MODEL-BASED DESIGN OF DISTRIBUTED GRID INTEGRATION OF PHOTOVOLTAIC POWER SYSTEM WITH INTELLIGENT BASED ENERGY MANAGEMENT SYSTEM

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Abstract: In the present day scenario, power demand has been posing a great challenge due to ever increasing power demand as a result of population growth, new industry development, etc.; rapidly depleting fossil fuels makes us to switch to the other power source as the fossil fuels impacts environment in many aspects. Hence the need of the hour is to concentrate on alternate energy source which must be environment friendly as well. An analysis of photovoltaic cell operation under various weather conditions was performed and based on that, MPPT controller was developed exclusively using a FLC (Fuzzy logic controller). The primary goal of this research work is to propose intelligent control-based energy management system for microgrid integration of photovoltaic power scheme with the energy storage device. The intelligent controller operates the bidirectional converter for battery charging and discharging depended on power demand. The proposed structure has been modeled in the MATLAB environment and the system performance was analyzed accordingly. Finally, the simulation results were evaluated and compared with IEEE 1547 standard for evaluating the efficiency of the anticipated system.

Key Words: Solar PV, Fuzzy logic, MPPT, Energy management system, MATLAB

1. Introduction

Power generation using non-conventional energy ends up in the exhaustion of its reserves and escalates the release of greenhouse gases, in such a way spoiling the atmosphere results in global environmental change. Included with these frightful outcomes, it is essential to consider the improvement of alternative energy called renewable energy sources. Sun powered vitality is conceded nowadays as a standout amongst the most accommodating origin of sustainable power source, because of its relatively less impure and preservation, boundless source, free and plentiful, looks horribly encouraging, accessible in every nation and every day.

The drawback of the sunlight based vitality is that the sun does not sparkle 24h daily, when the sun goes down or is vigorously shaded, sun powered PV boards quit delivering power. Also, transformation of solar energy into electrical energy is exceedingly low predominantly in low radiation zones Hadjer Bounechba [33].

The maximum power point track acts a key role in the photovoltaic power framework. PV (photovoltaic) power generation changes with respect to sun light irradiance and temperature. Nowadays many researchers have been concentrating on developing distinct MPPT techniques for improving the MPP to PV system ÖzgürÇelik, Ahmet Teke [22]. There are two noteworthy arrangements are existing such as indirect and direct MPPT controller. The indirect MPPT techniques are used for offline analysis of PV system performance, although direct MPPT techniques have been used to determine PV voltage and current during online condition. The present trend in the automobile industry is that electrically powered vehicles are encouraged. The electrically powered vehicles or the electric vehicles (EV) offer many distinct advantages over the internal combustion engine based vehicles, which depend on the fossil fuels. The question of availability of the fast depleting fossil fuel reserve and the effects and influence of burning them, in vehicles, towards the environment and the concern for climate change are all the discouraging factors that lead to the development of technologies for generation as well as utilization of electrical energy in vital domestic and industrial applications.

In this paper, the direct method has been expanded by using fuzzy logic controller to trace the maximum power of PV system. This method is very simple then no numerical model is required for planning the controller. Distributed generation will prompt various sources which can have the capacity to make sense of the variety in the generation of power across the network. Due to the deficiency of (or) the over improvement of sustainable power source for the duration of the day, this power source can be able to control battery electric vehicles.

These battery electrical vehicles would require achieving longer distances Arash Anzalchi [21] and accordingly requiring all the more charging sites along the path. Expanding the power change productivity is one among the inventive investigates around the world. This target can be proficient by decreasing the amount of material which is required for each cell. Another approach can be executing more extensive range to create power out of the sun. Silicon PV sheets have effectiveness rate of around 20%, Researchers prevailing in each part of creating power in each perceptible and near infrared areas of the sunlight based exhibit range. To accomplish the goal of an even more extensive scale selection of PV systems and furthermore to extend the potential advantages, a smoother progress should be started by grid system administrators and the PV generators by means of amending the integration guidelines and creating propelled control procedures respectively. Regardless, most of the currently active grid standards/codes appear to be a great extent to require the grid-connected PV inverters to stop empowering once a grid unsettling is validated Y.Yang [9] which is against energy changeover. In addition, particular auxiliary services by PV systems have not yet been evidently characterized. To make the most of solar PV energy in a cost-effective way, a typical control procedure must be uncomplicated, however adaptable for future progressed PV inverters.

Fuzzy logic manages reality and it's a type of few esteemed rationale. It supervises with way of thinking that is fairly accurate and also having linguistic values instead of crisp values. Fuzzy logic deal with the idea of truth value that lies between entirely true and completely false (0-1) Z. Cabrane [1].Fuzzy set theory used the concept of fuzzy set membership whereas probability theory uses the idea of subjective probability. L. Suganthi [11]. That is to mention, MPPT control can be implemented by sorting out the direct relationship between weather parameters and control signal that avoids the issues of delay and inaccuracy of detection circuits. In this paper, the MPPT algorithm Neerparaj Rai, Bijay Rai [3] has been tested with numerical simulation in the MATLAB environment and analysis the PV performance at constant and variable irradiance as well as temperature. In section 2 PV mathematical models were presented and simulated in MATLAB.

The fuzzy controller based MPPT techniques has been developed and analysed under various weather conditions in part III. The energy management system has been reeling under severe crisis as a crucial part of grid integration of renewable energy system, the energy management system has been developed and analysed in section 4. The proposed objective model has been formulated in section 5 and evaluated the simulation results. The conclusion of proposed research work is presented in section 6.

2. System configuration

PV boards are made up by an enormous range of basic cells. The equation of the PV cell requires the connection between the output voltage, (V_{PV}), and the output current, (I_{PV}).

The following mathematical models of electrical characteristics are considered to design 20 kW photovoltaic module and simulated using MATLAB environment. The schematic diagram of PV cell is shown in Fig 1 [36].

2.1 Photovoltaic equivalent circuit model

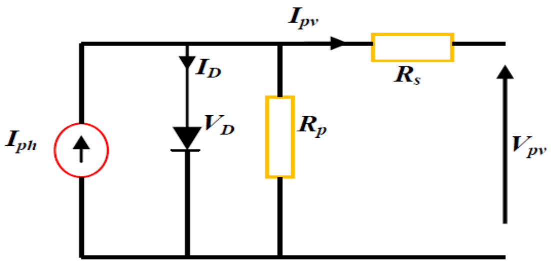

Fig.1. Schematic diagram of solar cell

Table 1 Solar Panel - Technical Specification

Electrical parameters at NOCT	
Output Power P_{max} (W)	Above 220.0
Voltage at P_{max} (V)	33.98 (Minimum)
Current at P_{max} (A)	6.48 (Maximum)
Open-circuit voltage V_{oc} (V)	42.5
Short-circuit current I_{sc} (A)	6.94
Electrical parameters at standard test conditions (STC) Irradiance of 1000W/m2, spectrum AM of 1.5 and cell temperature of 25°C Best in class AAA solar simulator (IEC 60904-9) used, power measurement tolerance ±3%	

From the schematic circuit diagram is obvious that the current delivered by the solar cell is equivalent to that created by current source. [9]:

$$I = I_{ph} - I_d$$

$$I_d = I_o[\exp(\frac{V}{A.N_s.V_T}) - 1]$$

$$V_T = k.T_c / q$$

The open-circuit voltage, V_{OC}, is the extreme voltage offered from a PV cell, and this happens at zero current.

$$V = \frac{NKT}{Q} in \frac{I_L - I_o}{I_O} + 1 \text{ Volt}$$

$$I_L = \frac{G}{G_{ref}} * (I_{Lref} + \alpha_{Isc}(T_c - T_{cref})) \qquad (5)$$

$$I_O = I_{or} * (\frac{T}{T_{ref}})^3 \exp^{((\frac{QE_g}{KN})*(\frac{1}{T_r}-\frac{1}{T}))} \quad (6)$$

$$I_{orn} = \frac{I_{sc}}{\exp^{(\frac{V_{ocn}}{NV_{tn}})}} \quad (7)$$

Ish= I_L. It is the extreme value of the current produced by a PV cell. It is formed by the short circuit situations: $V = 0$.

$$I_{sh} = I_L - I_O((\exp^{(Q\frac{V-IR_s}{NKT})} - 1) \quad (8)$$

Irradiation: G=radiation W/m^{2}.

3.Maximum Power Point Tracking (MPPT) for Photovoltaic System

The renewable resource plays an ever increasing role to fulfil consumer power demand due to their abundance in availability and a less impact to the environment.

The main obstacle in PV energy expansion is the investment cost of the PV power system and its implementation. PV energy generation is not consistent throughout the day due to vagaries of weather. The competency of power production is very low (the efficiency range is only 9-17% in low irradiation regions).

Thus, MPPT technology leads a predominant role in PV power propagation for optimal power generation at various weather conditions. Hence we have discussed fuzzy logic controller based MPPT mechanism for 20 kW PV system [22, 33].

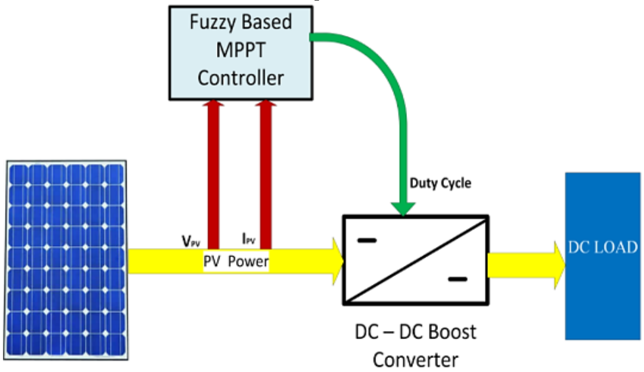

Fig.2. PV - MPPT Block diagram

The proposed fuzzy-based MPPT block diagram is depicted as exposed in fig 2. Fig 4 reveals the structure of the fuzzy controller that has two inputs and one output. The fuzzy membership function has been exclusively designed by the trapezoidal method for both input and output membership values. The defuzzification of proposed fuzzy controller is to convert the classical output to the control objective by using the centre of gravity method.

The MPPT fuzzy controller has two inputs such as PV voltage and PV current proven in fig 5 respectively. The MPPT fuzzy controller generates duty cycle based on the input of the fuzzy controller and fed into boost converter. Finally, the fuzzy inference rulings are designed based on changes of PV Voltage and current under various weather conditions as shown in fig 5 then the surface view of fuzzy rules are presented in fig 6. The above designed fuzzy controller has been implemented in MATLAB simulation of 20 kW PV system and its boost converter is shown in fig 9.

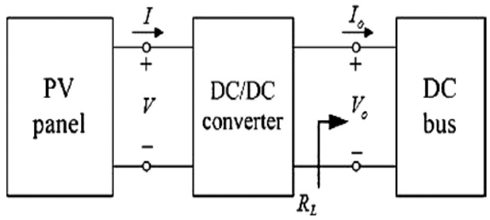

Fig.3. Structure of PV system with DC Bus

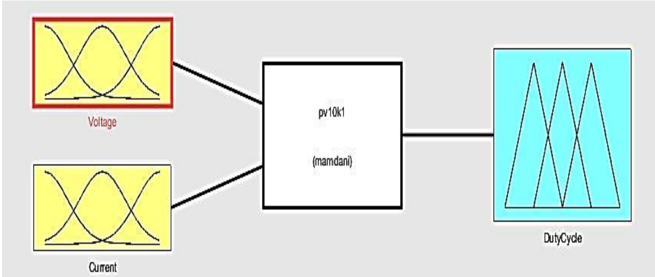

Fig.4. Fuzzy Controller configuration

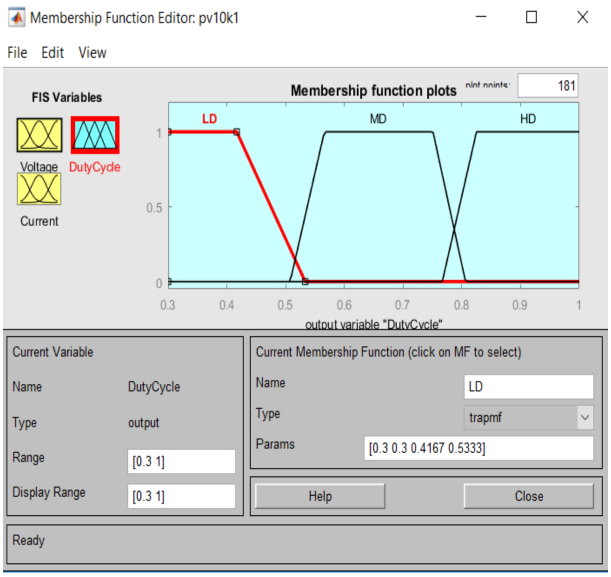

Fig.5. Fuzzy output membership function for MPPT of PV system

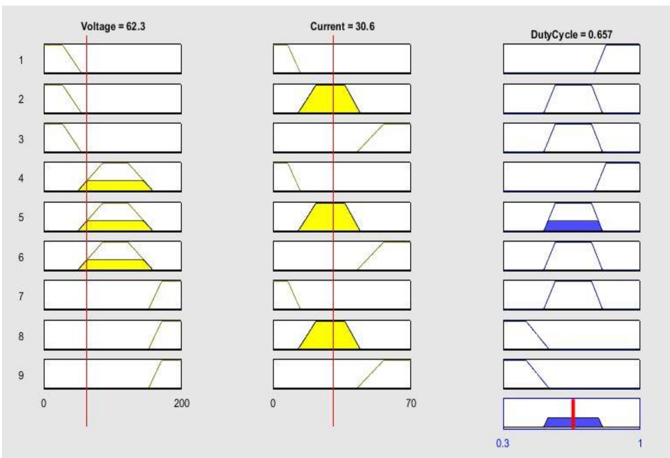

Fig.6. Fuzzy Rules for PV system

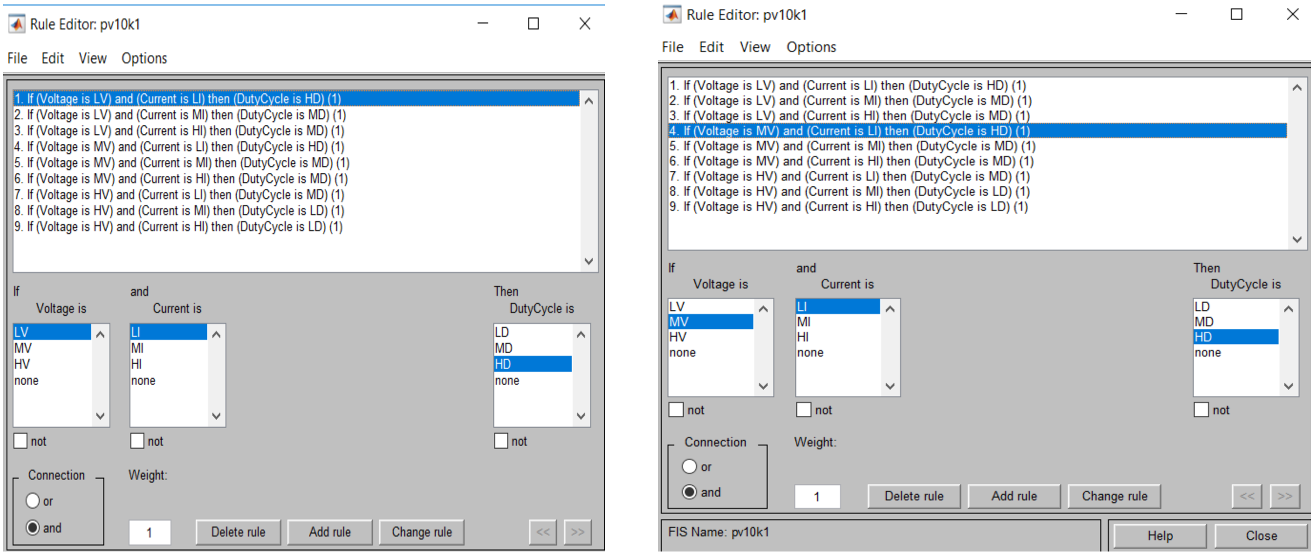

Fig.7. Fuzzy rule editor

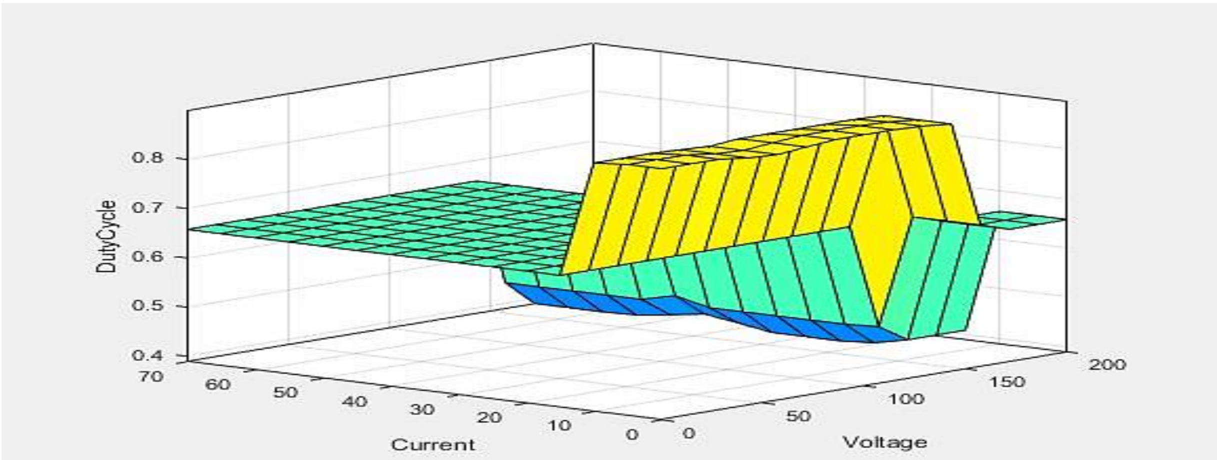

Fig.8. Fuzzy surface viewer

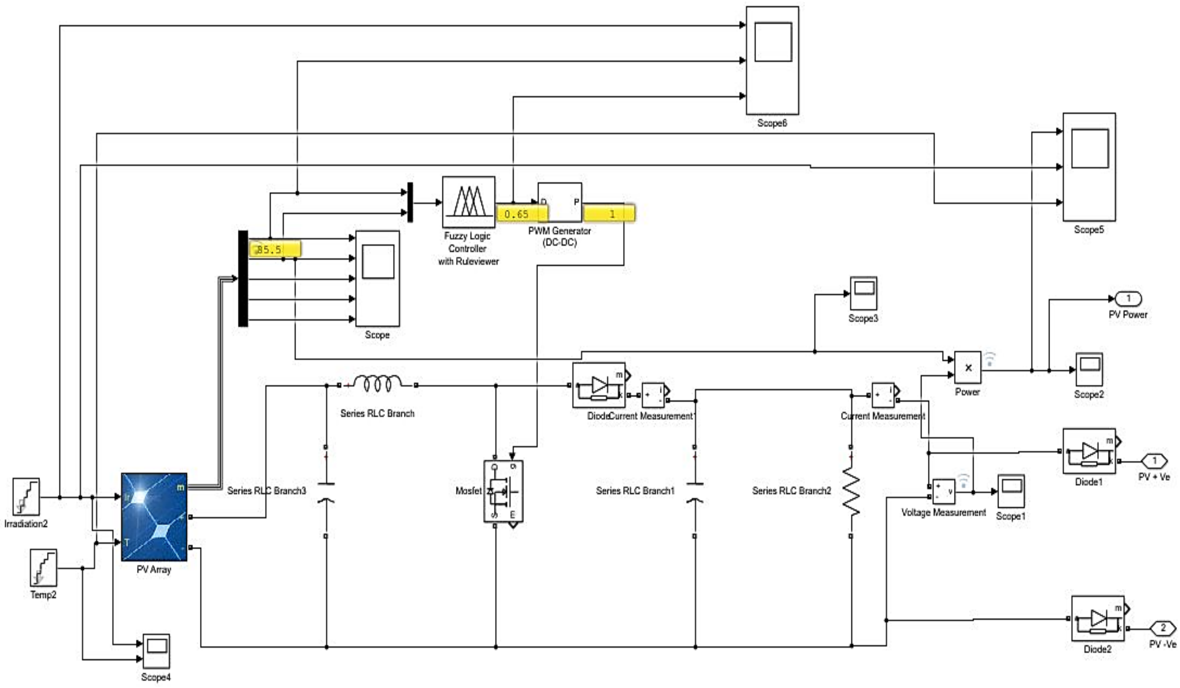

Fig.9. Fuzzy Simulation model for MPPT of PV system

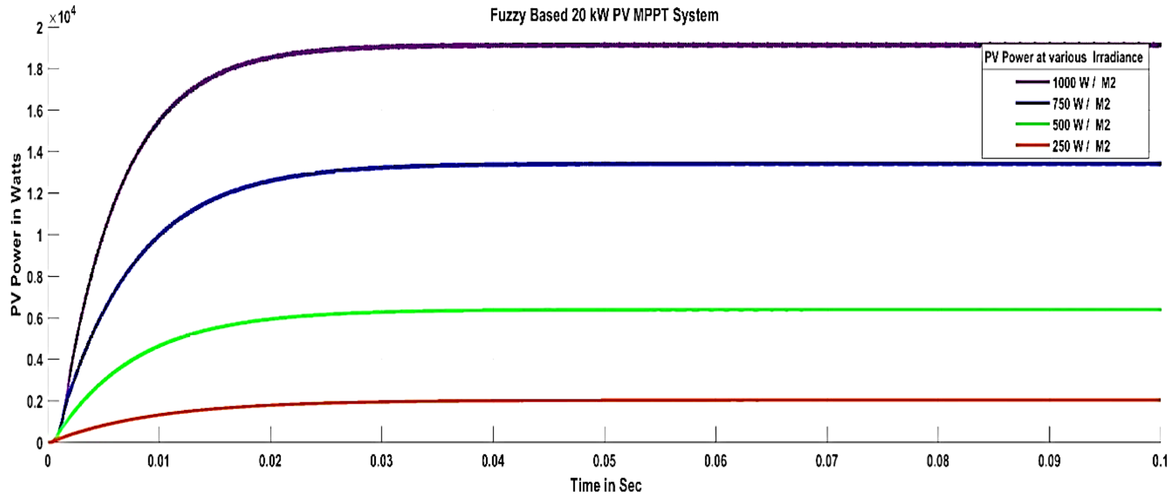

Fig.10.Fuzzy based 20 kW PV system output Power at various irradiance

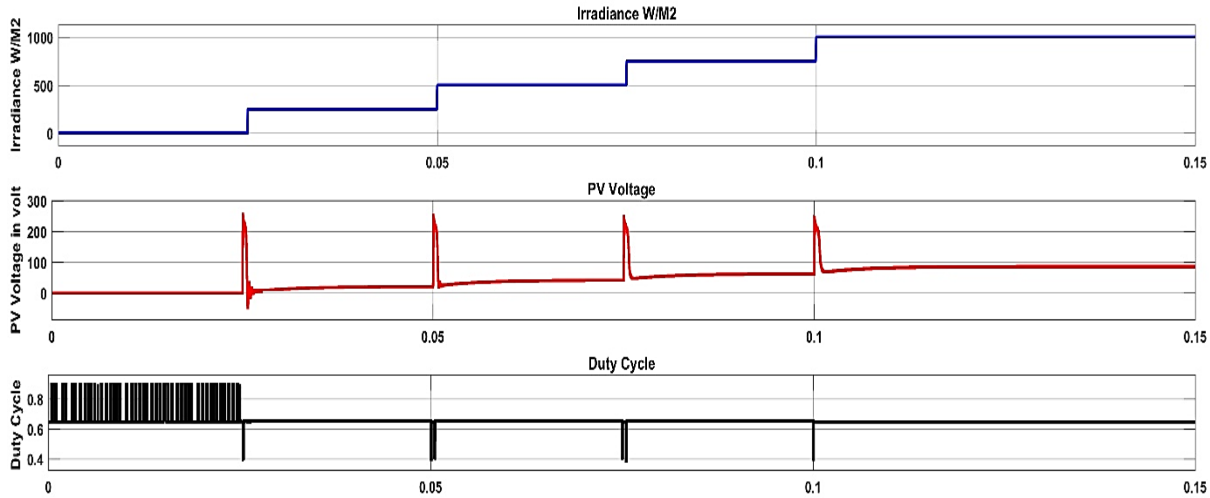

Fig.11. Duty cycle generation at various weather conditions

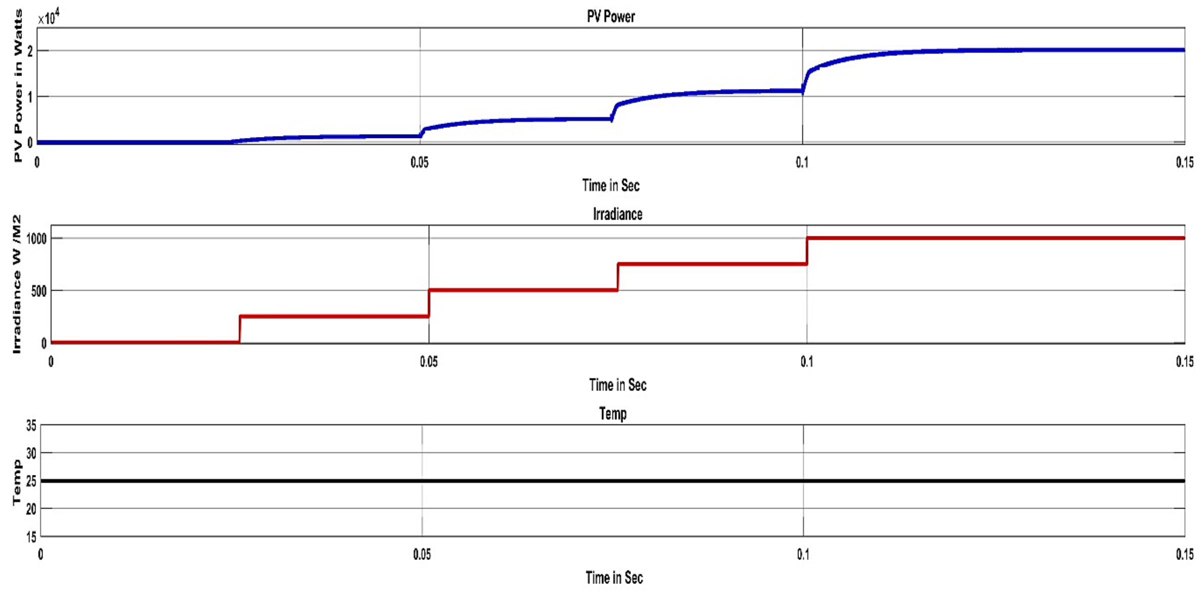

Fig.12.Analysis the PV System performance at constant temperature

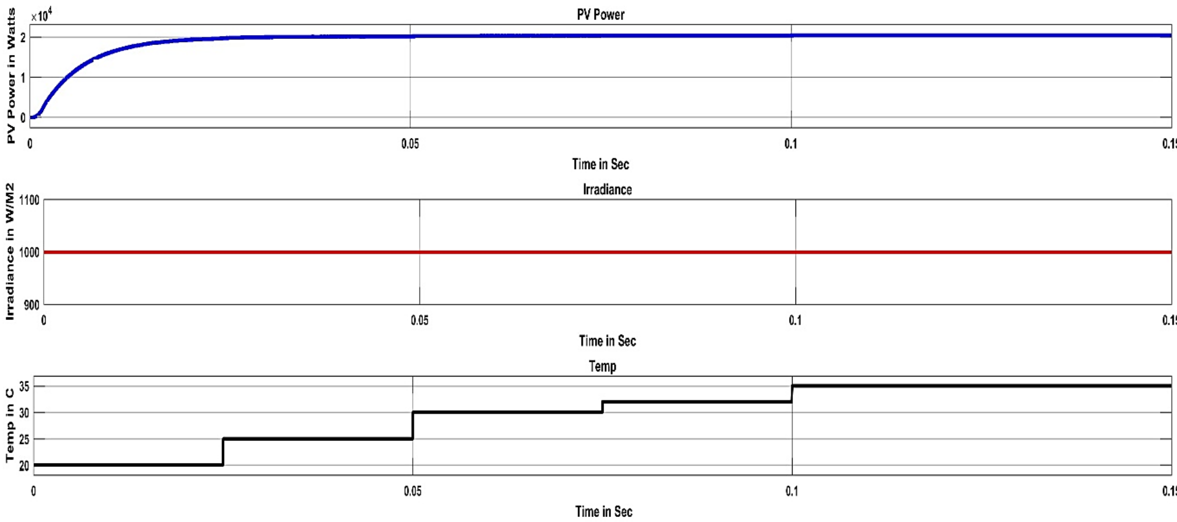

Fig.13.Analysis the PV System performance at constant irradiance

4.MPPT Results Discussion and Battery Management System

The proposed fuzzy logic controller has been tested and simulated in the MATLAB background and analysed the fuzzy controller performance under various weather conditions such as variable irradiance (1000 W /M^2, 750 W /M^2 , 500 W /M^2 and 250 W /M^2) and temperature (20 °C ,25 °C, 30 °C,32 °C and 35 °C). The simulated results according to the above conditions were discussed. Figure 10 represents PV boost converter and its output power at various irradiance. The fuzzy controller output signal of converter duty cycle is at various weather conditions. The proposed MPPT system has been in two different cases like Case 1: constant temperature and variable irradiance shown in fig 12. Case 2: constant irradiance and variable temperature in fig 13. In this paper, we have designed and modelled energy management system for grid integration of PV power system. Also the energy management system has been playing an ever important role in battery operation, such as charging and discharging. Two conditions were taken in to account for battery operation. Battery will get charged when Photovoltaic power is superior to power demand and battery will release when Photovoltaic power is lesser than power demand. The above objective is achieved by using fuzzy controller-based energy management system and its controller structure is presented in fig 14.

The proposed controller has one input and two outputs. The input membership function modelled by trapezoidal method (negative error, Zero Error, and Positive Error) and the output membership function by trapezoidal method (ON and OFF) respectively. The fuzzy controller outputs will operate the bidirectional converter switches like Q1 and Q2. The fuzzy inference rules are formed with respective input values. The case 1 concentrates on battery charging during PV power greater than power and the case 2 discussed about the battery discharging process during PV power is lesser than power demand.

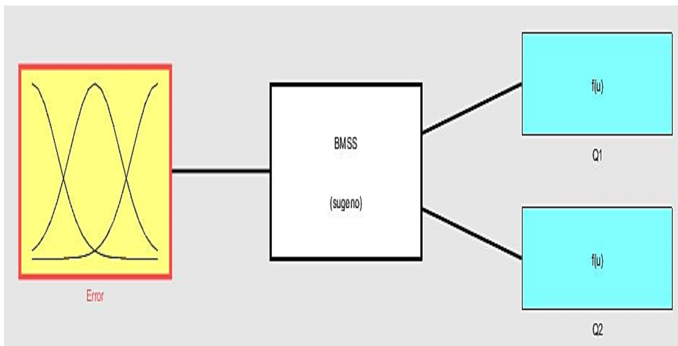

Fig.14. Fuzzy Controller structure for battery management system

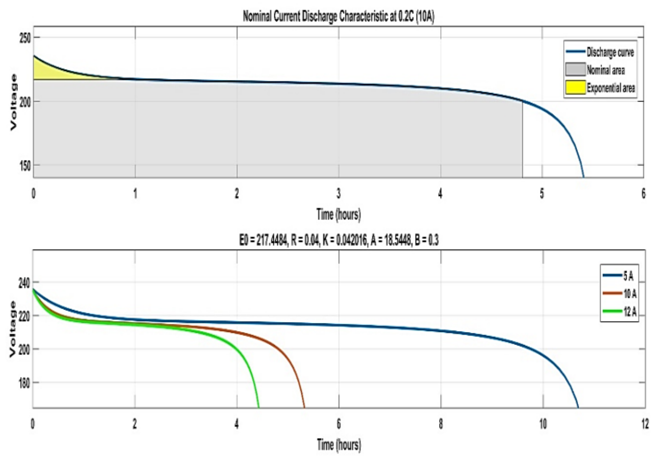

Fig.15.Battery Characteristics

5.Experimenal Set up of BMS

The experimental setup for the BMS comprises the greater part of the fundamental materials expected to make an essential BMS framework, including: a microcontroller, switches, circuit isolation devices, and measuring devices. The microcontroller picked was an Arduino for its simplicity of implantation and accessibility as the focus is the logic control system, not the hardware choices. The switches are built from two IRF530 MOSFETs each and arranged as a bidirectional switch for a sum of 16 MOSFETs. The circuit isolation devices utilized as a part of this circuit are generic optocouplers which are fed by a 12V to 15V step-up circuit to allow enough voltage to turn on the MOSFETs completely.

The measuring device, particularly the ADC is built-in to the Arduino through the analog pins. In any case, for current measurements a differential operational amplifier was used to amplify the voltage across a 15mΩ sense resistor and then provided to the Arduino to calculate the estimated aging Cheng, Ming-Wang [35] of the battery cells.

The setup of the physical BMS can be found in Figure 16. On the left there are the Sony VTC4-18650s in a battery case, associated with a terminal hub which at that point interfaces with the corresponding bidirectional MOSFET switches on the top-most breadboard.

The hardware underneath the MOSFETs is a part of the isolator circuits, which isolates the microcontrollers from the higher voltage levels of 15V, as appeared on the left display. The 15V is given by a step- up converter, which is provided by a 12V divider outlet – rather than the divider outlet plug, the framework could get its energy from the batteries, on the right-hand side the switched capacitor could be seen, with the ADC setup directly to the single switched capacitors left. The second blue display screen shows the aggregate run time for the framework, regardless of whether the framework is adjusted the voltages of every cell. The balancing process can likewise be delayed by essentially tossing the physical switch in the bottom left-hand corner. To wrap things up, in the base center is an Arduino Mega that contains the State flow code for the desired battery management system.

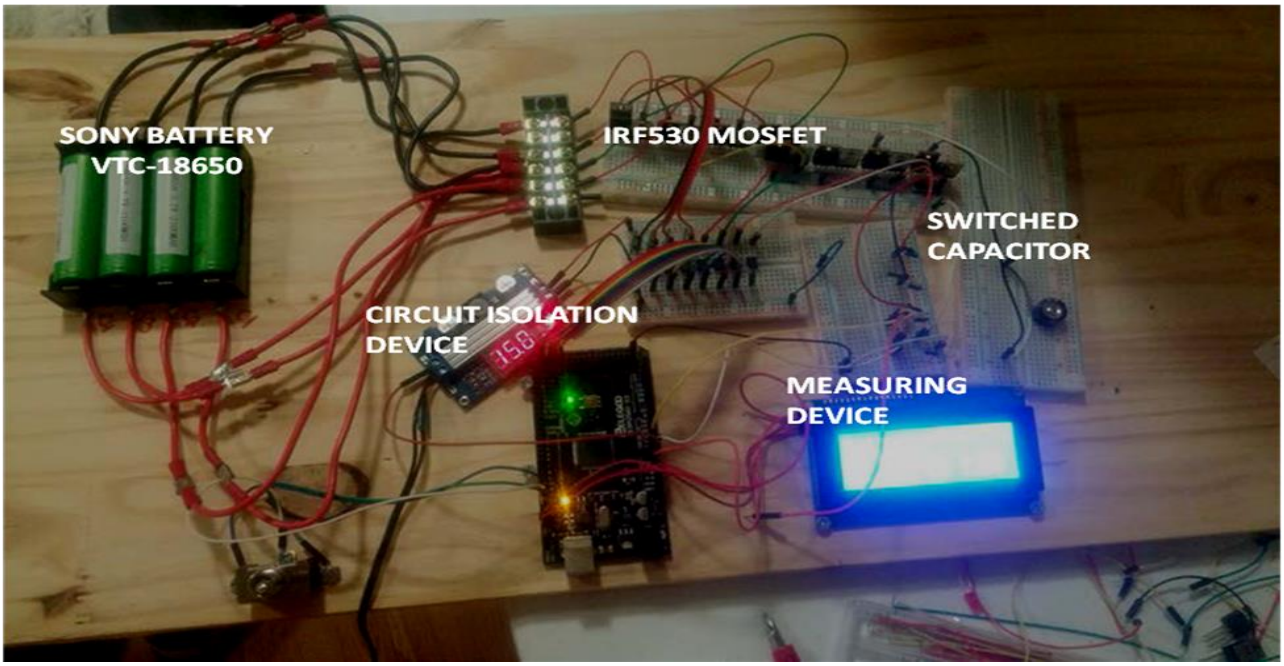

Fig.16. Experimental BMS

6.Grid Integration of PV Power System

The proposed 20 kW PV power system and fuzzy based energy management battery storage arrangement have been discussed. The above model was simulated in the MATLAB environment and presented in fig 17. The voltage source converter represents the crucial role for grid integration of PV system; since the PV cells generate only DC power, an inverter was introduced to convert DC to AC. The grid integrated inverter is controlled by Phase lock loop, voltage regulator, and finally based on the regulator output the PWM generator provides operating signals to the inverter for synchronizing process and the above model tested and simulated with various power demand conditions and observed the power waveform from PV, Grid, Load Demand and Battery as shown in fig 18. Conclusively, the point of common coupling (PCC) voltage and current waveforms are measured as shown in fig 19. The PCC voltage and current THD values are measured as shown in fig 20 & fig 21 then evaluated with IEEE 1547 to standardize the power quality.

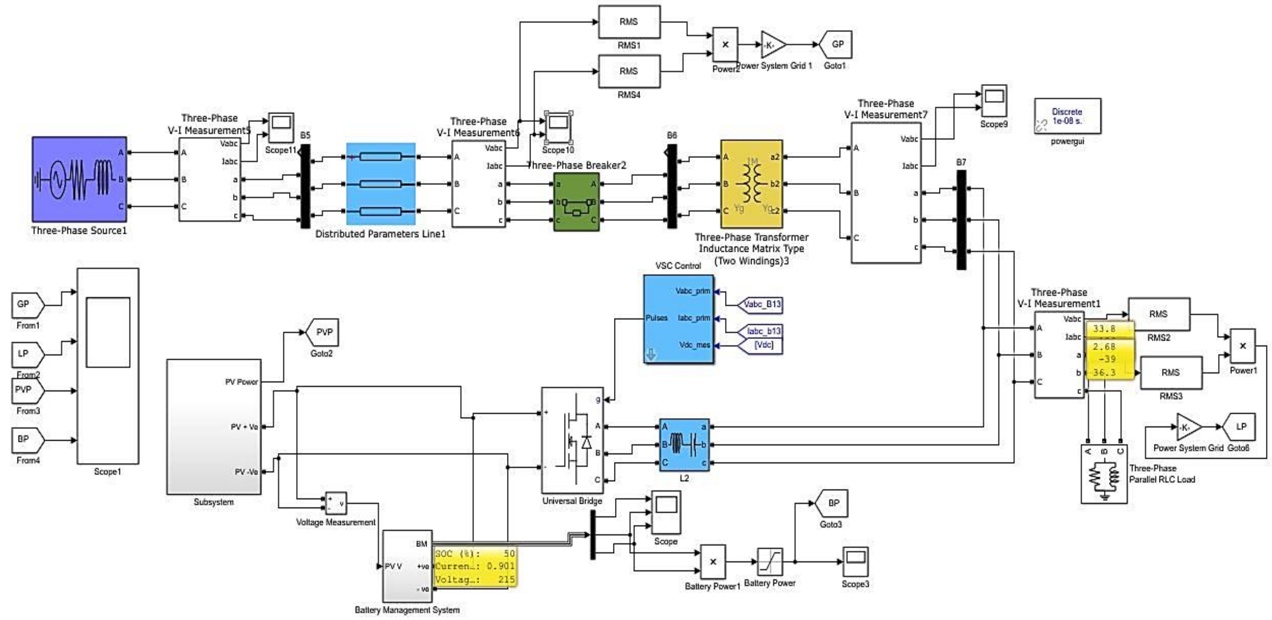

Fig.17.Proposed Simulation model

Table 2 Interconnection system default response abnormal voltages [36]

Default settings		
Voltage range (% of Base voltage)	Clearing time (s)	Clearing time: adjustable up to and including of (s)
V<45	0.16	0.16
45≤V<60	1	11
60≤V<88	2	21
110<V<120	1	13
V≥120	0.16	0.16
[a]Under mutual agreement between EPS and DR operators, other static or dynamic voltages, clearing time trip settings shall be permitted. **[b]Base voltages are nominal system voltages stated in ANSI C84.1-2011. Table 2**		

A key thought, and challenge, in setting PQ (Power quality) requirements for DER (Distributed energy resources) is performance dependence on the frequency response and relative capacity at the PCC. This can be significantly true for voltage-related limits like RVC and flicker counting on the relative capacity of the PCC, and for production of harmonic currents reckoning on the harmonic electric resistance at the PCC.

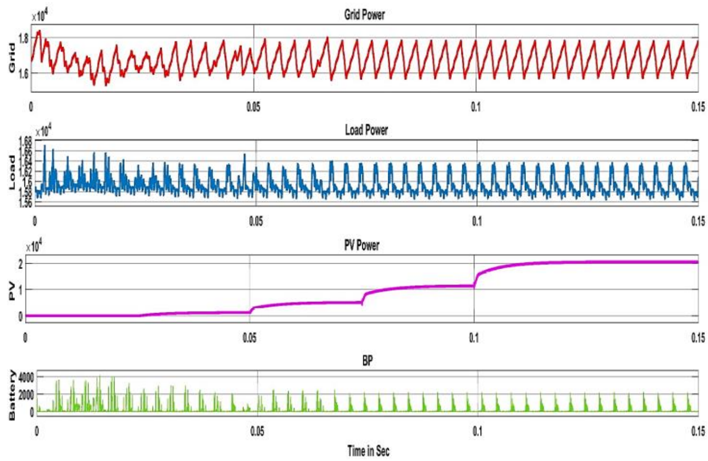

Fig.18.Various Power Generation Waveform

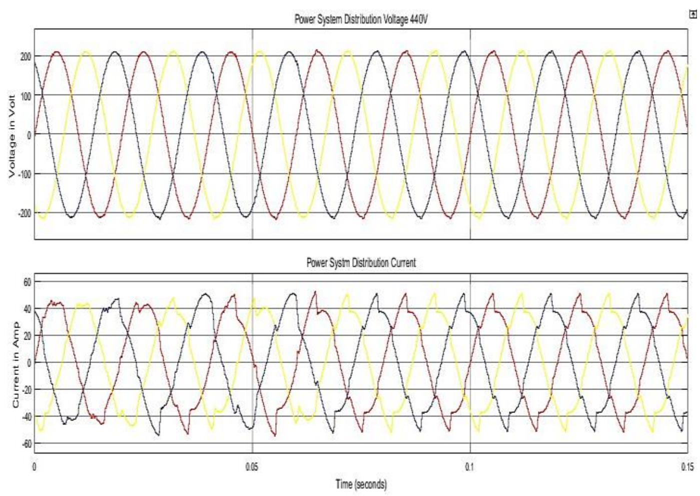

Fig.19.Distributed Grid voltage and Current after integration of PV system

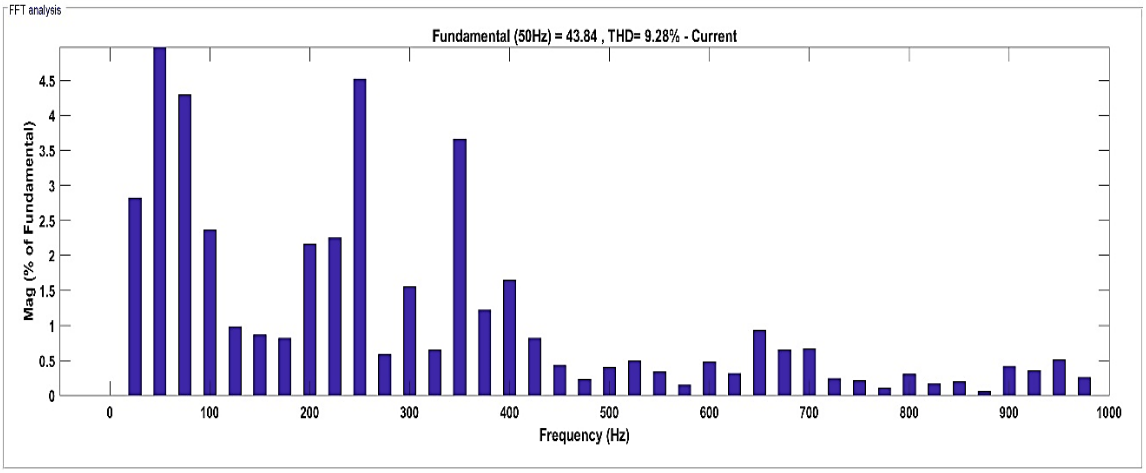

Fig.20.Distributed Grid Current THD

Table 3 Interconnection system default response abnormal Frequencies [36]

	Default settings		**Range of adjustability**	
Function	Frequency (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s): adjustable up to and including of (s)
UF1	<57	0.16	56-60	10
UF2	<59.5	2	56-60	300
OF1	>60.5	2	60-64	300
OF2	>62	0.16	60-64	10

Short-term overvoltage associated with the DER typically depends on PCC loading and grounding details. There square measure potential interactions between the DER and also the grid that will not be simple to predict during a study or take away from the certification method. Most of the discussions during this annex address these interactions relative to setting power quality limits.

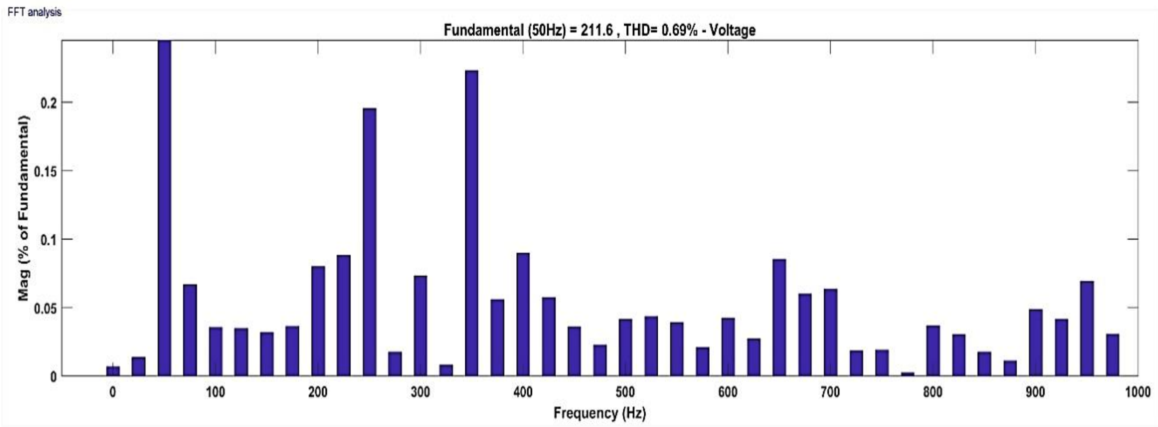

Fig.21.Distributed Grid Voltage THD

Conclusion

This paper dealt with grid integration of PV power system with intelligent controller-based energy management to improvise the power quality. Therefore the objectives were achieved by modelling a mathematical design of PV system and simulated PV system at various weather conditions with fuzzy based MPPT system. The fuzzy based energy management system was exclusively developed and tested under various power demands and the operation was analyzed in terms of battery charging and discharging. Finally, the proposed objective of grid integration of PV system was simulated in MATLAB and was analyzed under various operating conditions. The result of the simulation was compared with 1547 standard and justified the enhancement of efficiency of the proposed system.

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