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# A Novel Controller for Isolated Solar Photovoltaic System with Super Conducting Magnetic Energy Storage and Fault Ride through Capability

**Aseem K, Selva Kumar S**

***Abstract: :*** ***Energy storage system plays a crucial role in providing stabilization and improving power quality in isolated microgrid, especially in renewable energy based microgrid systems. Among the renewable sources, Photovoltaic (PV) based power systems are famous and increasing day by day due to its merits and advantages. Three phase fault are common in microgrid and leads to unsteady condition in the PV output power. When there is a fault in solar PV system, the photovoltaic power output decreases and results in abnormal voltage drop in the system. Efficiency and reliability of PV system is also a major issue. To overcome the issues occur due to fault in isolated PV system, it is to have Fault Ride through (FRT) capabilities. When failure occurs in PV system, FRT capability allows the system to maintain stability. FRT also allows the PV system to survive the system during the condition of fault on the system. Moreover, energy storage systems plays major role in the PV based systems. A Super Conducting Magnetic Energy Storage system (SMES)is proposed in this paper which is for providing power stabilization in isolated microgrid under fault condition. SMES can provide the real and reactive power according to the requirements of PV based power system. The proposed SMES can be a good solution for minimizing the effect on the system due to fault condition in PV system. Using MATLAB/SIMULINK, isolated PV with SMES was simulated and analysed for its performance with and without fault condition. This proposed theory is proven by an extensive simulation results.***

***Keywords*****:** ***:Incremental Conductance(IC), Maximum Power Point Tracking, Microgrid, SMES, Fault Ride Through (FRT) capability***

## INTRODUCTION

The priority of power generation through renewable energy systems is gradually increasing in the world. Where the power generation by Photovoltaic (PV) is drawing the attention of researchers due to its merits and advantages when compared with rest of the renewable energy systems. With the rapid increase in integration of photovoltaic based power generation, it become necessary to ensure that PV system can operate effectively under various disturbances in the power system. Energy storage system performs a vital role in the

reduction of fluctuations in power, frequency and output voltage of photovoltaic system. Various energy storage systems are available nowadays such as super capacitor energy storage, Super Conducting Magnetic Energy Storage system (SMES), flywheel, compressed air energy storage etc.

Compared to these energy storage technologies, SMES have attracted greater attention in renewable integration systems because of its fast response, high efficiency and over 95% charge and discharge capability. SMES can be used for load leveling, voltage stability and for improve dynamic stability [1].

Currently, there are a lot of research works conducted to evaluate the role of SMES in renewable integration, and here a brief review is presented. In [2], the relation between power rating of SMES and the capacity of energy required are explored. In [3], an integrated evaluation method to determine the output capability of SMES is discussed. The integration of Superconducting Coil (SC) in mitigating the fluctuations in the network which is distributed and with Plug-in battery electric vehicle is proposed in [4]. In [5], the optimized design of SMES is proposed. New revolutions of SMES magnet are discussed in [6-8]. In [9], applications of SMES in minimizing the fluctuations of voltage and frequency of wind power generator system are investigated. The performance evaluation of power conversion system using SMES is discussed in [10].

The increased demand of photovoltaic power generation and its integration into main grid improved the overall power system reliability. Various disturbances in the power system will reduce the performance, power generation capability and efficiency of the PV system. PV can make a new revolution in renewable integration if it is equipped with a robust control. In summary, it is expected that for an improved performance of PV system, it must have the capability to ride through fault during disturbance, maximum power point tracking, and harmonic reduction capabilities.

This paper focuses on the stabilization of isolated photovoltaic system under three phase fault and implementation of SMES for alleviating the fluctuations in the output power of PV cell.

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## ISOLATED PV SYSTEM

The isolated PV based micro grid is represented using the block diagram as shown below in Fig. 1. It consists of a PV array for power generation, boost converter with MPPT algorithm, DC to AC converter and loads. The modeling of respective modules in the Fig.1 is carried out from [11-13]. The parameters of PV cell/array as mentioned in Table.1.

PV array is connected to three phase inverter (Voltage Source Converter (VSC)) through DC-DC boost converter as shown below in Fig. 1. The Maximum Power Point Tracking (MPPT) [11-13] algorithm is executed in the boost converter by practicing the technique of 'Incremental Conductance + Integral Regulator' the PV system maximum power is achieved. Then the power is transmitted to load using three phase voltage source inverter.

The PV array consists of more number of cell which are series connected, in this paper considered PV array to generate a 250V DC while modeling of PV system. By using boost converter, the generated voltage through PV system is increased to 500V. The solar irradiance and the temperature are the factors of power generation through PV. The power which is generated is transmitted to load using three phase VSC. Then the 500V DC link voltage is converted to 260V AC using VSC and keeps the power factor as unity The VSC control system includes two control loops: one is an external control loop which is responsible for regulating DC link voltage to +/- 250V (500VDC) and the other is internal control loop that regulates $I_d$ and $I_q$ currents (the components of active and reactive current) in load. The current reference $I_d$ is the DC voltage controller output. For maintaining the power factor at unity the current reference $I_q$ is set to zero. The three modulating signals $U_{abcref}$ utilized by the PWM generator are obtained by converting the current controller voltage outputs $V_d$ and $V_q$. By practising the technique of incremental conductance, Maximum power point tracking is achieved. In this method the boost converter duty cycle is adjusted for the maximum power [13, 14].

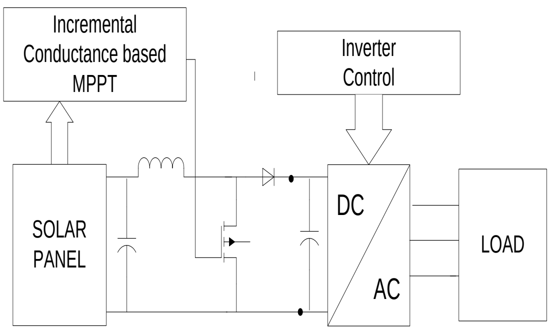


**Fig. 1 Configuration of isolated PV system.**

**Table- I Design parameters of PV Cell**

| Parameters | Value |
|---|---|
| Parallel strings | 66 |
| Module connected in Series | 5 |
| Open circuit voltage($V_{oc}$) | 64.2V |
| Short circuit current | 5.96A |
| Maximum peak voltage | 54.7V |
| Maximum peak current | 5.58A |

### A. Incremental conductance algorithm for Maximum power extraction

Incremental conductance (IC) technique quantify the maximum power by comparing the instantaneous conductance of solar PV array with the incremental conductance When these two are same then the algorithm generates the voltage signal (Voltage corresponding to maximum power) which is the reference signal to boost converter. This voltage is maintained until the radiation varies and repeats the process. IC is based on the principle that the power change according to the change in voltage is zero. The MPPT algorithm has implemented from (1) to (3) and an elaborated flowchart is shown below in Fig. 2.

$$\frac{dp}{dv}=0 \qquad (1)$$

$$\frac{dp}{dv}=1+v\frac{dI}{dv}=0 \qquad (2)$$

Maximum power point is reached when,

$$\frac{dI}{dv}=-\frac{I}{v} \qquad (3)$$

When $\frac{dI}{dv}>-\frac{I}{v}$ implies that the PV output voltage is less than MPPT voltage, then incremental conductance will track the point of maximum power by increasing its duty cycle.

When, $\frac{dI}{dv}<-\frac{I}{v}$ the incremental conductance will track the point of maximum power by decreasing its duty cycle. In this work, point of maximum power is tracked with respect to the change in duty cycle.

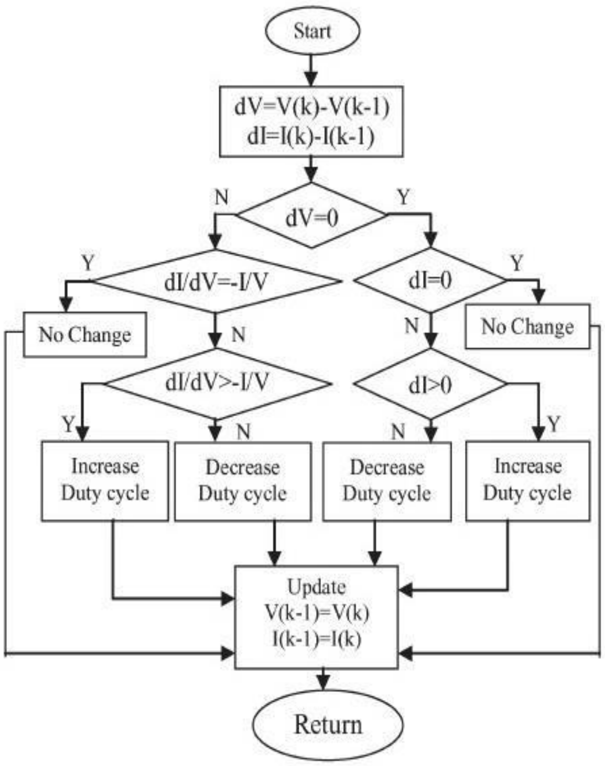


**Fig. 2 Flowchart of the IC algorithm**

### B. Control of DC-DC converter

Fig. 3 shows the configuration of DC-DC converter. From the figure, the output voltage from the PV array is converted into a higher voltage using boost converter. An incremental conductance technique has implemented to regulate the pulse to the converter to work as MPPT converter/control. For achieving the maximum power from PV system uses incremental conductance algorithm. In this way the converter tracks the maximum power point. In this work, boost converter is designed with a duty ratio of 0.5 and PV output will give the maximum power when duty ratio is 0.464.

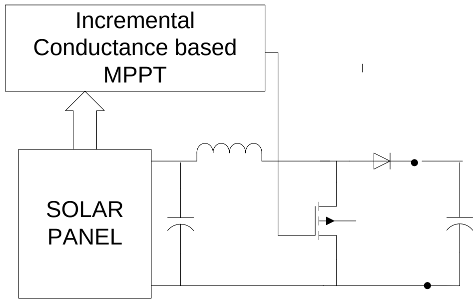


**Fig. 3 DC-DC converter for MPPT of PV system**

## Isolated PV System With SMES Storage

Using the system model as given in Fig. 4, detailed simulation analysis of isolated PV with SMES unit subjected to three phase fault is carried out. Modeling of the system is developed from reference [10, 15-16]. The output power of photovoltaic system decreases considerably from its rated value during the condition of fault. By connecting SMES to the system the output power of PV can be well improved. Three phase to ground fault leads to an unsteady condition in the isolated PV system. It leads to fluctuations in the PV output voltage and power. There will be imbalanced active power in the overall system. By connecting SMES unit, the imbalanced active power will be absorbed by SMES unit and provide the reactive power based on the fault condition.

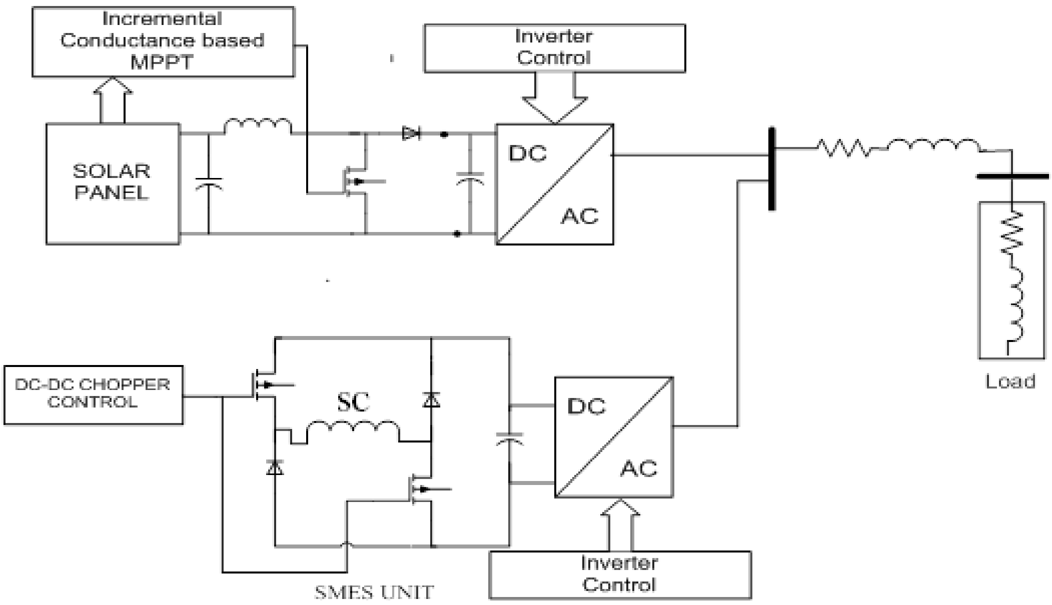


**Fig. 4 Configuration of isolated PV system with SMES unit**

### C. SMES Unit

SMES coil stores the electrical energy in the form of magnetic field when DC current flows through it. This unit includes a power conditioning unit, transformer, DC-DC chopper and superconducting coil as shown in Fig. 5.DC-DC Chopper is used for the charging and discharging of SMES real power and VSC for reactive power. The SMES stored energy and power is given by (4) and (5).

$$E = 0.5LI^2 \quad (4)$$

$$P = \frac{dE}{dt} = LI\frac{dI}{dt} = VI \quad (5)$$

Here, $E$ indicates energy stored in SMES, $L$ indicates the inductance, $I$ indicates current, and V is the voltage. The modeling of SMES is carried from [10].SMES under normal operating condition will regulate the PV array's output power and voltage. The converter for SMES is designed in such a fashion that the coil will be charge or discharge based on the fault condition. Through the comparison of the voltage across the coil, Charging and discharging mode is determined.

### B. Control strategy of SMES

Voltage source inverter of SMES unit is controlled using feed forward compensation by a PI controller. Second order optimal principle is used here for tuning PI parameters [11]. Control block diagram for SMES is shown in Fig. 6. The switching signal for the chopper is done by comparing duty cycle with triangular signals. The duty cycle is determined by stored energy across the coil. The voltage across the coil will be charging and discharging where the duty cycle is less than or greater than 0.5 respectively. The energy management in microgrid is very important for maintain satisfactory power quality.

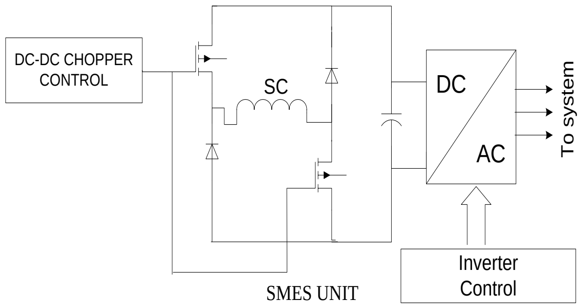


**Fig.5 Configuration of SMES unit**

### SIMULATION RESULTS

The modelling and analysis of the PV system with MPPT for stability analysis is carried out. Based on the Fig. 4, the Simulink model of PV system is built and the PV response with and without fault under various operating conditions are simulated in MATLAB.

### D. Isolated PV system without MPPT, without SMES under No fault condition

Fig. 8 shows the PV response when the switching pulse for the converter is not optimized using MPPT control. When MPPT control is not enabled, the PV output power keeps on fluctuating. However, to test the system performance in this case considered changes in both irradiance and temperature as shown in Fig. 7. In this case, we are not incorporated MPPT, hence Maximum power point tracking is not possible. Isolated PV system fails to operate at its best efficiency point during this condition. The PV system is designed to operate in 100kW. But when MPPT is not enabled, The power output of the PV is limited to 20kW.

Fig. 5 i

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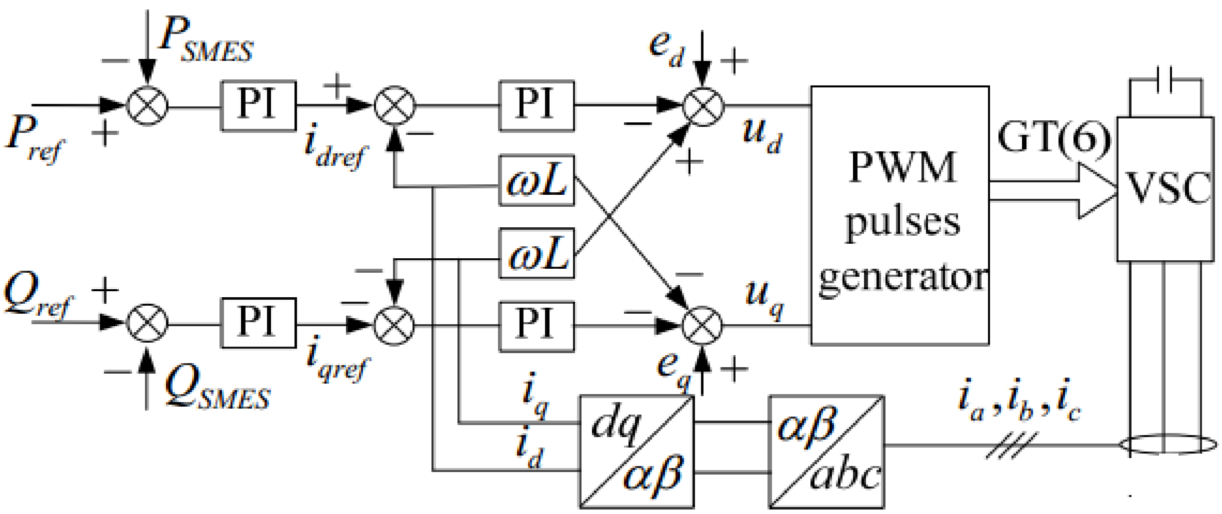


**Fig. 6 Block diagram of VSC controller**

### E. Isolated PV system with MPPT without SMES & No fault

According to the Fig. 8, the pulses to both boost and VSC converters are blocked from t=0 sec to t= 0.05s, PVvoltage corresponds to open-circuit voltage (i.e., Nser*Voc=5*64.2=321 V). Again the boost and VSC converters are de-blocked at t=0.05s.As the duty cycle of boost converter is fixed, the DC link voltage is regulated at Vdc=500V.At t=0.25s steady state is reached.

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Therefore the resulting PVvoltage is V_PV = (1-D)*Vdc= (1-0.5)*500=250V. The PV array output power is 92.91 kW whereas specified maximum powerat 1000W/$m^2$ irradiance is 100.7kW.MPPT is enabled at time t=0.4s. Then PV voltage corresponds to its maximum power point voltage. The performance of the isolated PV system is governed by the irradiation and temperature. As shown in Fig.9,when irradiation is ramped down at t=0.6s, MPPT tracks the maximum power at this interval by adjusting its duty cycle.When irradiation decreases solar power input decreases, therefore the PV output power will decreases. At

time t=2s when temperature increased to 50 C the PV output power as well as voltage decreases.

**F. Isolated PV system under fault, with MPPT and without SMES**

Fig.10 and Fig.11 show the output response of isolated PV system under different fault condition. Three phase to ground fault is imparted between t=1s to t=1.5s with the fault resistance as 1Ω. The generated power by the PV reduces from 100 kW to 20 kW during this interval of fault due to change in DC voltage. There is a considerable drop in the PV output voltage during fault condition. When fault occur in an isolated microgrid, it creates an unbalanced condition in the output response of the PV. The output power and voltage of the PV deviate greatly from its rated value. This will also leads to imbalanced voltage across DC link. The voltage ripples in the DC link generated due to fault condition can even damage the entire power system. When SMES is not considered, PV terminal voltage drops to 20% of its rated voltage.

**E. Isolated PV system under fault with MPPT & SMES**

From the Fig.12 and Fig.13, when SMES is added to the model, power and output voltage of PV is well improved. SMES is successful in achieving FRT capability in the isolated PV system. When fault occur, there is an imbalanced active power in the entire system. SMES during this instant will take the imbalanced active power and provides the reactive current. Thus SMES can provide power stabilization and improve power quality in isolated PV system under fault condition. SMES is a good option to implement FRT capability in isolated PV system.

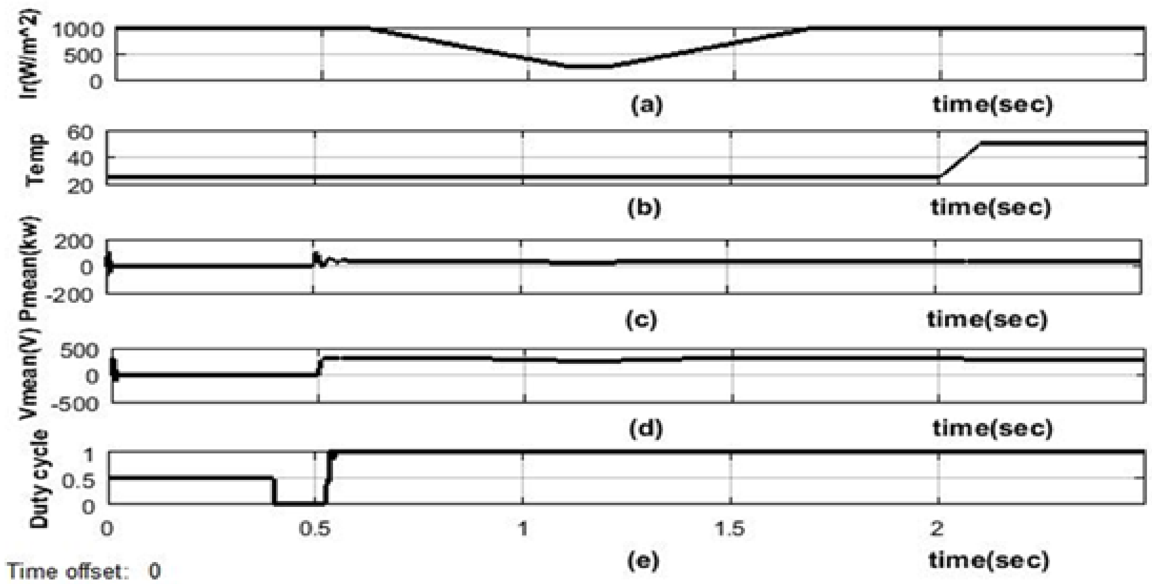


**Fig.7 Isolated PV system without MPPT, without SMES and no fault present (a) variable Irradiance, (b) variable Temperature(T), (c) PV output power. (d)PV voltage (e) Duty cycle**

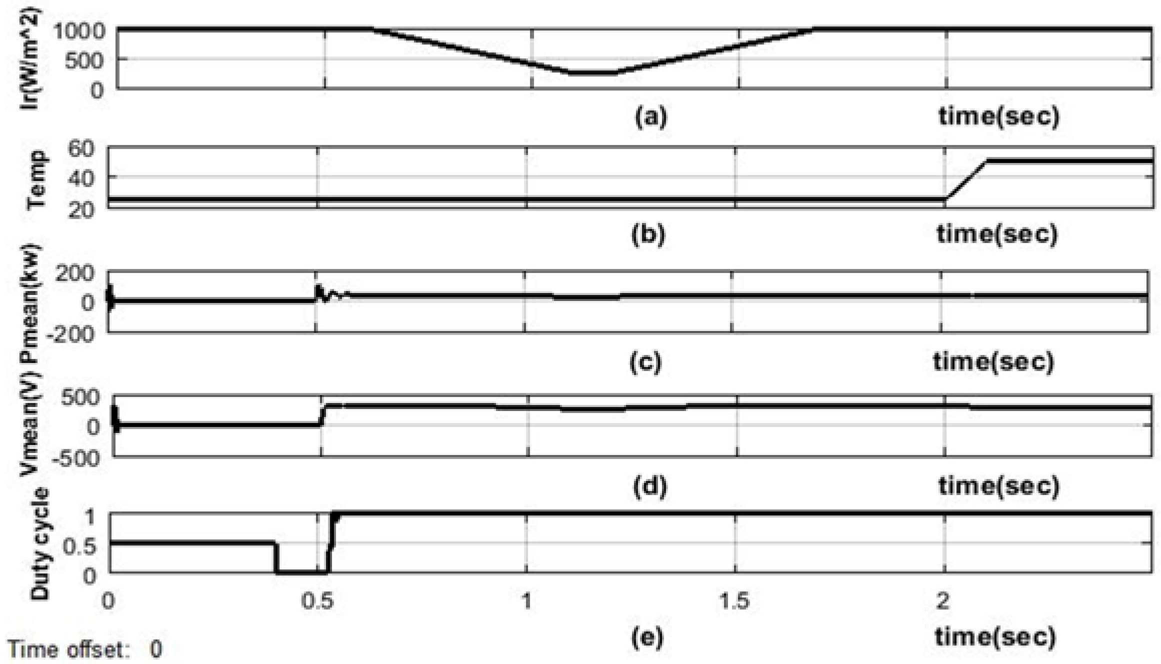


**Fig. 8 Isolated PV system with MPPT, without SMES and no fault present(a) Constant Irradiance, (b)Constant Temperature(T), (c) PVoutput power, (d)PV voltage, (e) Duty cycle**

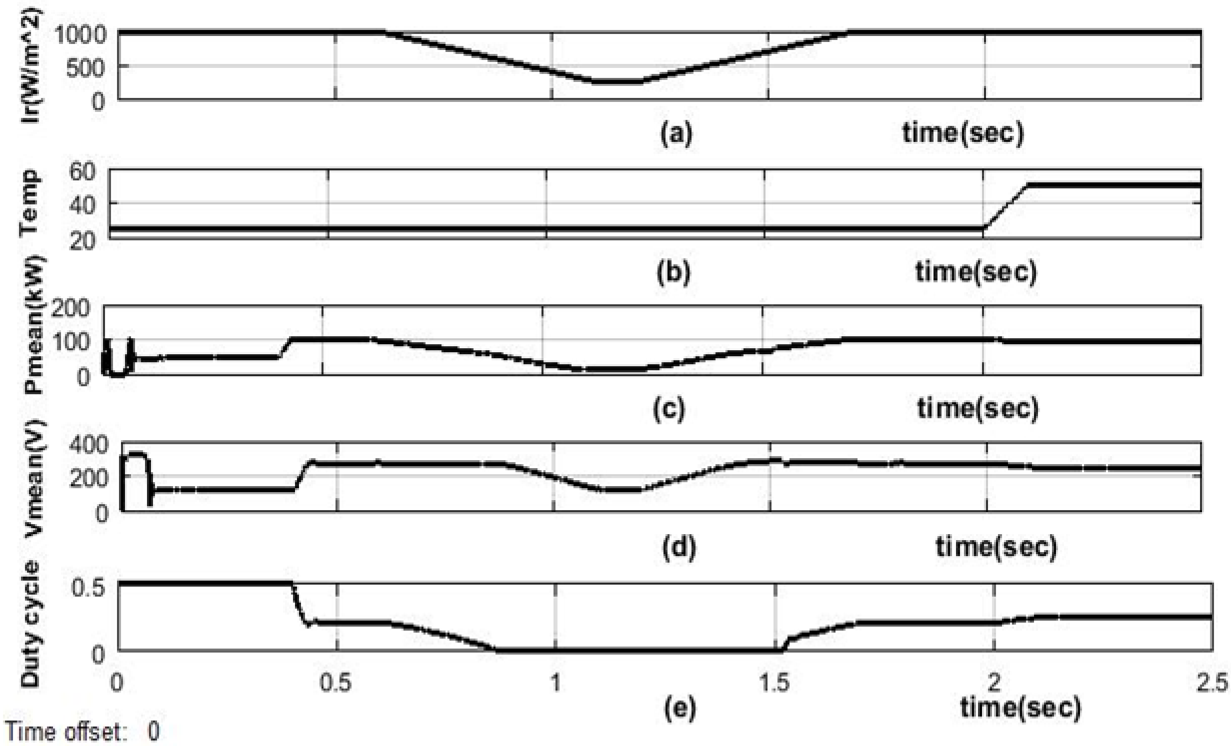


**Fig. 9 Isolated PV system with MPPT, without SMES and no fault present(a) Variable Irradiance, (b)Variable Temperature(T), (c)PV output power, (d)PV voltage, (e)Duty cycle**

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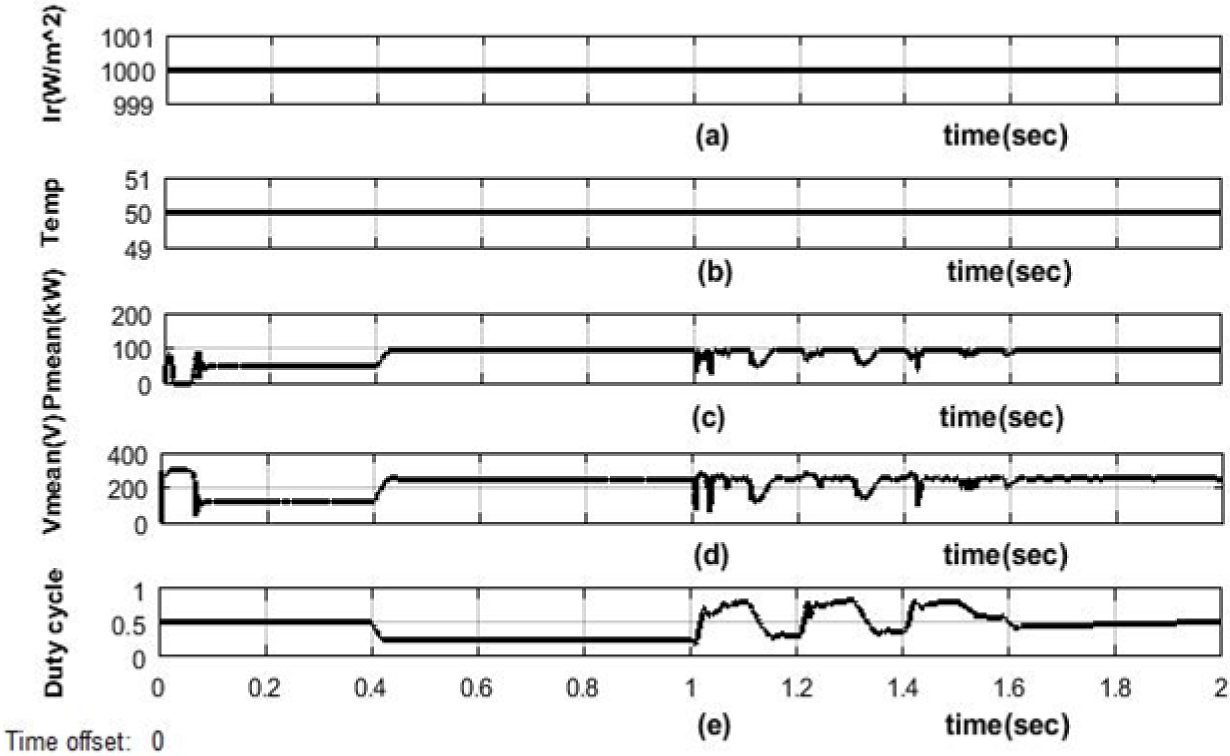


**Fig. 10. Isolated PV system with MPPT, without SMES and fault present at constant irradiance and temperature (a)Irradiance, (b)Temperature (T), (c)PV output power. (d)PV voltage, (e) Duty cycle**

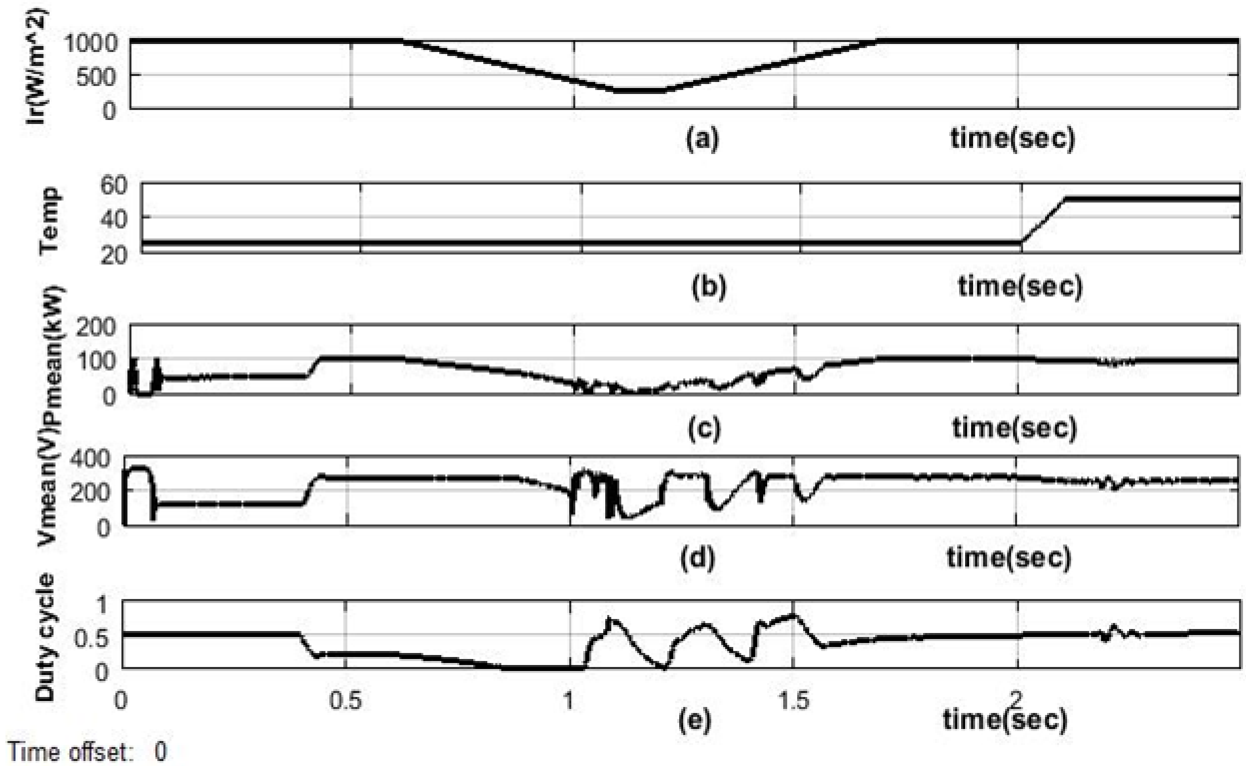


**Fig. 11. Isolated PV system with MPPT, without SMES and fault present at varying irradiance and temperature (a)Irradiance, (b)Temperature, (c)PV output power. (d)PV voltage, (e) Duty cycle**

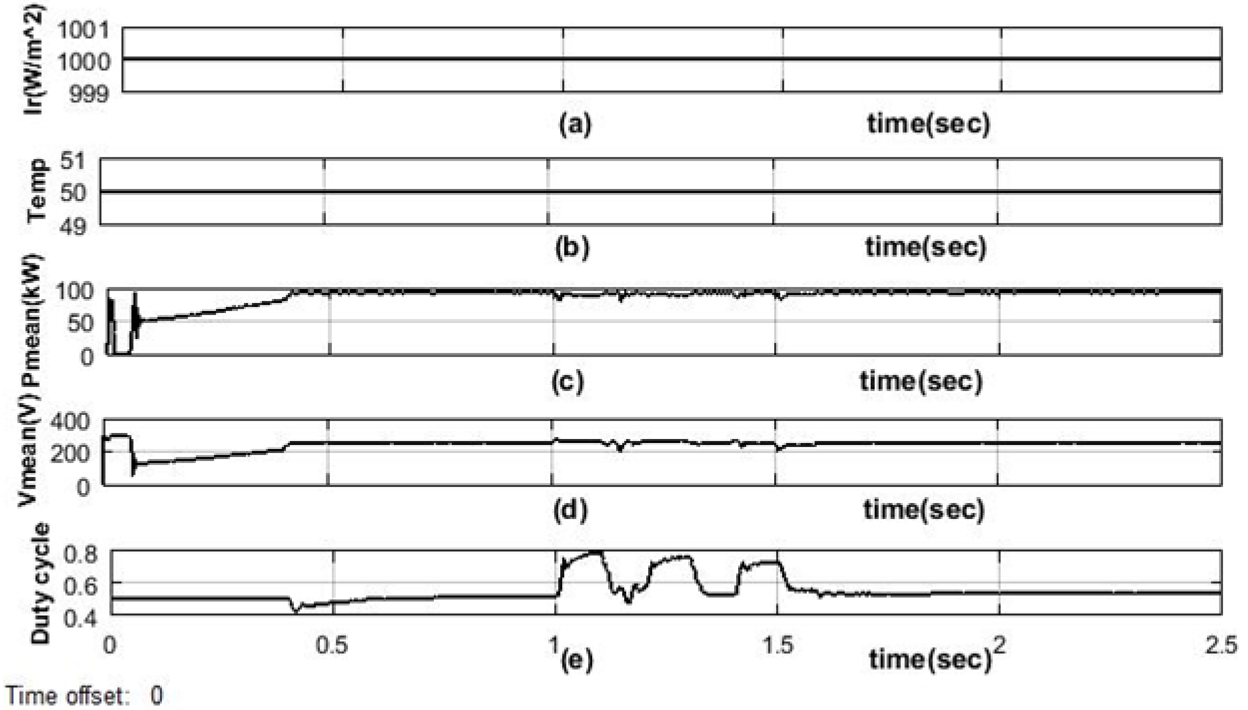


**Fig. 12 Isolated PV system with MPPT, with SMES and fault present at constant irradiance and temperature (a)Irradiance, (b)Temperature, (c)PV output power. (d)PV voltage, (e) Duty cycle**

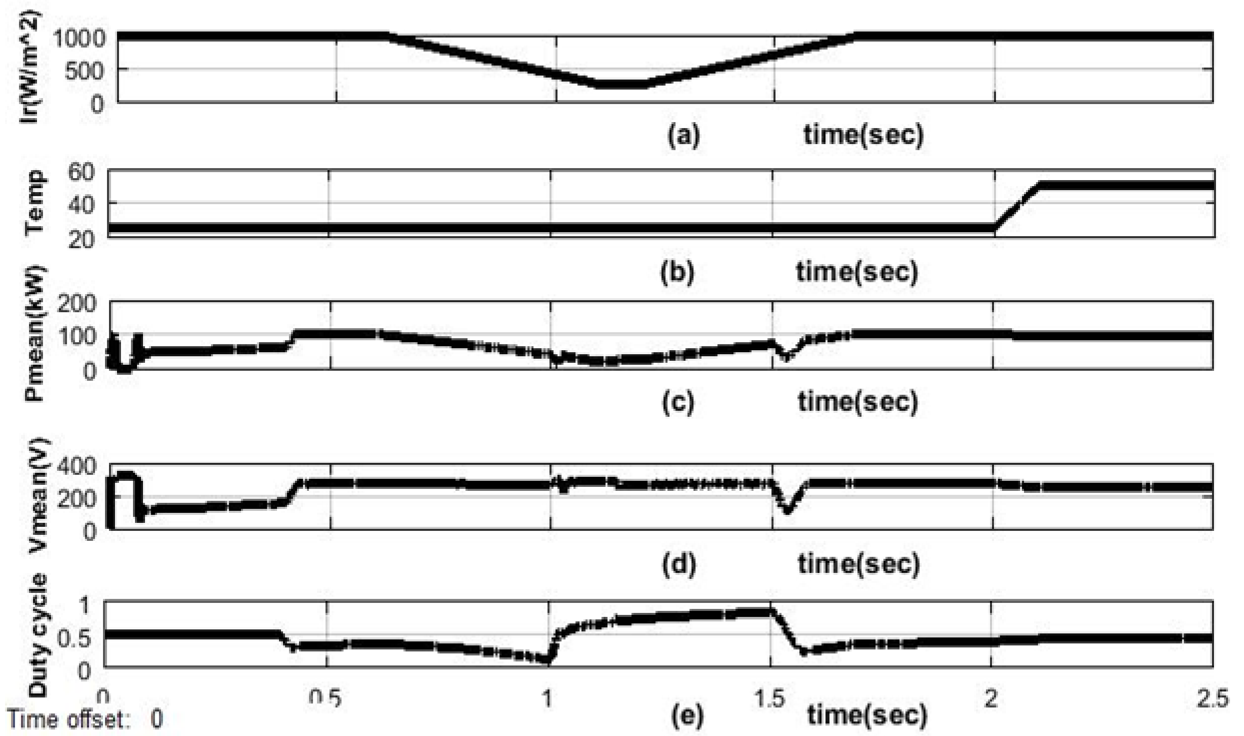


**Fig. 13 Isolated PV system with MPPT, with SMES and fault present at varying irradiance and temperature (a)Irradiance, (b)Temperature, (c)PV output power. (d)PV voltage, (e) Duty cycle**

## II. CONCLUSIONS

This paper discussed the implementation of SMES to reduce the fluctuations in the PV responses during fault conditions. A 100 kW isolated PV system along with the MPPT controller is used in this model to evaluate the performance of controllers. During normal operating conditions, isolated PV system will increase its output power generation using incremental conductance based MPPT algorithm. When fault occurs, SMES will take the immediate action to reduce the fluctuation on DC voltage, it leads the improvement in stability on voltage at AC load. The obtained simulation results made sure that the SMES is capable to alleviate the PV power fluctuations and regulate PV voltage under fault condition. When SMES is not connected, the PV output power and voltage drops to 20kW and 70V during fault condition respectively. When SMES is connected, the power and voltage profile of isolated microgrid is well enhanced. There is absorption of active energy about 70kW and release of reactive energy about -50kVAR during the fault interval. From the analysis and results, the isolated PV based power system power system can be protected from the SMES due to its fast response time. Hence, SMES with proper controller can stabilize the system during transient faults in the power system.

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