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Battery Modelling For A Photovoltaic System With Battery Management System Using Fuzzy Logic Controller

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Abstract*: *The need for energy is increasing day by day. Energy production from conventional fuels reduces due to the lack of availability in fuel. Using fossil fuel and its gases also reduced due to the high occurrence of pollution. This point increased the demand for harvesting energy from non-conventional sources of energy such as solar, wind, etc. The abundant source of solar energy can be harvested to satisfy the growing energy demand on the various applications requirement. This paper focus on how solar energy is been harvested and stored for the continuous supply of energy to the required load demand. Mathematical modeling and design of a stand-alone PV system with maximum power point tracking (MPPT), boost converter and battery storage system with BMS is developed. BMS is a system which manages the battery to operate in its safe limits by continuous measuring of state of charge and the state of health. The fuzzy logic controller is included in the MATLAB Simulation environment for optimistic switching of charging and discharging switches.

Index Terms: PV system designing, battery modeling, maximum power point tracking, fuzzy logic controller, state of charge(SOC)

I. INTRODUCTION

The continuous draining in the level ofoil production due to the lack of availability and changes occurred in the climateprovides awareness about the usage of the nonconventional source of energy. Nonconventional sources of energy are solar, wind, hydro etc.. The day by dayincreaseinthe industry by implementing most modern research methods in the field of photovoltaic applications is due to this trend of energy production.The maximum efficiency obtained from any system depends on the energy management system used by it [1]. The most challenging task in the photovoltaic system is the absence ofsolar energy threw out the day. The maximum solar radiation falling on to the surface will be changing based on the latitude and longitude of a particular place [9]. The average total available sunshine hours in a particular location will be a maximum of 4 Hrs to 5Hrs in India. Thus the need foran energy storage system is much essential in the photovoltaic system for the supply of electrical energy continuously.

Batteries are commonly used as an electrical energy storage system in most of the photovoltaic applications. Different types of batteries with different ratings are used based on the need for the applications. The overall capacity of the battery will decay due to different properties such as outgassing, corrosion, decomposition of the materials, corrosion etc..[2]. For avoiding interruption in the supplied power fromthebattery a battery management system is much essential. The weakening of battery occurs when its workbeyond the specific safe operating conditions. The maximum ageand safe operation for a battery can be easily obtained by the constant monitoring of current which is delivered during the charging and discharging of the battery in standard temperature conditions. The state of charge and state of health (SoC & SoH) are the state of the battery which can be used for the estimation of the lifetime of the battery. The present charge level of a battery is known as the state of charge (SoC) which will be measured typically based on at a particular temperaturemeasured the current which is going in and out from the battery.

II. PROPOSED SYSTEM

The system is designed for optimal switching of charging and discharging switches of a battery and to protect the battery from over and under charging. In this paper, the system is designed and modeled for connecting DC loads applications. Ac loads can also be connected by using a DC to AC inverter which is considered as one of the future work of this paper. The renewable energy source (Solar panel) is used for the power generation. Maximum power from the solar panel is obtained by using a standard P&O MPP algorithm [10&11]. A normal boost converter is used to step up the DC voltage which is obtained from the PV panel[12,13]. In order to optimize the switching of charging and discharging switches (K1 & K2) of the charge controller, a rule-based fuzzy logic controller is implemented. Over and undervoltage charging can be eliminated by using this type of charge controller.

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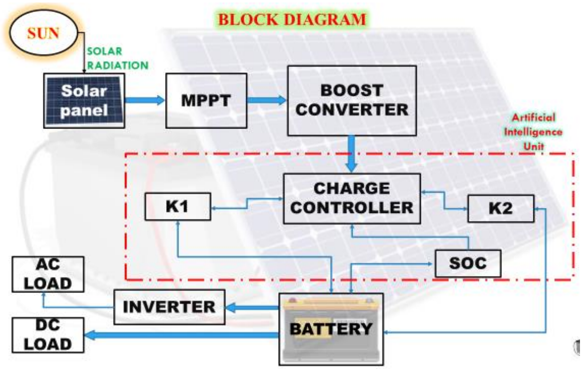

Fig :1 Block diagram

Fig 1 illustrates the block diagram of the proposed system

BATTERY MANAGEMENT SYSTEM

The common source which is used for energy storage is the battery. There are different types of batteries are available based on the requirement. The chemical reactions which performed inside the battery module will represent the overall performance of a battery. The degradation of the chemicals presented inside the bat will result in step by step decreasing charge of the battery [3].SOC (State of Charge) determines the safe charging and discharging of a battery. The charge available in a battery at a particular time is defined as the state of charge of any batteries [3] & [4]. State of charge of a battery is measured in terms of current,voltage, temperature, and also certain information needed in different conditions. Perfect estimation of SOC will protect the battery from damaging and will provide better lifespam.their are different methods and types for measuring the SOC of a battery. Pulse charging method is considered as the most efficient fast charging method based on [6] and [7].

The modeling of battery for this system is done based on the below block diagram in fig2. Mathematical modeling of a lead-acid battery is been done by using MATLAB simulation software. Charging and discharging modes are the two modes of operation of a battery. When the battery current (I_{bat}) shown as positive it will be in charging state, whereas when the current is in negative the battery will be in discharging state.

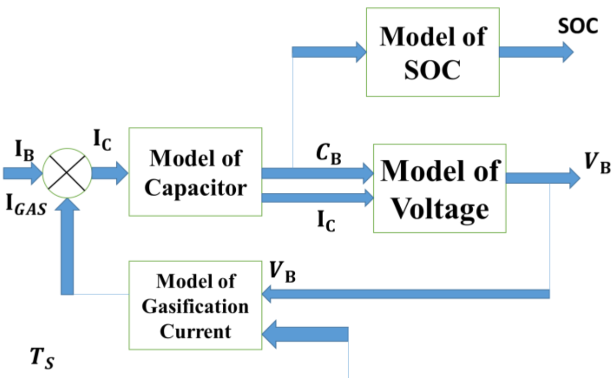

Fig: 2 block diagram of battery modeling

Following equations had chosen for the modeling of a lead-acid battery. Equation 1 does the representation of the terminal voltage of the battery.

$V_{bat} = V_I + I_{bat}R_I$ (1)

The below Table 1 and Table 2 illustrates the mathematical equation which is used to measure the voltage and resistance is both charging modes and in discharging mode.

Table 1- measurement of Voltage and resistance in the charging mode of operation

CHARGING		
I_{bat}	$+ve$	
Rich	$\left[0.758\frac{0.139}{[1.06 - SOC(t)]n_s}\right]\frac{1}{SOC_m}$	(2)
Vch	$[2 + 0.148\,soc(t)]n_s$	(3)

Table 2- measurement of Voltage and resistance in discharging mode of operation

DISCHARGING		
I_{bat}	$-ve$	
Rich	$\left[0.19 + \frac{0.1037}{[SOC(t) - 0.14]n_s}\right]\frac{1}{SOC_m}$	(4)
Vdch	$[1.926 + 0.124\,soc(t)]n_s$	(5)

Following equations where used for finding SOC at the time interval "t" (6).

$$SOC(t+dt) = soc(t)\left[1 - \frac{D\,dt}{3600}\right] + \frac{K_b\left(V_{bat}I_{bat} - R_I I_{bat}{}^2\right)dt}{3600} \quad (6)$$

In order to convert the measured SOC in W.hr from the time below equation (7) is used.

$$SOC(t) = SOC(t-1) + \frac{1}{3600}\int_{t-1}^{t}\left[\frac{K_b V_I I_{bat}}{soc_m} - SOC(t-1)D\right]dt \quad (7)$$

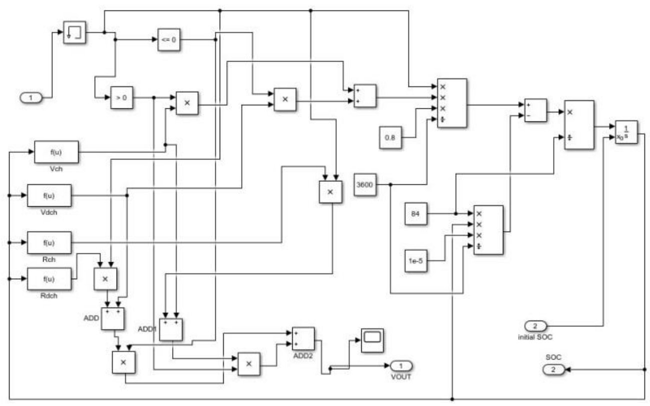

Fig 3: Mathematical modeling of a battery.

Above fig 3 shows the mathematical simulation blocks of a lead-acid battery which haddone by using MATLAB Simulink 2019 simulation software. "In1" represents the input of the battery modele, whichwill be the maximum boosted current from the solar photovoltaic panel. "VOUT" represents the battery output voltage. The initial state of charge is a constant that assigned by usthrough a constant block and the state of charge can be measured by using SOC block.

Total output battery voltage VBAT is obtained by the series connection of 35 Nos of 2V cell together. A constant value of 84 is set as the maximum state of charge (SOCm) with 1.5*10-5 as the discharge limit (D) and 0.8 as the efficiency (Kb). In this equation only one value is selected (fro R1 & V1) either the battery is in any state (discharging or charging)[5].

III. FUZZY BASED BATTERY CONTROLLER

Efficient battery management is obtained by implementing anefficient battery controller. The main principle of a battery controller is determining the charging and discharging time of a battery. How far we can able can optimize the battery management that much we will be able to increase the system efficiency. There are many methods and algorithm for the optimization of battery management system[8]. In this paper fuzzy logic controller is used for the optimizing the charging and discharging time of a battery. The below fig 4 represents the rule-based fuzzy logic controller which is developed in MatlabSimulink. K1 and K2 represent the charging and discharging switches of the battery.

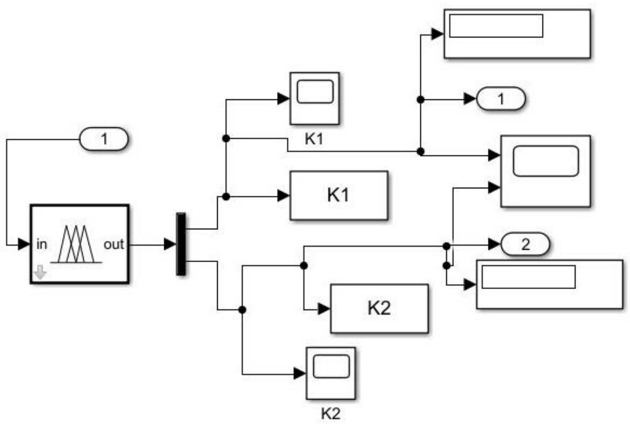

Fig 4: Implementation of a fuzzy logic controller in Matlab Simulink 2018.

Fuzzy Inference System (FIS) had created in Matlab with the following details shown in table 3.

Table 3: Creation of a fuzzy inference system

Two input variable	Voltage (VB)	
	Current	
Two output variable	K1	Charging
	K2	Discharging

The below fig 5 represents the fuzzy logic designer window of Mamdani.

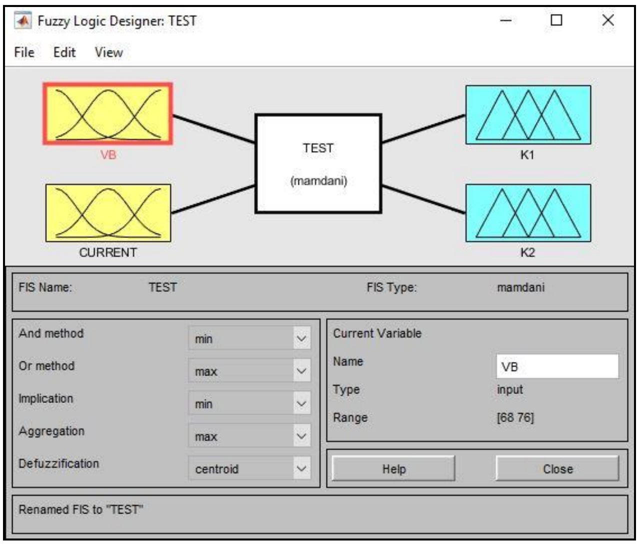

Fig5: Fuzzy logic designer window of Mamdani.

The two inputs which are used in the fuzzy logic designer is the battery voltage (VB) and the photovoltaic current (Ib). K1 and K2 represent the charging and discharging switches respectively.

IV. RESULTS AND DISCUSSION

The designed PV array in Matlab Simulink 2019 was able to generate a maximum voltage of 26.1V along with 7.65A of maximum current. The duty cycle of the boost converter was connected by using maximum power point tracking. The boost converter was able to increase the generated PV voltage from 26.1V to 42.77 V. Maximum power which was able to generate from the PV panel is around 200W.

The overall system is designed and modeled in Matlab Simulink 2018a software. The below figure 6 represents the overall simulation of the battery management system by using a fuzzy logic controller.

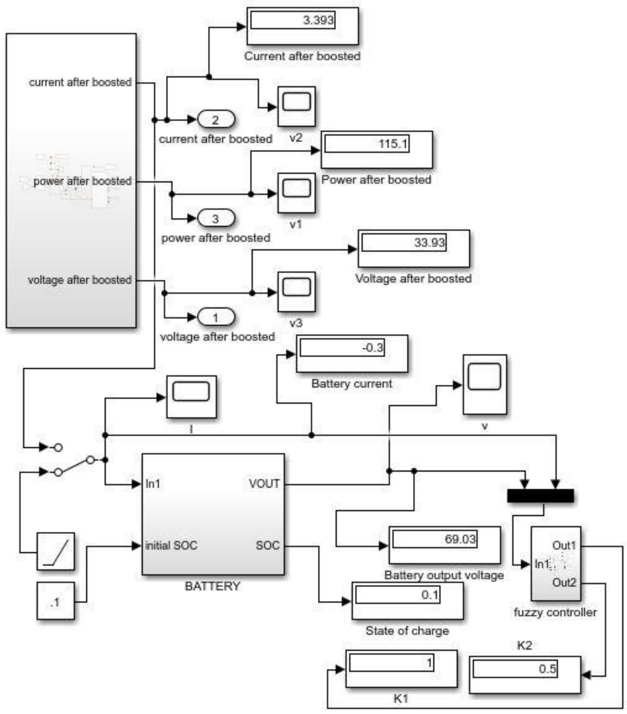

Figure 6: overall battery management system representation in MATLAB Simulink 2019.

The limits used in the Vb (battery voltage) ranges from 66 to 76 V. five membership functions are used for the most accurate selection of result such as

BUD(Battery under discharge),
BD(battery discharge),
BIC(Battery in charge),
BC(Battery charged),
BOC(Battery overcharged).

The below table 4 represents the limits used by different membership functions.

Membership function name	Min	Avg	Max
BUD	66	68	69.98

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BD	68	69.98	72
BIC	69.98	72	74.02
BC	72	74.02	76
BOC	74.02	76	77.98

Table 4: limits for different membership function in battery voltage

The below table 5 represents the variation in the solar photovoltaic current (Ip). Ip varies from -3A to +3A. The variables, which are in associated with Ip,is denoted asNC (negative change) and PC (positive change).

Membership function name	Min	Avg	Max
NC	-3	-1.5	0
PC	0	1.5	3

Table 5: limits for different membership function in the photovoltaic current.

The below table 6 and table 7 shows the ON and OFF switching limits of both charging and discharging switches (K1 and K2) respectively.

Membership function name	Min	Avg	Max
OFF	-.05	0	0.5
ON	0.5	0	1.5

Table 6: limits for different membership function in charging (K1)

Membership function name	Min	Avg	Max
OFF	-.05	0	0.5
ON	0.5	0	1.5

Table 7: limits for different membership function in discharging (K2)

The triangular membership function is used in both battery voltage (VB) and photovoltaic current (Ib).

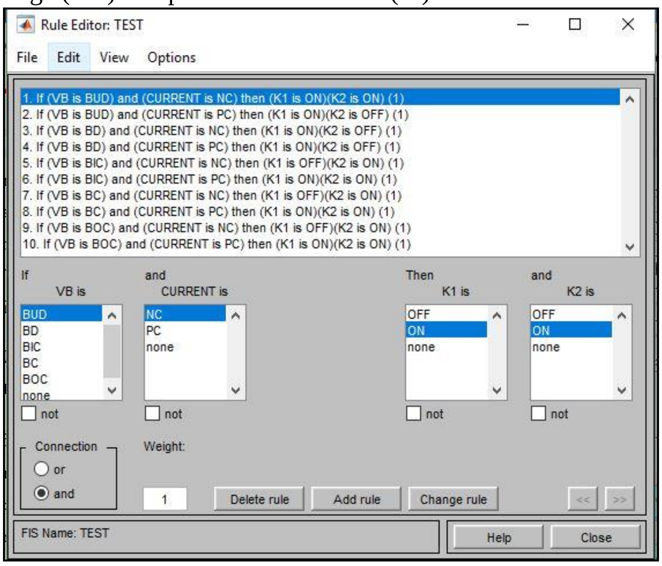

Figure 7: Rules used for the optimal switching of K1 and K2.

The above Fig 7 illustrates the different rules which is used for the optimization of switching both charging and discharging switches.

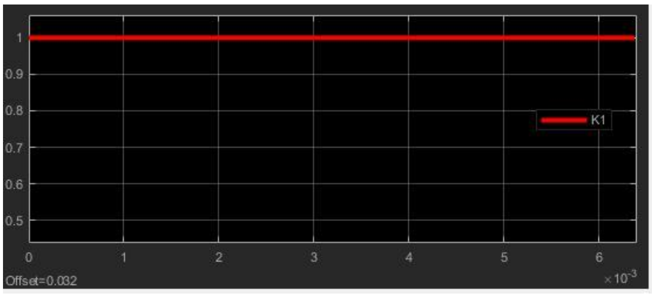

Fig 8: Operation of Switch K1

Fig 8 illustrates the operation of switch K1 which is connected between the solar panel and the battery the switch is varied from 0.5 to 1.

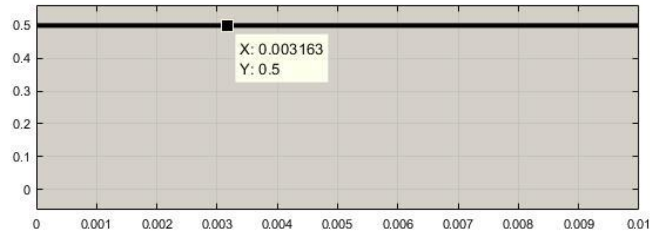

Fig9: operation of switch K2

Fig 9 shows the operation of switch K1 which is connected between the battery and the Load.

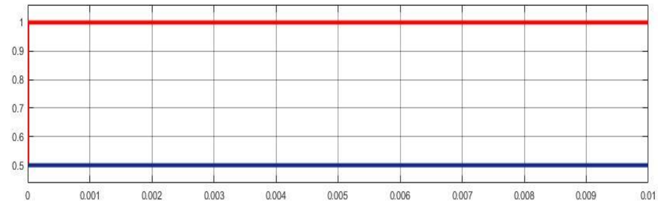

Fig 8: Operation of switch K1 and K2

Fig 8 shows the operation of cahrging and discharging switches (both K1 and K2) together.

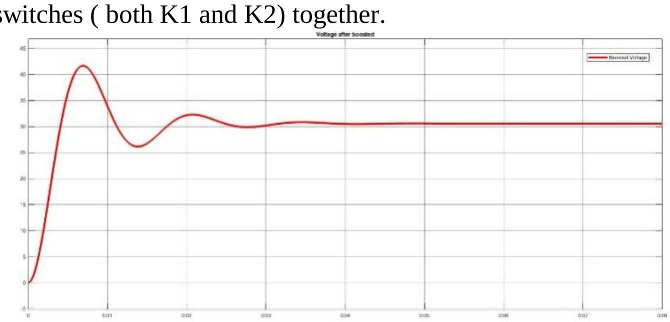

Fig 9 : Voltage after boost converter

Fig 9 shows the maximum voltage which is generated by the boost converter from the solar panel.

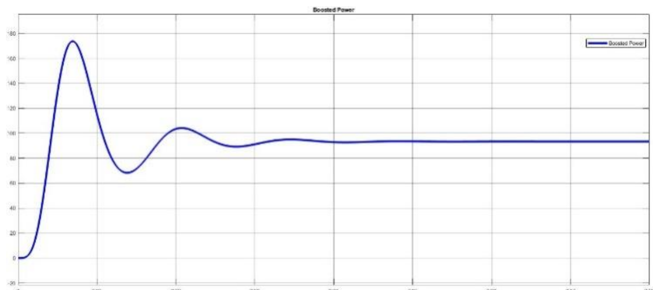

Fig 10 : Maximum generated solar power after boosting

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Fig 10shows the maximum power (115.1 W) which is able to generated after the boost converter.

V. CONCLUSION

To power up the total required load demand conventional energy resources as insufficient.This leads us to think about going fora substitute energy sources like RES (renewable energy sources). RES are the energy, whichwas able to generate from abundant free natural resources (solar, wind, tidal etc.).The emitted solar radiation from the sun is converted to electrical energy by using photovoltaic effect. Due to the discontinuous availability of solar radiation,a charging source is required for the continuous supply of energy to the load. The switching of charging and discharging switch is yet another challenging task in the battery management system (BMS). In this paper, a fuzzy logic controller is been developed for the optimal switching of charging and discharging switches.

A mathematicalmodel of a PV array is been modeled and which is connected to a boost converter. In order to track the maximum power, which is generating from the photovoltaic system maximum power point technique is required. In this paper, the maximum power point is tracked by using perturb and observe (P&O) methods.

Battery modeling of a lead-acid battery is modeled in MATLAB environment and rule-basedfuzzy logic based controlling system is implemented for verifying the efficient switching of charging and discharging switches (K1 and K2).

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