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Fuzzy Control Based Renewable Energy Sources for DC Microgrid Applications using FPGA Platform with EMS

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ABSTRACT

The main objective of this proposed system is to provide uninterruptible power supply to the load. This proposed system mainly deals with the Energy Management System (EMS) of the DC microgrid systems, using the fuzzy logic control. This proposed system consists of the power sources, which obtains its power from the PV panels, Wind turbine, and fuel cells stack. The EMS incorporates the fuzzy control that is responsible for the Energy Management and Battery Management. The fuzzy maintains the State of Charge (SoC) parameters of the battery. The fuzzy logic implementation of this system was done by using the Field Programmable Gate Array (FPGA) .

Indexing terms/Keywords

Keywords: SoC, Fuzzy Logic Control, EMS, FPGA, Microgrid, Renewable Energy Sources.

Academic Discipline And Sub-Disciplines

Environmental Engineering or Environmental Chemistry, Electrochemistry.

SUBJECT CLASSIFICATION

Renewable Energy Sources

TYPE (METHOD/APPROACH)

Experimental analysis using FPGA platform and simulated in Fuzzy.

1. INTRODUCTION

The microgrid system consists of the power sources, storage system and regulator systems. The microgrid system consists of the intelligent controllers responsible for the energy management, and has the interconnected and grid connected loads. The architecture of the microgrid system are discussed [1]. The microgrid system exists in many countries and in university campuses. The microgrid research organization such as Electrical Power Research Institute (EPRI) in india, has done many research in microgrid as well as in the smart grid systems. The microgrid acts as a platform for the implementation of the distributed energy sources [2]. In Maldives, the microgrid system consists of the power sources, storage systems, intelligent controllers, and load systems, its architecture of the microgrid system in Maldives are discussed [3]. In Chicago, the microgrid system was installed in the university campus of Illanos; the architecture of the entire system was discussed [4].

The block diagram of the proposed system is shown in the fig.1. This proposed system consists of three major blocks: generation block, storage block, and regulator block. The generation block comprised of the generating system that obtains its power from the PV panel, Wind turbine, and fuel cells stack. The storage block consists of batteries, and regulator block consists of EB system: 3 phase, 440 volts, and 50Hz. These generating systems, storage systems, and the regulator systems are connected to DC grid through DC-DC converter, Bidirectional DC-DC converter (BDC), and Bidirectional AC-DC converter respectively. The Maximum Power Point Trackers (MPPT) are associated with PV, and Wind energy conversion system. The power generation by PV and wind are equally distributed to the load, battery, and to the EB system. When PV and wind fails to generate power, the battery delivers power to the load, and EB systems. The entire operation of this grid system are governed and coordinated by the EMS. The EMS commands the generation systems to operate in accordance with the demand of load, and SoC of the battery. The EMS is provided with RS 485 and ZigBee communication protocol, to know the generation status, and SoC of the battery. The hardware implementation of the EMS is done by the FPGA platform.

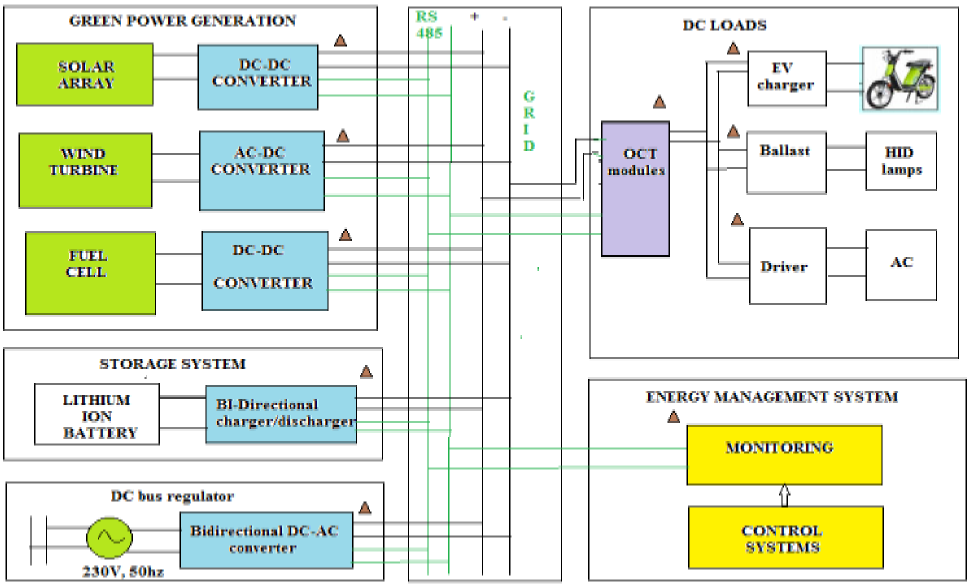

Fig 1: Block diagram of the proposed system

2. MODELING OF GENERATING SYSTEMS

2.1. PV Cell

The equivalent circuit diagram of the solar cell is shown in the fig. 3. The solar cell converts the light energy to electricity [5]. The expressions of the PV cells comprised of the PV output current I, diode saturation current I_0 expressed [6] by eqn. (1) to (3)

$$I = I_{Pv,cell} - I_0\left[\exp\left(\frac{V + R_s I}{V_t a}\right) - I\right] \qquad (1)$$

$$I_0 = \frac{I_{sc,in} + K_i \Delta T}{\exp\left(\frac{V_{ocn} + K_V \Delta T}{aV_t}\right)} \qquad (2)$$

The power in the PV panel is expressed by (3) [6].

$$\boldsymbol{P = V\left\{I_{sc} - I_0\left[exp\left(\frac{V}{A * V_t}\right) - 1\right]\right\}} \qquad (3)$$

The characteristics curves of the PV cell is shown in the figure 2 and 3.

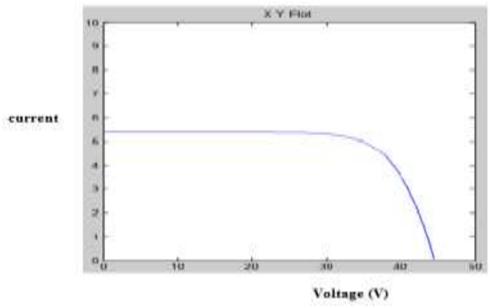

Fig 2: V-I characteristics of PV cell

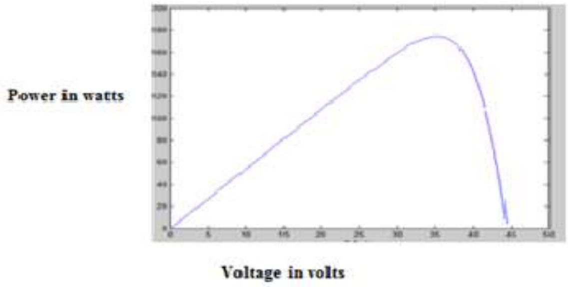

Fig 3: P-V characteristics of PV cell

2.2. Wind Energy Conversion System

The wind turbine is fed with the asynchronous generator and uncontrolled rectifiers, to integrate with the DC grid. The modeling of the wind turbine is based on these verifications expressed [7]

$$T_{turbine} = T_{em,max} = \frac{\rho_m}{\Omega_t} \qquad (4)$$

Where

ρ	Air density (kg/m)
S	Turbine swept area (m)
C_p	Performance coefficient of the turbine
V_{wind}	Wind speed in m/s

The tip speed ratio is expressed by Lambda

Ω_t = Mechanical speed of the turbine

$$P_m = \frac{1}{2}\rho s C_p(Lambda, \beta)V_{wind}^3 \qquad (5)$$

$$\Omega_t = \frac{Lambda \ V_{wind}}{R_t} \qquad (6)$$

The power electronics has rapidly change the applications of the wind mill in many grid connected applications, it is due to the development of the semiconductor devices and microprocessors. The gated switches employed Metal Oxide Semiconductor (MOS) transistors, and the number of controlled transistors are discussed [8].The wind turbine can be employed for the variable speed and constant speed operation by using DFIG and PMSG respectively [8], [9].

2.3. Fuel Cell

The different types of fuel cells were discussed [10]. The fuel cell, and fuel cell flow control of the fuel cell involves Humidifier and Hydrogen flow control. The simulation of fuel cell involving the steady state simulation and dynamic simulation was discussed [11]. The figure.6 shows the characteristics of the fuel cell.

2.4. Battery

The battery employed in this system is the lithium ion battery. The battery is meant for the storage application, it acts only during the emergency load conditions, when the SoC value reaches above 90%.The estimation of the SoC of the battery can be determined by the given equation.

$$V_{SOC}(t) = V_{SOC}(0) - \frac{1}{C_{CAP}}\int_0^T i(t)dt \qquad (7)$$

3. INTELLIGENT MANAGEMENT SYSTEM

Conventionally, the decentralized power supply systems are employed for the power generation. This decentralized system optimizes the use of components employed in the power system [12]. The intelligent management system is essential for this decentralized system for the purpose of optimization, and battery management. The intelligent management system is essential for the optimized load flow analysis. The intelligent management system also employs cost prizing of the power, which is consumed by the load. The switching operation of the power system, especially in the converter employed for the particular converting operation, will also be regulated by this intelligent control system.

The main objective of the installation of the intelligent management system is to avoid the inadequate operating time and to protect the storage system. The intelligent management system provides better solution to the load, which supplies from the fluctuating power supply resources. The algorithm implemented in this intelligent management system has been proven, that it provides the better solution for the battery management and optimization. The intelligent management system is responsible for balanced power generation.

The intelligent management system employs fuzzy control, for the purpose of optimization and distributed energy generation. The DC smart grid system, the non linear system requires this centralized control system, which offers the practical way for designing the intelligent management system. This management system requires the difference between the actual load and the total generating power of the system (PV, Wind, and Fuel Cell) for the battery management. The SoC of the battery is directly proportional to the life time of the battery. The fuzzy employed in this, maintains the SoC of the battery.

3.1 Fuzzy Control

Fig. 1 shows the block diagram of the proposed energy management system with management control. The fuzzy logic system has two inputs and one output. The fuzzy logic controller decides the charging and discharging operation of the battery, which depends on the SoC. The inputs and outputs of the fuzzy is expressed as follows.

$$P_e = \text{Total power Generation-Load requirement} \quad (8)$$

$$SoC_e = SoC_{command} - SoC_{now} \quad (9)$$

The input membership functions P_e and SoC_e are shown in the fig. 4 and 5 respectively. The output membership function of I_C, the charging current of the battery is shown in the fig. 6. The fuzzy employs the mamdani type of simulation. Fig. 7 shows the surface diagram of the fuzzy rules.

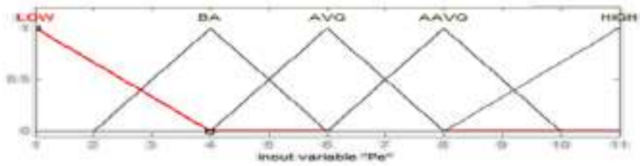

Fig 4: Input membership functions of P_e

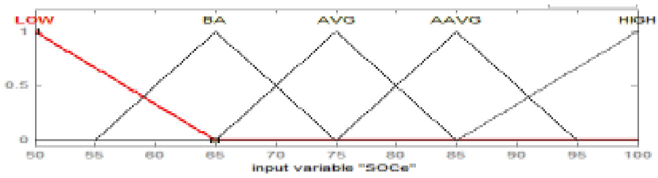

Fig 5: Input membership functions of SoC_e.

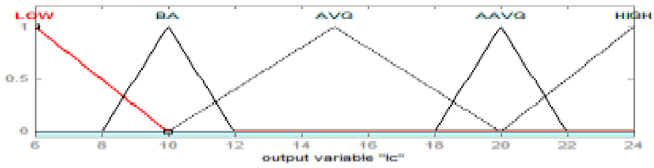

Fig 6: Output membership functions of I_c

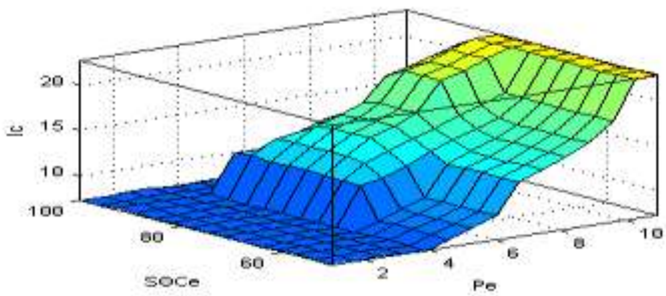

Fig 7: Surface diagram of fuzzy rules.

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The control rules of the fuzzy composed of five major grades of membership functions: Low (L), Below Average (BA), Average (A), Above Average (AA), and High (H). When P_e is said to be low, it implies the rate of generation from the generating sources are low. It (P_e) has a specified low values in the fuzzy as shown in the membership functions. When the P_e is high, it implies the generating power produced by the power resources are high. When the SoC_e is low, which implies the charging state of the battery is low, and it also says that the battery requires the charging current Ic. When the SoC_e is high, it denotes that the charging state of the battery reaches its limit, then the battery is ready to discharge its charges. The values of the SoC_e for the respective grades of the membership functions are shown in the fig. 10. The Ic, is the charging current of the battery, when the Ic is low then it implies that the charging current is low than the required current for the purpose of charging. The Ic is high which indicates the battery charging at the rated current. The fuzzy logic comprises of the number of rules, the lowest value of the SoC of the battery is the 50%. The fuzzy maintains the constant SoC parameters of the battery. The entire operation of the system is controlled by the centralized controller referred as fuzzy. The SoC of the battery is maintained at 50% as its lowest value, the battery has to discharge its charges, when the value of the SoC reaches more than 90%. The fuzzy rules are tabulated as follows:

TABLE 1 FUZZY CONCEPT RULES

	Pe					
	Ic	**Low**	**BA**	**A**	**AA**	**H**
SoCe	**Low**	Low	Low	BA	A	H
	BA	Low	Low	BA	A	H
	A	Low	Low	A	AA	H
	AA	Low	Low	A	AA	H
	H	Low	Low	Low	Low	Low

4. SIMULATION AND RESULTS

4.1. Simulation of PV systems

The PV system comprised of the PV panels, and DC-DC converter, produces the output power of 5.6 kW. The solar cell has the output voltage of 1V. The MATLAB simulink diagram for the solar power system shown in the fig. 8 and Fig. 9, shows the waveforms of solar PV system.

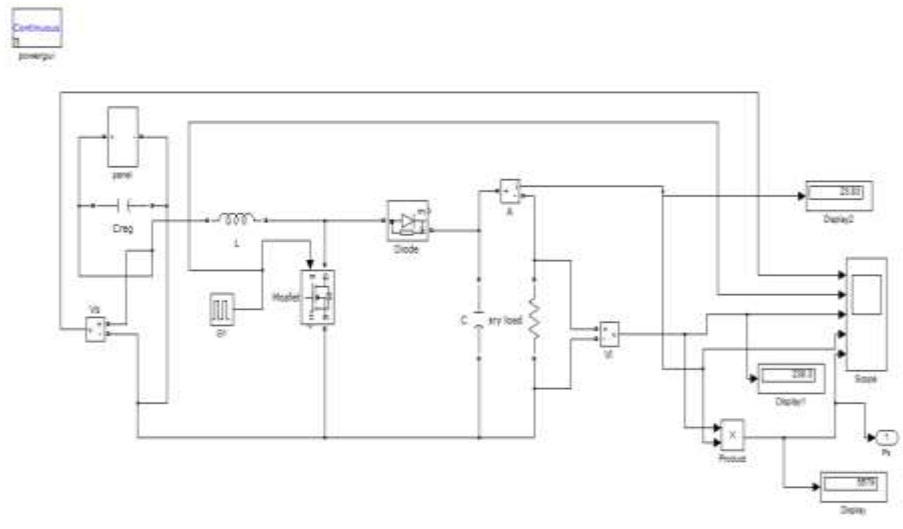

Fig 8: Simumation circuit diagram for PV system

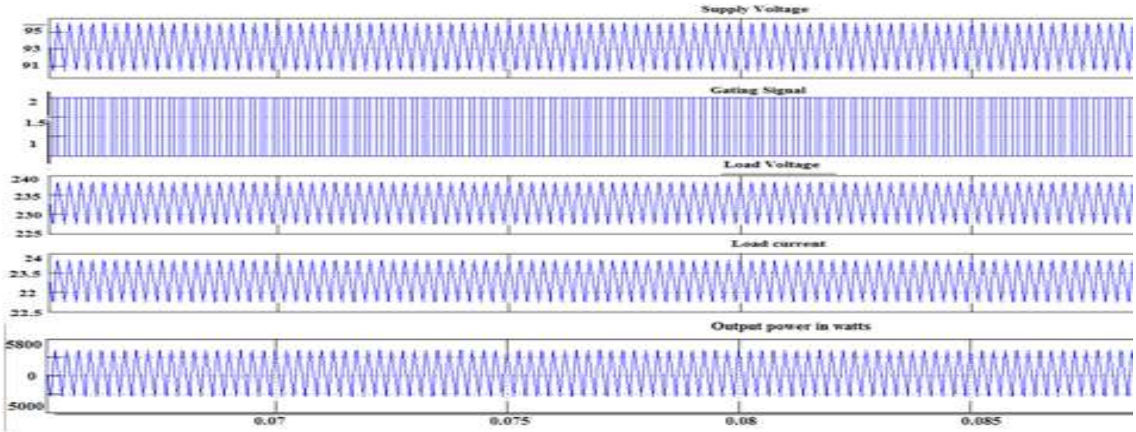

Fig 9: Output waveform of PV system with MPPT.

4.2. Wind Energy Conversion System

The wind energy conversion system consisting of the wind turbine and the asynchronous generator has a conversion system as a uncontrolled rectifiers. The output watts produced by this wind energy conversion system is 4.6 kW. Fig. 10 and 11 show the circuit diagram and the output waveforms of the wind energy conversions system.

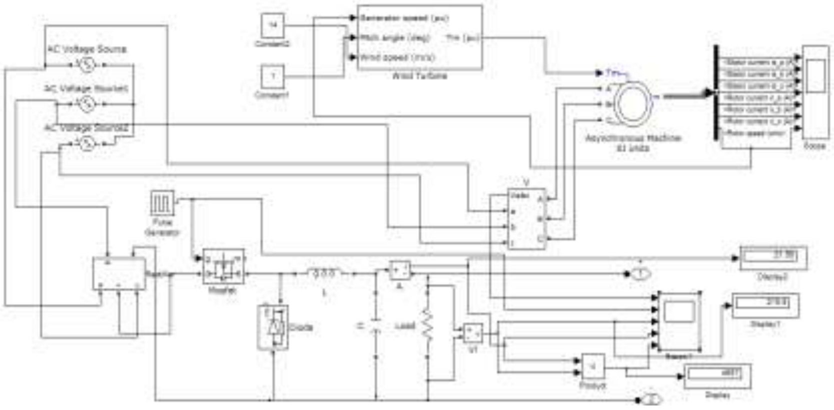

Fig 10: Circuit diagram of Wind energy conversion systems.

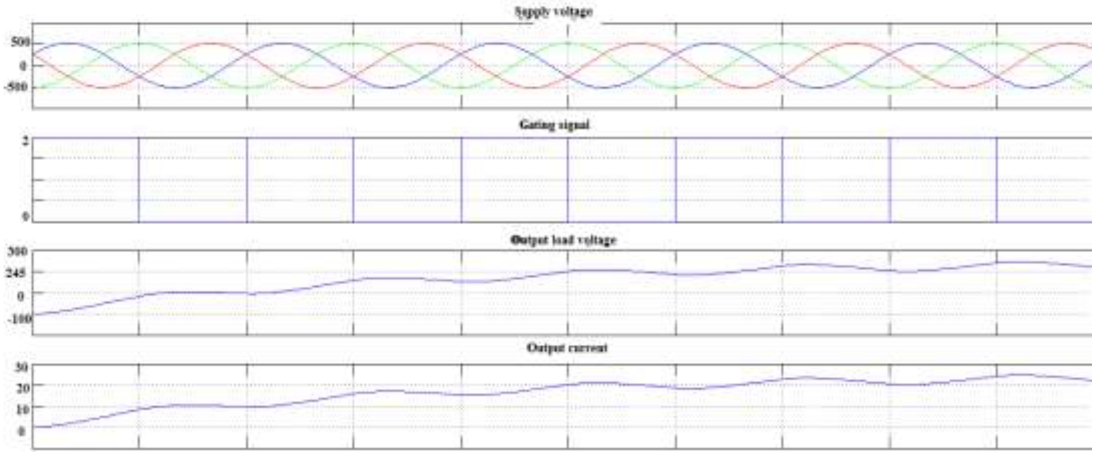

Fig 11: Output waveform of the wind energy conversion system.

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4.3. Fuel Cell

The fuel cell consists of the fuel stack connected to the DC-DC converter boost converter. The output watts produced in the fuel cell power generation is 4.6 kW. Fig. 12 and 13 show the circuit diagram and the waveform of the fuel cell power generation.

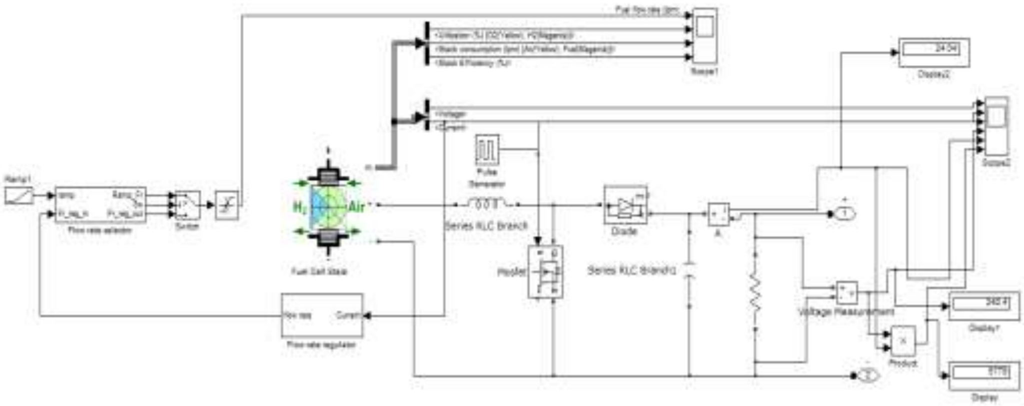

Fig 12: Circuit diagram of the fuel cell power generations.

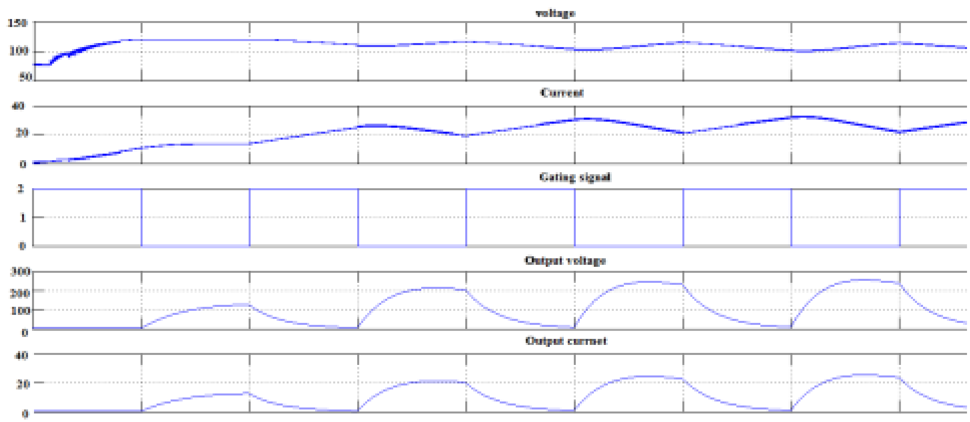

Fig 13 Output Waveforms of fuel cell power generation.

4.4. Integrated Power Sources

The integrated power system composed of the power sources such as the PV, Wind Turbine, and Fuel Cell. Fig.14 and 15 show the circuit diagram and output waveform of the integrated hybrid power system. The output voltage produced by this hybrid system is 240 V, and the current produced by this power system is 24 A.

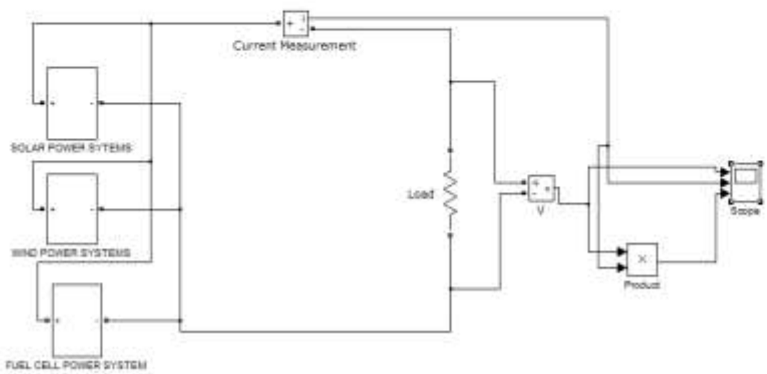

Fig 14: Simulation diagram of integrated power system

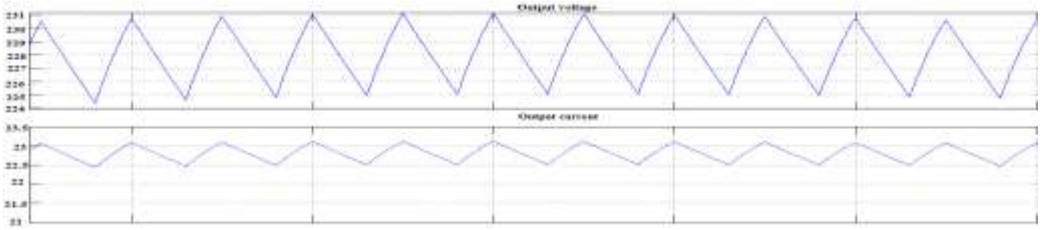

Fig 15: Output waveform of integrated power system

5. HARDWARE PROTOTYPE IMPLEMENTATION

The Hardware prototype of this system consists of power sources, battery and EB systems. The hardware prototype of this system was implemented for only 12 volt applications. The Energy Management incorporates the fuzzy logic control that was implemented in the FPGA platform.

5.1. Implementation of PV systems

The Maximum Power Point Tracking (MPPT) was achieved by using the switched mode converters such as the buck-boost converters. The fig. 16 and 17 show the hardware of the PV system with MPPT and without MPPT.

Fig 16: PV system without MPPT

Fig 17: PV system with MPPT

5.1.1. MPPT response of the PV System

The MPPT response of the PV system is obtained by the Xilinx programming interfaced with the MATLAB software which is shown in fig.18.

Fig 18: MPPT response of the PV system

5.2. Implementation of EB System

The EB system connected to the load with battery as its storage unit is shown in fig.19.

Fig 19: Implementation of EB system

5.3 Hardware Specifications

The hardware specifications are tabulated as follows in Table.2

Table 2. Hardware specifications

COMPONENTS	SPECIFICATION
Solar panel	12V 20W DC
Solar charge Controller	12V 6 AMPS
Battery	12v 7.2AH
LED kit(load)	12V, 10W, cool white
Regulated Power Supply (RPS)	10-30 volts
MOSFET	Irf640
ADC	0808
FPGA	Spartan 3E

6. CONCLUSION

In this system, the Energy Management System (EMS) achieves the optimization and distributed energy distribution in the microgrid systems. The EMS using the fuzzy control was implemented using the Field Programming Gate Array (FPGA). The simulation of the Energy Management algorithm, hybrid energy generation system and the integrated system are developed and simulated using the MATLAB simulink software. In future this system will be implemented using the Artificial Neural Networks (ANN) techniques. The applications of the system are residential application, industrial application, and vehicular application (Hybrid Electrical Vehicles).

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