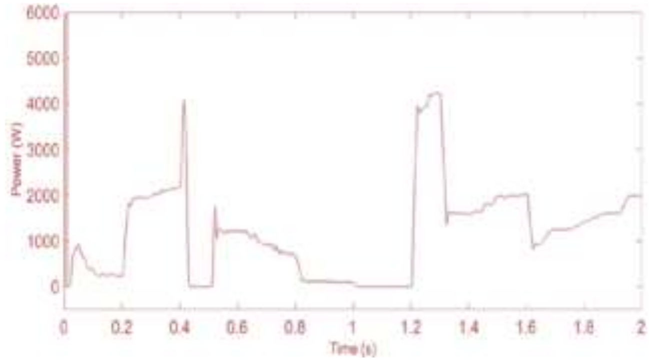

Fig. 12. Power output of Fuel cell system

The power responses of different sources and load demand of the hybrid system is shown in Figure 14. Figure 15 represents the total generated power and load power and it is seen that the total generation meets the load demand of the hybrid system. RMS voltage across the load is shown in Figure 16 shows the. Even during load transients, the voltage variations are found to be within acceptable limits (less ±5% of the rated value as per the standards). Figure 17 illustrates how the modulation index of the inverter gets adjusted to regulate the voltage during load changes as per voltage and frequency controller used. Figure 18 shows the frequency of load voltage (50 Hz) controlled within the limits as specified in the standards. Figure 19 depicts the harmonic spectrum of the load voltage. For the system considered the total harmonic distortion (THD) is 2.66%. As per the IEEE standards, the percentage of harmonics has to be less than 5%.

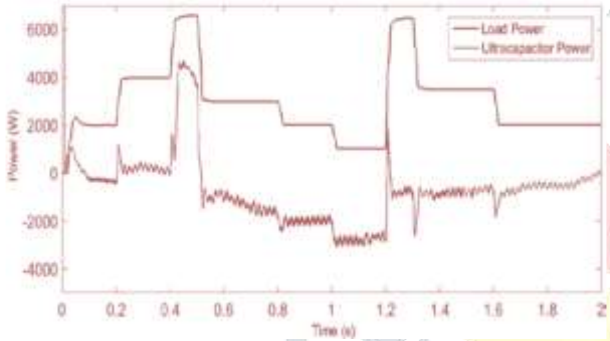

Fig. 13. Power of load and supercapacitor

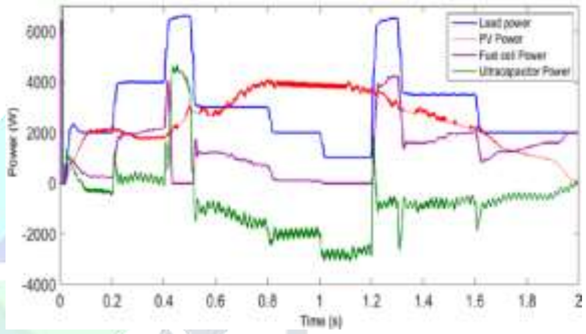

Fig. 14. Responses in Power with hybrid system

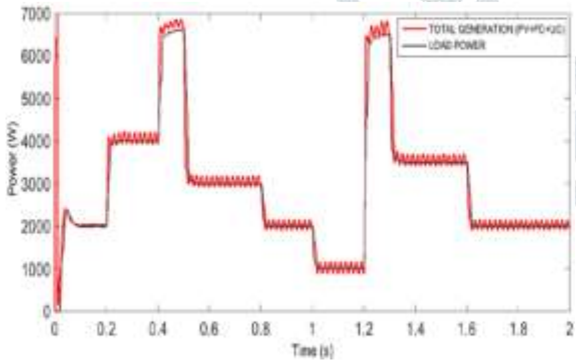

Fig. 15. Total generated power and load demand

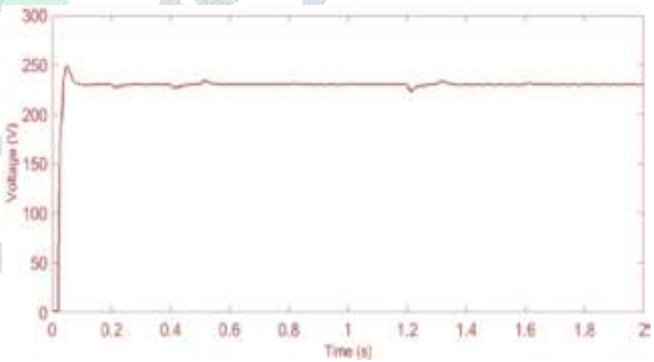

Fig. 16. Load Voltage

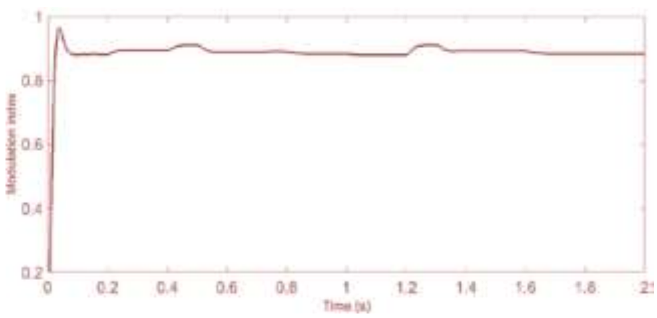

Fig. 17. Inverter Modulation index

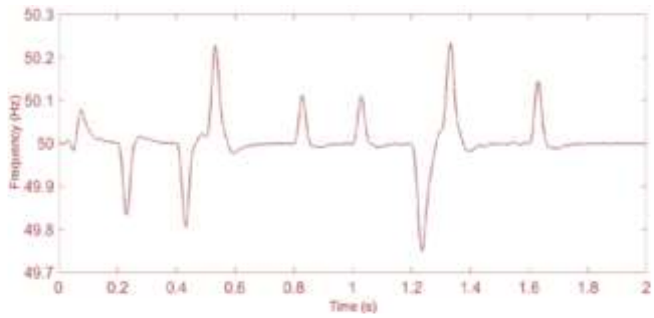

Fig. 18. Load voltage Frequency

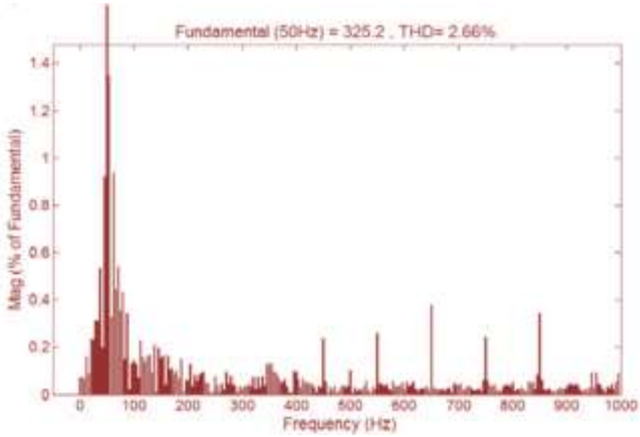

Fig. 19. Load voltage Harmonic spectrum

V. Conclusion

Using MATLAB /Simulink a detailed model of Photovoltaic and FC based hybrid system with supercapacitors and the control methods are implemented. The hybrid system considered in this paper use Photovoltaic array and fuel cell system as the major sources. The effective sharing of power to meet the load side demand and stable & safe operation under transient load is fulfilled by supercapacitors. From the results of simulation, it is reported that the control strategy is capable to regulate the frequency and voltage within the acceptable limits even in uncertainty of Photovoltaic power generation and variations in load so that quality supply with constant frequency and voltage will be received by consumer with less distortions.

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