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Enhancement of Solar PV Panel Using Single Integral Sliding Mode MPPT Control

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Abstract: The maximum power extraction using single integral sliding mode control scheme is established from the sliding mode control scheme. The sliding mode control (SMC) scheme extracts the maximum power during the partial shading weather conditions using the effective selection sliding surface duty cycle ratio in combination of dc/dc boost converter. This dynamic operation of sliding surface selection operation in partial shading conditions aids to enhance the solar panel efficiency compared to the other existing MPPT schemes. The effective dynamic operation of sliding surface mode control is designed using feedback loop control scheme to diminish the steady state voltage error of the solar panel, further to obtain the higher sliding duty cycle ratio. The dc-to-dc boost converter is made active using sliding duty cycle ratio as input gate signal boost converter switch. Hence, higher efficiency attains at higher sliding surface duty ration. This sliding surface duty ratio is limited in sliding mode MPPT control scheme and requires the necessary advancements to achieve the maximum duty cycle ratio. The single integral sliding mode control scheme (SISMC) offers the enhanced sliding surface duty cycle ratio with integration of voltage error obtained in SMC scheme. Therefore, the major application of SISMC compared to SMC scheme is the proposed SISMC schemeoffers the effective dynamic sliding operation using integrated steady state voltage error signal and allows to nullify the lacuna of maximum sliding duty cycle ratio. Hence, this paper aims to discuss the design and performance analysis of SMC scheme and proposed SISMC MPPT control scheme. To corroborate the performance of the proposed SISMC MPPT scheme, the MATLAB / Simulink model was designed and verified. Also,this paper presents the comparison results of proposed SISMC MPPT schemes with the SMC scheme.

Keywords: Sliding mode control (SMC), maximum power point tracking (mppt), single intergral sliding mode control (sismc), partial shading condition, solar PV

1. Introduction

The digital industrialisation and advancements in technology offers bulk amount electrical energy demand. The present energy fuel vagaries show profound influence on required bulk amount electrical energy demand [1]. In view of this, renewable energy utilities such as hydal, solar, wind etc. are operating as supplementary energy sources to meet the required bulk amount of energy demand [2]. Further, the electrical energy generation using the renewable energy sources offers eco-friendly socio-economical energy generation. Nevertheless, the paucity of renewable energy sources fails to replacement of commercial energy sources such as thermal, nuclear, diesel etc. The solar renewable energy source is the vivid energy source available abundantly in nature compare to other renewable energy sources. The major

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downsides of the solar renewable energy are its daytime accessibility and erratic in nature. The first down side may not be avoidable but the second down side may have resolved with appropriate working arrangement [3]. Several invigorating algorithms are proposed and developed to excerpt the highest power from the solar PV cell panels and limited to perform efficient operation at partial shading weather conditions [4] [5]. Hence, it is need of sophisticated MPPT algorithms which offers efficient power output at partial shading conditions [6].

Recently, sliding mode MPPT control algorithm schemes are developed to achieve the maximum solar PV panel efficiency [7] [8]. Also, this sliding mode MPPT control scheme satisfying the dynamic performance operation of partial shading weather conditions. The sliding mode control algorithm works on the principle of selection of solar panel sliding surface switching operation for actual weather climatic conditions [9]. The sliding switching operation in turn results in sliding duty cycle ratio. The sliding duty ratio varies with weather climatic conditions and higher efficiency may record for higher duty cycle ratio. The major problem identified in sliding mode MPPT control algorithm is its limited sliding surface duty cycle ratio [10]. Therefore, the SISMC scheme is suggested to resolve the high duty cycle ratio problem. The proposed integral sliding mode MPPT control algorithm amplifies the duty cycle ratio using integral action of steady state voltage error signal unlike feedback error voltage signal. Further, compared to the sliding mode MPPT control scheme, the SISMC scheme offers the enhanced dynamic switching operation and enhanced solar PV panel efficiency [11-16]. The MATLAB / Simulk model of 1 KW of solar PV panel was designed and verified the anticipated SISMC scheme. In addition, the sliding mode MPPT control algorithm also designed and compared with the anticipated SISMC scheme to verify the efficiency. Also, the efficiency of the proposed SISMC scheme is compared with the efficiency reported in literature [17].

2. Single Integral Sliding Mode Control

The single integral sliding mode MPPT control solar PV panel system consists a pulse with modulation (PWM) based dc to dc boost converter [12-15]. The major function of PWM is to activate the sliding surface switching actions based on the partial shading weather conditions. The complete schematic view of the proposed single integral sliding mode MPPT control solar PV system is shown in figure 1 [12]. The schematic view confirms the closed loop control system with integral sliding switching selection is the major function in the system. The sliding surface selection offers demonstrates the permitting higher solar photon energy for the solar PV cell at partial shading weather condition. Hence, higher the sliding surface selection ratio higher panel efficiency accomplished. Therefore, appropriate design aspects are spirited to obtain maximum sliding surface switching selection duty ratio.

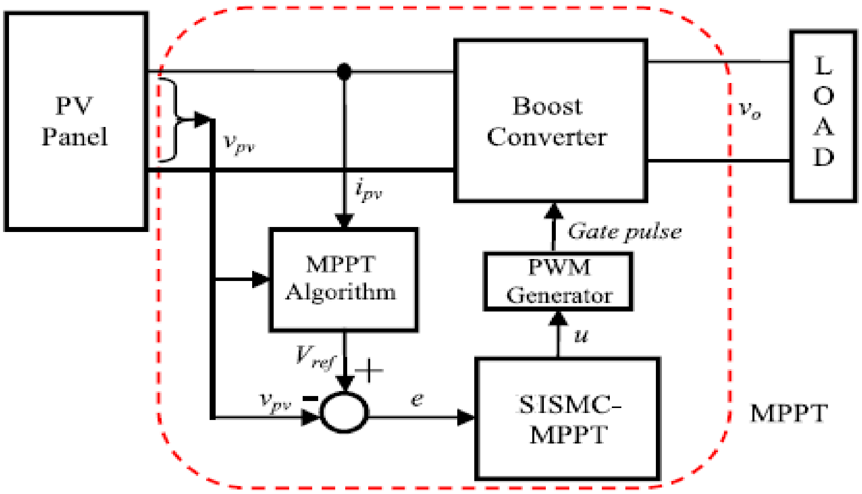

Fig. 1 Schematic view of solar PV system model with SISMC

The proposed scheme is allowed to integrate the existing voltage error signal so that the enhanced sliding duty cycle ratio as PWM pulses to the dc-to-dc boost converter. The proposed system contains typical solar PV panel for various nonlinear loads, PWM based dc-to-dc boost converter for enhancement of power at nonlinear loads. The projected system photo voltaic panel output current is expressed as i_{pvc} is given by

$$i_{pc} = I_{pc} - I_0 \left[\exp \left(\frac{v_{pc}+i_{pc}R_s}{N_{sc}V_{th}}\right)-1\right]- \frac{v_{pc}+i_{pc}R_s}{R_{sh}} v_{pc} \quad (1)$$

$$\text{with } i_{pc} = (I_{sc} + K_1 (T-298)) \frac{H}{1000} \quad (2)$$

$$V_{th} = \frac{a k_b}{e} T \quad (3)$$

$$I_0 = I_{0ref}\left(\frac{T}{298}\right)^3 \exp\left(eE_g \frac{eE_g}{k_b N_{sc} V_{th}}\left(\frac{1}{298}-\frac{1}{T}\right)\right) \quad (4)$$

Where I_0, i_{pc}, T, k_b, R_s, H, R_{sh}, I_{sc}, K_1, N_{sc}, V_{th} are initial state current, solar panel current, temperature, Boltzmann's constant, series resistance, irradiation, shunt resistance, short circuit current and its coefficient, series connected cell count, thermal voltage. Further, the boost converter corresponding circuits for various switching operations are presented in figure 2. From the figure 2, it is observed that the series of signals with duty cycle ratio of δ generated from boost converter control signal u.

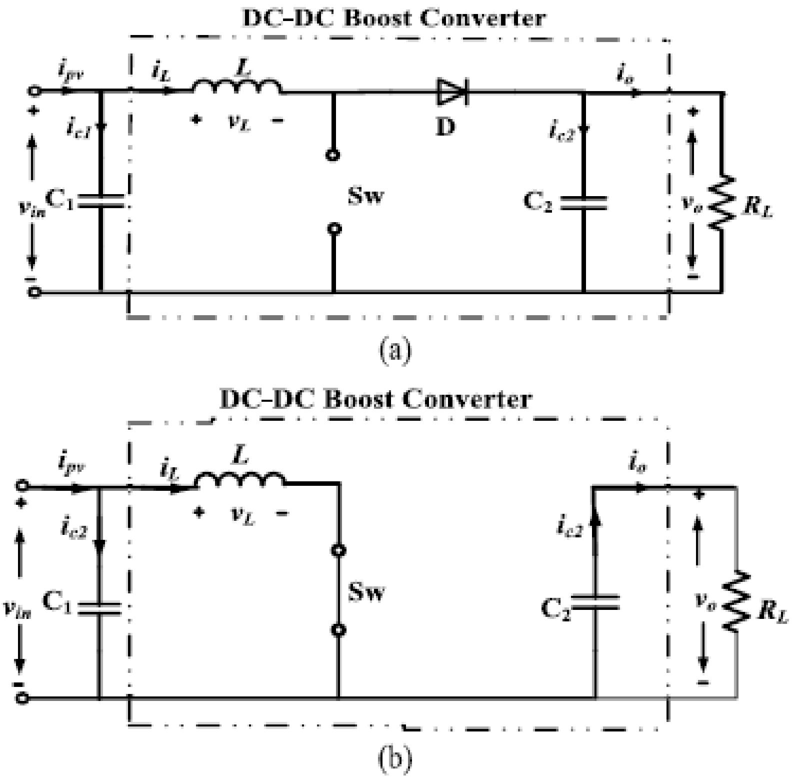

Fig. 2 DC-to-DC Boost converter operation (a) when switch is open u=1; (b) when switch is closed u=0

The open circuit voltage is calculated from the above equivalent circuit is given by

$$V_{oc} = N_{sc} V_{th}\ ((\ln i_{pc} + I_0)/\ I_0) \quad (5)$$

Now, the reference voltage for boost converter is calculated using open circuit voltage is given by $V_{ref} = M_{oc} .V_{oc.}$ Where M_{oc} is the PV panel material coefficient depends on the panel PV module assembly and material. This necessitates that the aim to design control technique such that the voltage reference magnitude and solar panel open terminal potential magnitude are equal. To obtain equal potential magnitudes, the proposed single integral sliding mode (SISM) MPPT scheme is designed from figure 3 [16]. Figure 3 dictates the calculation of sliding surface switching cycle duty ratio signal for gate signal of IGBT switch of the boost converter. Hence, the sliding surface $S_s(y)$ duty cycle ratio for the boost converter is

$$S_s(y) = \{\ \frac{d}{dt} + \beta\}^{j-1}\ e(y) \quad (6)$$

Where x denotes the state space of the vector of the proposed solar panel system design, j is the sliding switch demand to attain the steady state error and e(y) is the chasing error representation. If

$$J=1 \text{ obtains } S_s(y) = e(y) \quad (7)$$

The chasing error e given in boost controller is

$$e(y) = e(y1) + e(y2) + e(y3) \quad (8)$$

$$\text{where} \quad e(y1) = (Vref - v_{pc}) \quad (9)$$

$$e(y2) = \int (Vref - v_{pc})\, dt \tag{10}$$

The proposed MPPT scheme is intended to mitigate the steady state error e(x) using single integral step working practice which is given from equations (7) to (10).

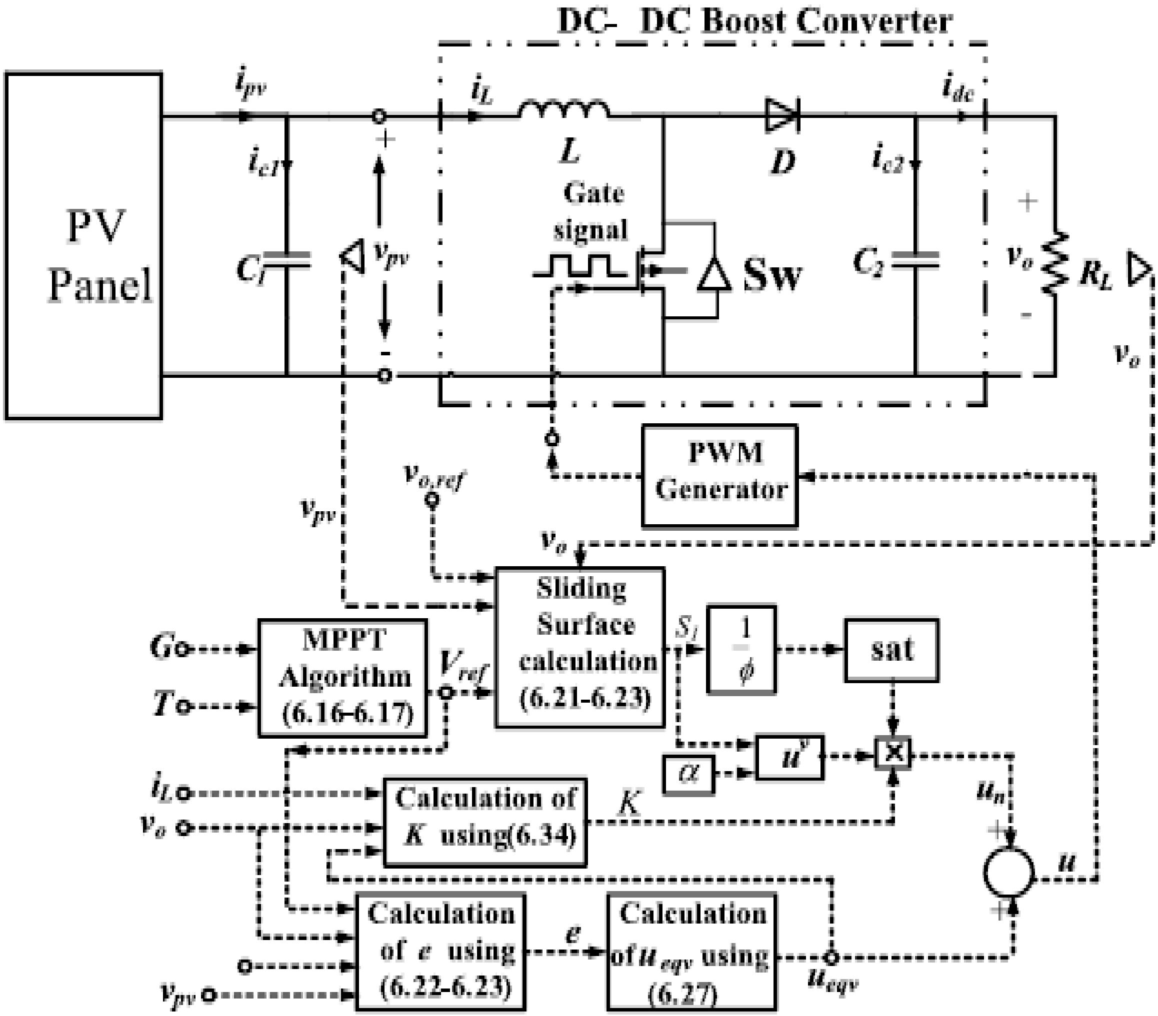

Fig. 3 SISMC based MPPT design

3. Simulation Design

To validate the proposed single sliding surface MPPT control scheme 1 KW solar PV panel structure was designed in MATLAB / Simulink. The proposed system analysis was performed for non-linear RL load conditions. To the same non-linear RL load conditions, the SMC scheme is designed and compared the output results with the proposed control algorithm to validate the capability of the proposed algorithm. The MATLAB / Simulink designed model of the proposed SISMC MPPT scheme is shown in figure 4. To the same model, the control algorithm is modified and analysed for sliding mode control MPPT scheme.

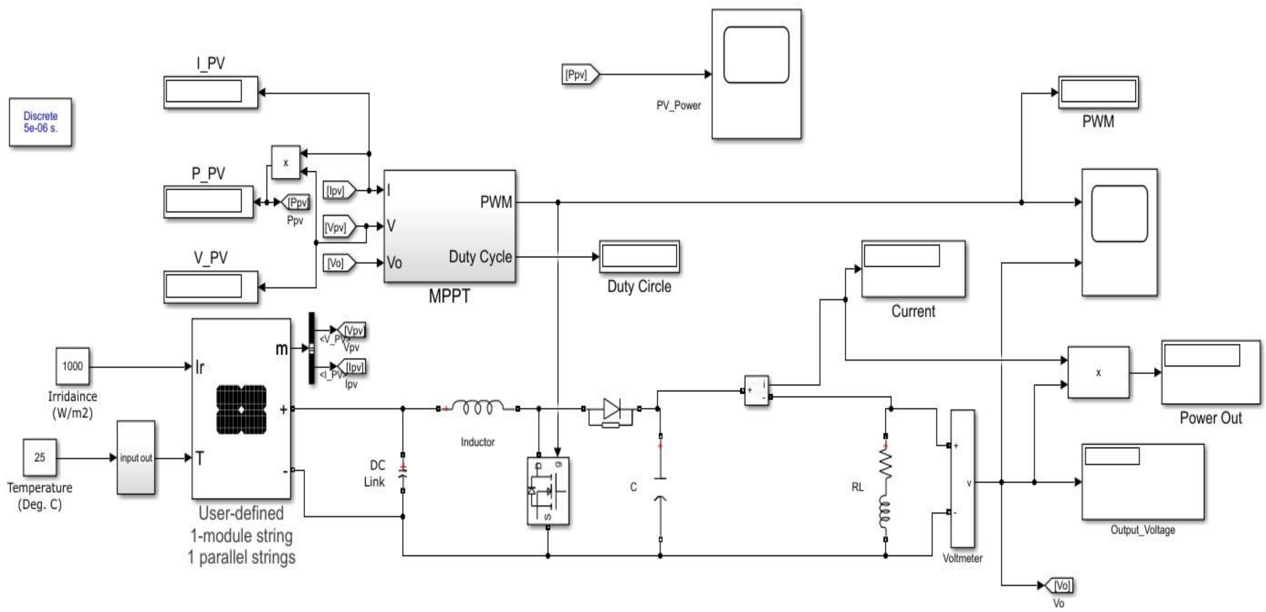

Fig. 4 - Matlab/Simulink design model of proposed sliding mode MPPT based PV design

The proposed simple solar PV panel system configuration used for this simulation study is:
PV array: 1 parallel and 1 series connected module per string
Maximum rated Power: 60.003 W
Potential at open circuit terminal: 22 V
Current at shorted terminal: 3.8 Amp
RL load: Load Active Power 1000 W; Reactive Power 200 VARs

4. Results

In order to authenticate the efficiency of the presented single integral SMC scheme, the output power at load is compared with the solar PV panel output power and the corresponding output power variation is observed from figure 5.

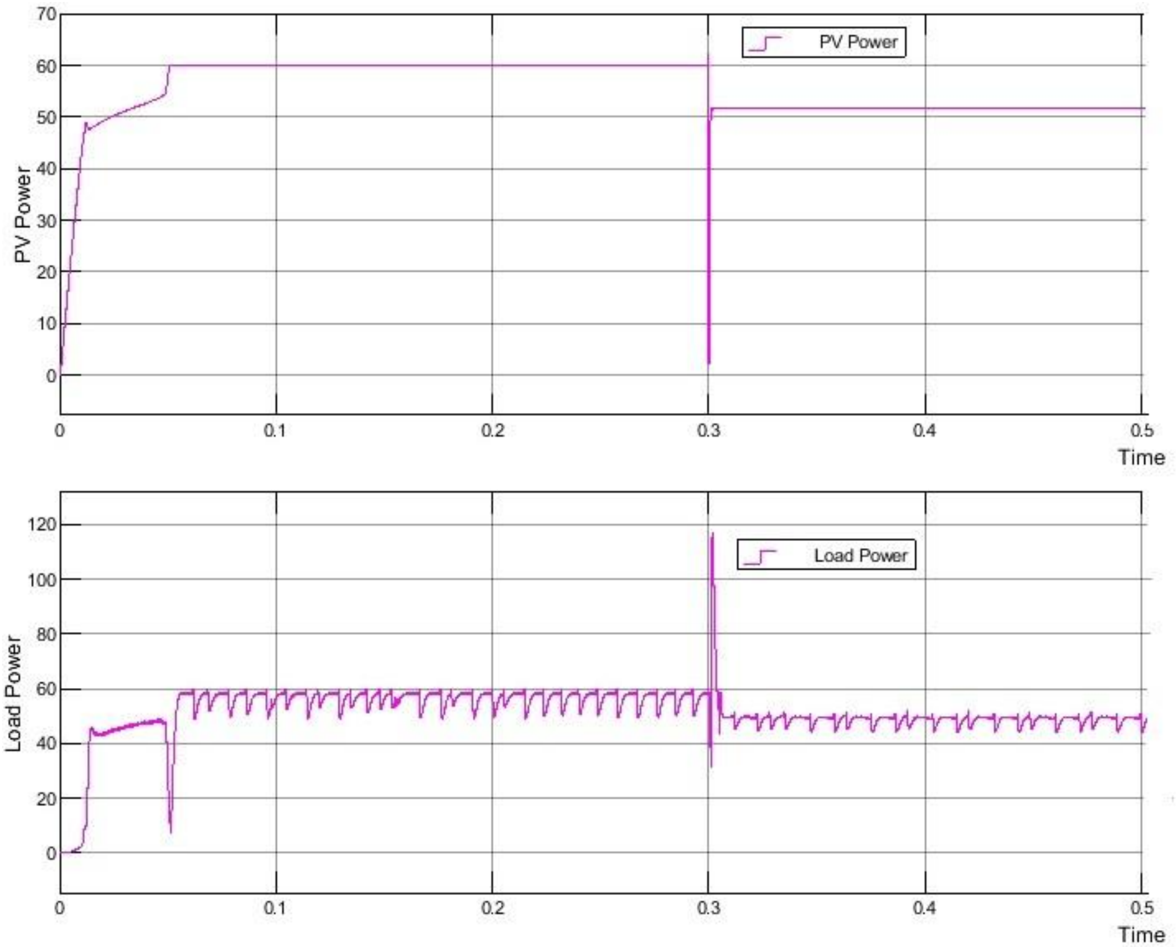

Fig. 5 - Load and source output power variation of SISMC design

It is clear from the figure the outpower achieved higher at the load compared to the solar PV panel output power. From the figure 5, it is confirmed that the 96.8 % efficiency is achieved using proposed scheme. Also, it is observed that the sliding surface duty cycle ration of the proposed algorithm meets 0.92 and which is nearly unity. Higher the duty cycle ratio i.e., nearer to unity attain the effective dynamic sliding surface duty cycle ratio and vice versa. This authenticates that, the anticipated SISMC scheme operated effectively with high sliding duty cycle ratio under partial shading weather conditions.

Additionally, the output power for same non-linear RL load conditions is observed for sliding mode MPPT algorithm control MPPT scheme to check the performance the efficiency of the proposed SISMC scheme. Therefore, the output power variation at the load terminals for sliding mode MPPT control algorithm is observed in figure 6. Similarly, the load potential and current variation of the proposed SISMC scheme is observed from figure 7. The figure 6 shows the output power and solar PV panel output power of the designed sliding mode MPPT control scheme. Similarly, it is observed from figure 6 that, the efficiency of the SMC scheme calculates 94.63 % and which is less compared to the present SISMC scheme.

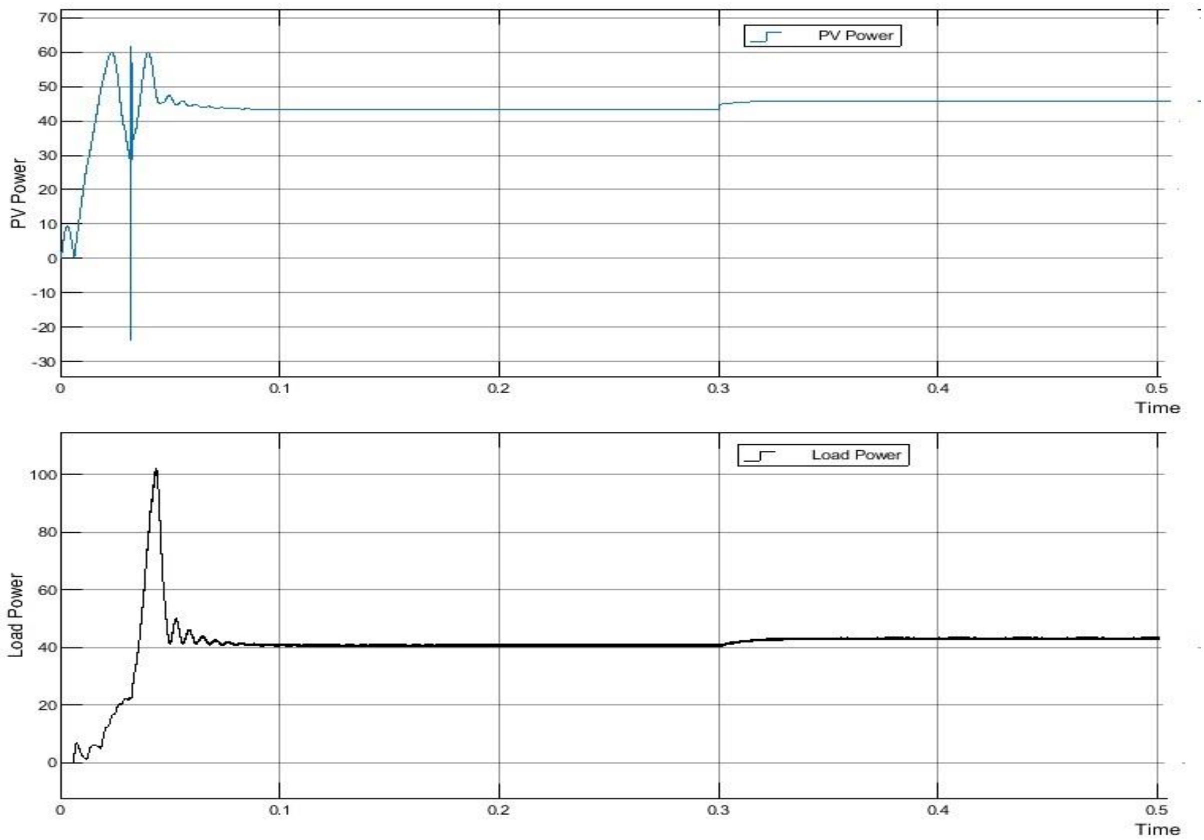

Fig. 6 - Load and source output power variation of SMC design

Similarly, the load potential and current variation of the proposed SISMC scheme is observed from figure 7.

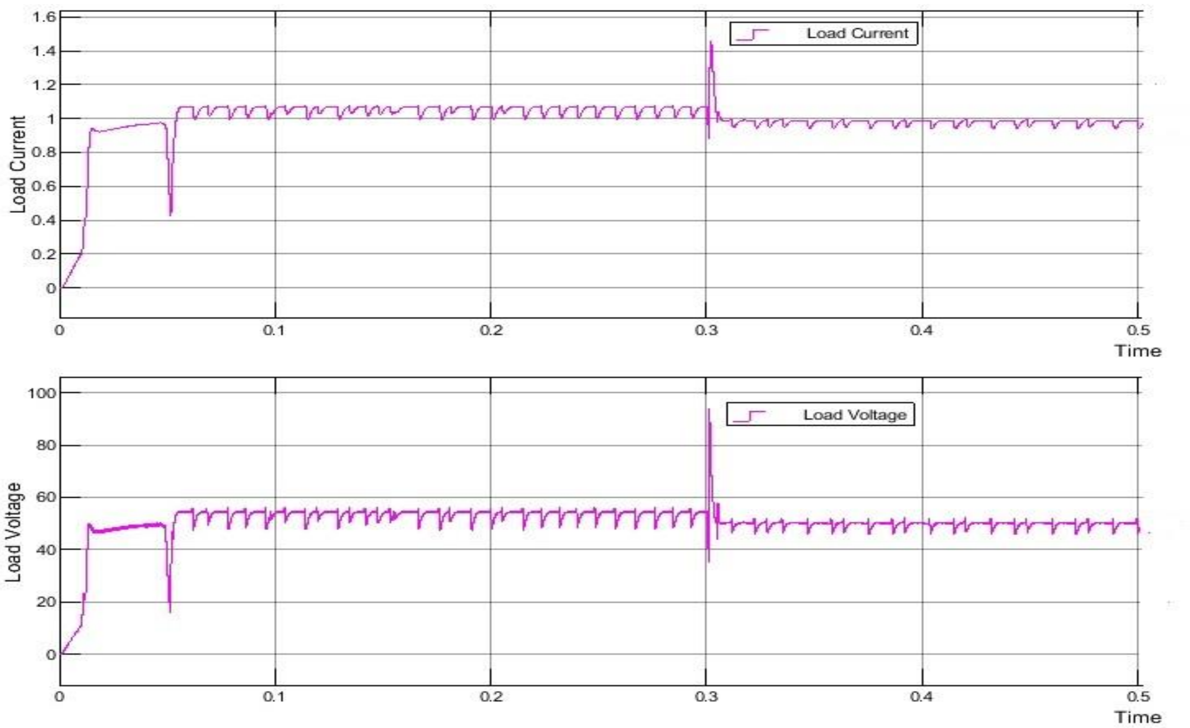

Fig. 7 - Voltage and current variation of SISMC scheme

Moreover, it is measured that the sliding surface duty cycle ratio of the sliding mode MPPT control scheme is at 0.7226 only. Therefore, the sliding duty cycle ratio of SMC scheme is limited to effective dynamic sliding surface switching operation compared to the present SISMC MMPT scheme. This authenticates that, the proposed SISMC scheme is much efficient compared to the sliding mode control MPPT scheme. In addition to this, higher efficiency was measured for the proposed SISMC scheme compared to the efficiency of the Perturb & Observe algorithm reported in literature [17]. Also, it is evident from figure 5 to 7. The minimum error voltage settling time of the proposed SISMC scheme is recorded compared to the SMC scheme. Therefore, the complete performance comparison of the proposed SISMC scheme with SMC scheme and P&O scheme reported in literature [17] is given in table 1.

Table 1 - Comparison of efficiencies of proposed SISMC with SMC scheme and P&O scheme reported in literature [17]

Parameter	P&O MPPT SCHEME	SMC MPPT Scheme	SISMC MPPT Scheme
Settling time	0.6	0.8	0.5
Efficiency	95.6	94.6	96.8
Sliding Surface Duty Cycle Ratio	-	0.7466	0.921

5. Discussion

It output power and voltage variation from the figures 5 and 7 shows the effective performance of the proposed SISMC scheme compared to the SMC control scheme and also with the other schemes presented in literature [17] for partial weather conditions. The sliding duty cycle ratio of the proposed scheme is nearly one compared to the SMC scheme which confirms that the proposed SISMC MPPT scheme provides enhanced sliding switching operation. Also, it is observed from the table 1 that the settling time of the proposed SISMC scheme shows minimum compared to the SMC MPPT scheme. Although, minimum settling time is recorded for the P&O scheme compared both SMC and SISMC MPPT scheme, but this scheme is limited for partial shading weather conditions. This authenticates that, the proposed SISMC schemes offers the mitigation of steady state error potential which allows the enhancement of maximum efficiency of the solar panel during the partial shading weather conditions. Therefore, from the performance analysis presented in above sections the proposed SISMC scheme adequate for partial shading weather conditions compared to the other existing MPPT control algorithm schemes and is limited achieve unity sliding surface switching duty cycle ratio. This may suggest to implantation of other custom device which may increase the cost of the proposed designed system. In view of this, further development is needed in the proposed SISMC MPPT scheme to nullify the overall system design cost.

6. Conclusion

The MATLAB / Simulink design model of proposed single integral sliding mode scheme (SISMC) is presented and analysed with other schemes available. From the presented performance analysis, the following inferences are drawn:

1. The proposed SISMC scheme is records higher solar PV panel efficiency for nonlinear load variations compared to other existing schemes.
2. The enhanced sliding dynamic performance is achieved for the proposed SISMC scheme under partial shading weather conditions compared to the SMC scheme.
3. The improved sliding duty cycle ratio offers the stable and reliable operation with the proposed SISMC scheme.

Therefore, the proposed SISMC scheme is offers enhanced solar PV panel efficiency under partial shading weather conditions compared to other existing schemes.

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