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Modeling and Simulation of a stand-alone PV and Fuel Cell Hybrid system for DC Load

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Abstract: **Renewable energy resources are gaining more attentions for electricity production nowadays because of the continuous depletion of fossil fuels. DC micro grid is a better choice because of its simplicity. PV and wind turbines gives fluctuating power because of their dependence on the environmental factors. FC is a better choice to be used in combination with the PV array as a backup generation system. In this paper, PV and FC hybrid generation system of 13kW is analyzed under the steady state condition on the simulation software MATLAB 2017(a). The proposed system is applicable for high voltage industrial loads and low voltage residential appliances. Power electronic boost and buck converter is used for the regulation of voltage at different buses. Performance of the system is analyzed using simulation software MATLAB 2017(a). Results shows the regulated output parameters for the DC loads.**

Keywords: *MPPT, DG, PV, FC, PEMFC.*

I. INTRODUCTION

The continuous depletion in the fossil fuels around the world, have diverted the focus of the researchers to the utilization of renewable energy resources. Distributed Generation (DG) system is the allocation of power system near to the end consumers. The absence of the long-distance transmission lines and big power plants, made the DG sources environment friendly. The decentralized system is compared with centralized system in terms of reliability, efficiency and environmental concerns. DG system is concluded to be the better choice for the sustainable development in the long run [1]. Europe is expected to have the highest growth of DG for the next five years that is 32%, and 26% for both North America and Asia. The highest expected demand of DG for five years is 49% for solar and 18% for wind as concluded in IEEE survey 2012 [2]. The output of the most renewable energy resources such as solar and wind turbine are dependent on the environmental conditions. The characteristics of their output is thus unpredictable. The hybrid system is used to overcome such instabilities because of distinct micro source characteristics, in order to enhance power quality and reliability [3]. Fuel Cell can be used as a backup power source, past literature shows that for stand-alone applications PV/wind/FC system gives stable results [4-6]. A 2.24kW PV-FC hybrid generation system is designed for stand-alone application. It was observed that the output power of the PV array varies during the whole year. An electrolyzer is coupled to the PV array for hydrogen production. Fuzzy regression algorithm is used for MPPT design [7]. Proton Exchange Membrane Fuel Cell (PEMFC) is gaining more popularity because of its high density of power, small size and low emission as compared to other types of the Fuel Cells [8]. The author has proposed PV/wind/FC hybrid generation system of 3.8kW for remote areas that is installed in the Istanbul. PV and wind is used as the main power source and FC is used as the backup generation source in order to overcome the instabilities of power in case of shortage or natural disasters. The control system is designed that transfer the flow of surplus power towards the electrolyzer to generate more hydrogen that can be utilized to generate power through FC in case of need. The average daily energy consumption E_{av} is calculated as

$$E_{av} = \sum_{i=1}^{r} V_r I_r D_r \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here V_r, I_r, and D_r are the voltage, current and the duty cycle of the daily used appliances [9]. Hybrid system of Photovoltaic and PEMFC along with electrolyzer is proposed for the different climatic conditions of Ankara in Turkey. The results shows that the system is sufficient for supplying stand-alone system during the summer season. Excess power is utilized to produce hydrogen for back up generation system. However, due to the variation in the solar irradiance, the system must be connected to the grid during winter season [10-12]. The authors have used Maximum Power Point Tracker (MPPT) for their hybrid PV and FC system, to increase the efficiency of the system.

II. PROPOSED SYSTEM

The proposed system consists of PV and FC electricity generation system, DC/DC boost converters, DC/DC buck converter and DC loads. Here the PV array is considered as the main source of electricity generation. The output power of the solar system fluctuates because of the uncertain variations in the solar irradiance and temperature. In order to compensate such uncertainties, a backup FC electricity generation system is proposed.

The output voltage of both generation system is first increased through an individual boost converter and then connected in parallel to a common DC bus. Heavy loads are connected to

high voltage side. For residential loads, buck converter is used in order to decrease the voltage to a desired value. The block diagram of the proposed system is shown in Fig 1.

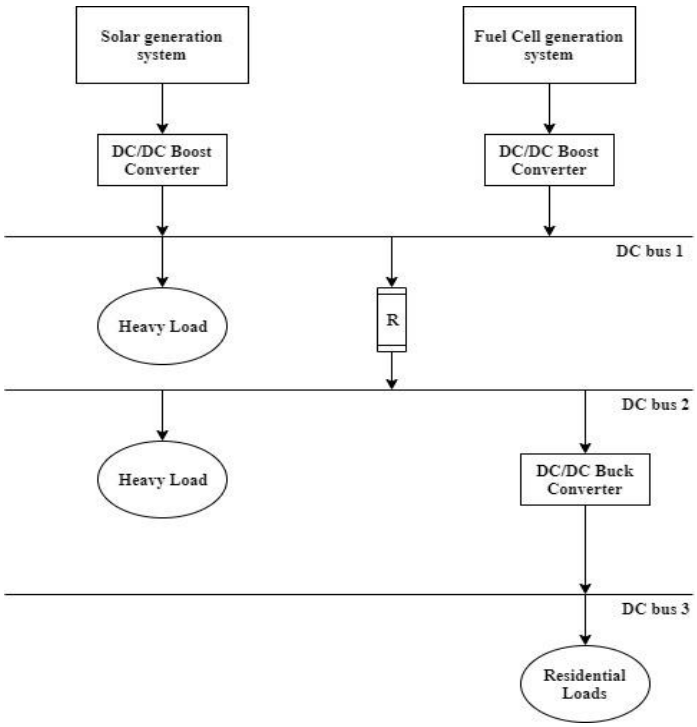

Fig 1: Block diagram of the proposed model

The simulation software of MATLAB 2017(a) is used for the simulation of the proposed model. Proper parameters for the PV array and FC stack is chosen according to the demand. In this system 20 parallel strings are selected for PV array. Each string consists of 5 series connected module and each module consists of 100 cells. Temperature variation of 25℃ to 50℃ are selected. 48V, 6kW Fuel Cell stack is selected. DC/DC boost and buck converters are designed by the electronic components of the MATLAB library.

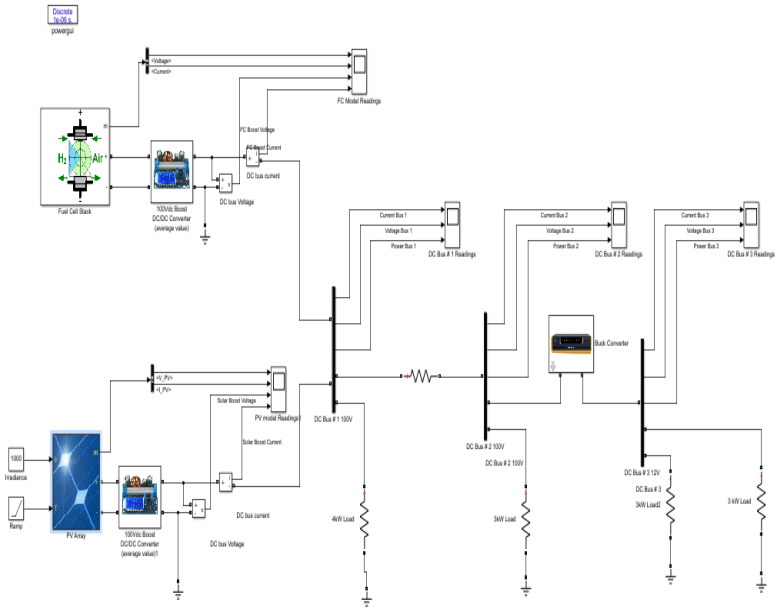

Fig 2: Simulation model of the proposed PV and FC hybrid generation system

III. RESULTS AND DISCUSSIONS

The simulation results are taken for four seconds. The voltage at output of PV array is 48V. The output voltage is step up to 100V for heavy loads and transmission through DC/DC boost converter as shown in Fig 2. The output current at 48V was 154A, when the voltage has increased to 100V; the value of current reduced to a value of 80A as shown in Fig 3.

Similarly, the parameters were selected so that FC gives the output voltage of 48V. The output voltage of FC stack is then increased to 100V through DC/DC boost converter as shown in Fig 2. The current of the Fuel Cell at 48V is 110A. However, when the voltage has increased to 100V for DC bus 1, the current at 100V reduced to 50A as shown in Fig 3.

Since this is the DC micro grid, the Power at buses can be calculated by the multiplication of voltage and current as

$$P = VI \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The power supplied by PV array system is 8kW and the power that Fuel Cell stack supplies is 5kW. Since PV array and Fuel Cell generation systems are connected in parallel to bus 1. The power at DC bus 1 becomes 13kW as shown in Fig 7. The system supplies the voltage of 100V at bus 1 at the current of 130A as shown in Fig 3 and Fig 6.

The heavy load of 4kW that runs on 100V is connected at DC bus 1. Consequently, the power must be 9kW at DC bus 2. As shown by the results of Fig 6 and Fig 3, the voltage at DC bus 2 is 100V and current at DC bus 2 is 90A. The power waveform is shown in Fig 7, thus DC bus 2 supplies power of 9kW.

Since DC bus 2 is capable of supplying 9kW and the load of 3kW is connected at DC bus 2, the power at DC bus 3 becomes 6kW. The buck converter is connected between DC bus 2 and

DC bus 3, in order to step down the voltage from 100V to 12V for supplying power to two distinct residential loads of 3kW. The voltage level and current response is shown in Fig 6 and Fig 3. The power waveform is shown in Fig 7. It can be seen that when voltage is step down for residential loads, the level of current increases.

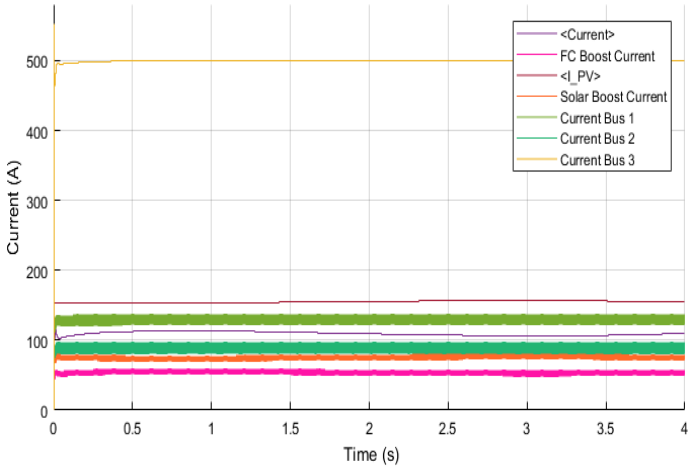

Fig 3: Steady state current at DC buses and generation systems

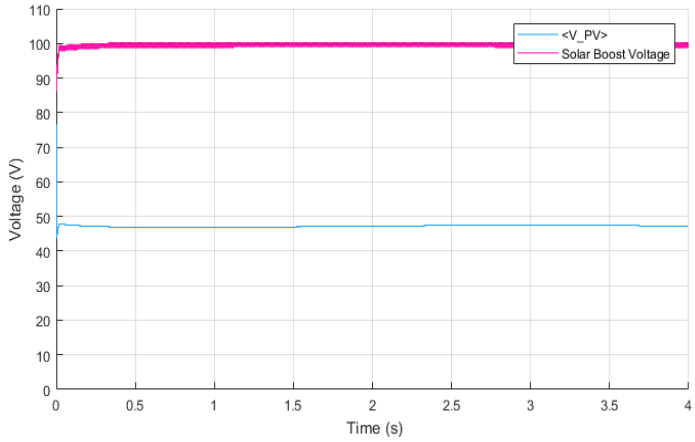

Fig 4: Output Voltage of PV array and Solar boost voltage

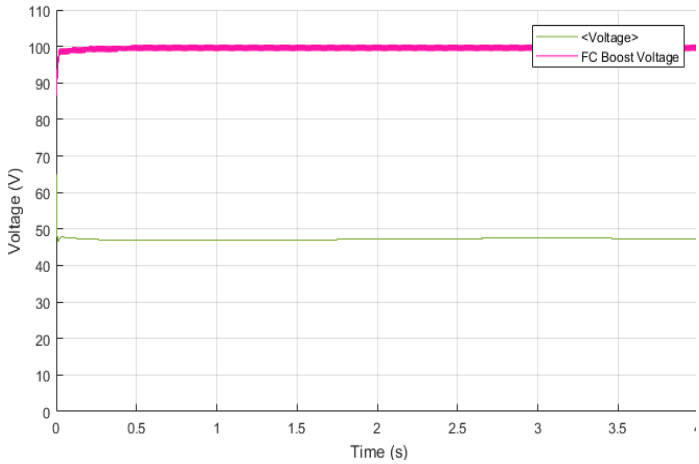

Fig 5: Output Voltage of FC and FC boost voltage

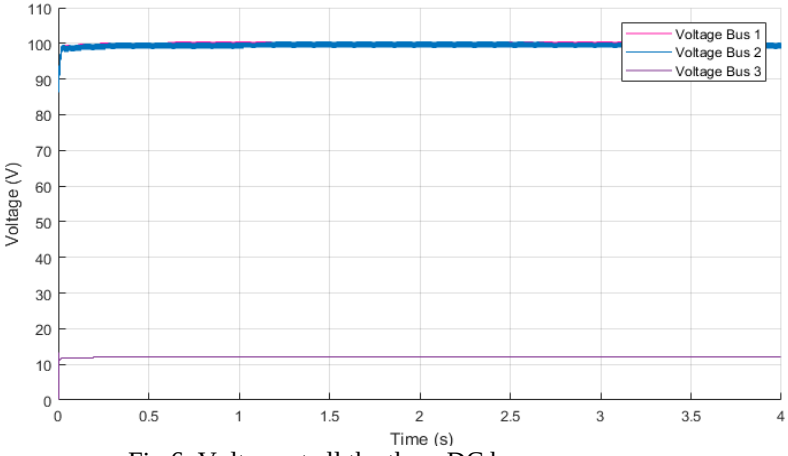

Fig 6: Voltage at all the three DC buses

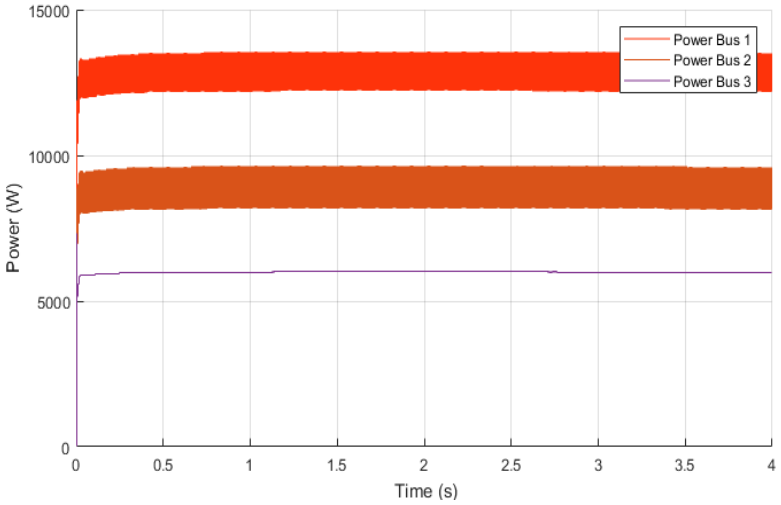

Fig 7: Power at all the three DC buses

The results can be depicted in a tabular form as shown in Table 1 below. The parameters i.e. voltage, current and power at all the three buses are given in the Table.

Table 1

PV-FC hybrid system output parameters

Selected Bus	Voltage (V)	Current (A)	Power (W)
DC Bus 1	100	130	13k
DC Bus 2	100	90	9k
DC Bus 3	12	500	6k

IV. CONCLUSION

Due to the continuous depletion of natural reserves of fossil fuels for electricity production, nowadays the world is moving towards the renewable energy resources to meet the demand. For DC micro grids, Photovoltaic (PV) and Fuel Cell (FC) generation system is suitable because they supplies DC output. In this research paper, PV and FC hybrid generation system is proposed for DC micro grid. The hybrid generation system is operated in an islanded mode. The results shows that this micro grid is suitable to supply power to the industrial and residential loads in an islanded mode.

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