An Experimental Implementation and Testing of GA based Maximum Power Point Tracking for PV System under Varying Ambient Conditions Using dSPACE DS 1104 Controller

Neeraj Priyadarshi*‡, A. Anand*, A.K Sharma*, F. Azam*, V.K. Singh*, R.K Sinha*

* Department of Electrical & Computer Science Engineering, Millia Institute of Technology, Purnea (Bihar), 854301 INDIA

‡ Corresponding Author; Neeraj Priyadarshi, neerajrjd@gmail.com

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Abstract- Maximum power point trackers (MPPT) are required to obtain the accurate and high tracking efficiency from the photovoltaic (PV) panel. In this paper, a genetic algorithm (GA) based MPPT is proposed because of its simple design implementation, high convergence speed and excellent capability to get global peak power point under variable weather conditions. Also, cuk converter based PV power system is selected because of excellent buck-boost power capability, better voltage regulation and lower power losses compared to other dc-dc converter. The proposed MPPT tracker has been tested under steady as well as transient operating conditions. The experimental responses are validated through control data acquisition system of real time dSPACE DS 1104 kit, which provides better performance characteristics with small steady state error compared to conventional MPPT algorithm.

Keywords: Cuk Converter, dSPACE, GA, MPPT, PV.

1. Introduction

Due to gradual depletion of fossil fuels, the requirement of electrical power has increased globally. The renewable energy technology is effective and suitable solution of energy crisis due to its eco-friendly, green and pollution free characteristics. Among all renewable energy sources, the photovoltaic (PV) system is considered as a most promising technology due to its excellent reliability and reduced greenhouse emission [1-5]. However, the present PV system contributes less compared to other renewable sources because of low tracking efficiency and high installation cost. Therefore, there is a need to enhance the tracking efficiency of the present PV system by controlling the maximum power point tracking (MPPT).The MPPT methods provide high tracked efficiency of PV system at any operating conditions [6-10].Several dc-dc converters have been used extensively for the application of PV power generation utility. Due to excellent buck-boost power capability, better voltage regulation and lower switching losses, the cuk converter based PV power system is considered. Also, it comprises current sourcing ability, which makes easy parallel connection of several PV panels at the common point of coupling [11-14].The PV cell output mainly depends on level of irradiance and environmental temperature. The high tracked power from PV panel achieved only when the load impedance is matched with source impedance under specific weather conditions because the maximum power point (MPP) varies corresponding to environmental conditions. The process of obtaining global MPP is called maximum power point tracking (MPPT). The MPPT trackers are needed because of non-linear V-I characteristics. Numerous MPPT controllers have been implemented for efficiency optimization of the PV panel such as perturb and observe (P & O), incremental conductance (INC), fuzzy logic controller (FLC), neuro-fuzzy based MPPT controllers etc [15-18]. The P & O method has less convergence speed and unable to track the peak power under changing weather conditions. The intelligent fuzzy logic and neuro-fuzzy based MPPT work efficiently under rapid changing atmospheric conditions.

The main disadvantages of these MPPT methods are problem of power pulsation, oscillation around MPP and unable to find random search.

Various deficiencies appeared when PV panels are exposed under partial shading conditions. The conventional MPPT methods are failed to obtain the global MPP operating point, therefore the low power yield has been encountered. However, the intelligent fuzzy logic and neural network based MPPT algorithms require extra power controller such as sequential seeking extreme and polar controllers to obtain the accurate performance under partial shading conditions [19].

Kumar et al [20] described maximum power point tracking using Genetic algorithm for photovoltaic system. In this study boost converter has been considered to provide optimal solution to the PV power system using GA algorithm which is realized using MATLAB/Simulink. Nevertheless, the control algorithm has not been realized practically.Dahmane et al [21] discussed GA based MPPT for PV system using MATLAB/Simulink environment. In this research work a boost converter has been employed for MPPT tracking purpose. However, this control algorithm has not validated experimentally under unfavorable weather conditions.

The firefly based MPPT algorithm has more power tracking capability compared to conventional MPPT controllers under partial shading conditions [22-23]. As the firefly algorithm depends on distance from light source, it can communicate within a limited range and has several assumptions to define objective function as well as execution of the algorithm. Moreover, the recent optimized firefly algorithm has more implementation complexity, slow simulation convergence time and require large controlling parameters as a major drawbacks compared to GA based MPPT algorithm. Other drawback of using firefly is that it does not remember any better situation for each firefly which causes the firefly to move regardless of it and so they miss the better situation. Also, the practical implementation of firefly based MPPT method with cuk converter for PV system using dSPACE is more expensive and has high design complexity.

The Moth search based MPPT algorithm provides optimal solution in case of multiple peaks problems. This algorithm is based on movement of moth in night which depends on transverse space orientation and maintenance of fixed angle with reference to moon [24-25]. However, it has low convergence speed, deficient precision and slow processing time compared to GA based MPPT controller.

The global search optimization based proposed Genetic algorithm (GA) is able to get MPP, which overcomes the problems associated with other MPPT methods. There are mainly two important aspects viz. ability to find local maxima and calculation of average fitness function for population on whch GA algorithm is cosidered as best optimized method.

In this research work, Genetic algorithm (GA) based MPPT controller has been discussed which works on evolutionary method. The proposed GA based MPPT has simple design, fast computational convergence speed and capable to find the locus of global peak operating point compared to all intelligent techniques. The GA based MPPT is implemented using MATLAB/simulink and then run using dSPACE DS 1104 real time controller. The practical responses validate the excellent performance characteristics of the proposed MPPT controller. It enhances the response time, system stability and reduces the oscillation around global MPP under varying ambient conditions. The novelty of this research paper is experimental implementation and validation of GA based cuk converter controlled circuit for MPPT using dSPACE DS 1104 interface has neither been discussed nor tested before under varying ambient conditions by authors best knowledge.

2. Mathematical Modeling of Cuk Converter

Among different dc-dc converter, cuk converter has been selected to perform the main functions of MPPT control. In this paper, a cuk converter is employed because of its better efficiency and negligible switching loss characteristics compared to other dc-dc converters. It works as a power interface between PV panel and load. The cuk converter comprises two inductor and capacitor, one anti-parallel diode and switch connected to the load. The capacitor is responsible for energy transfer from source to load.

The cuk converter works in mainly two modes of operation. In first mode of operation, the power switch is ON, so that the capacitor 'C' releases energy to the load while in another mode of operation, the power switch will get switched off and capacitor 'C' will start charging. At input and output stage, the cuk converter operates in current continuous conduction mode. Therefore, no external filter is required to exterminate harmonics contents in input and output side.

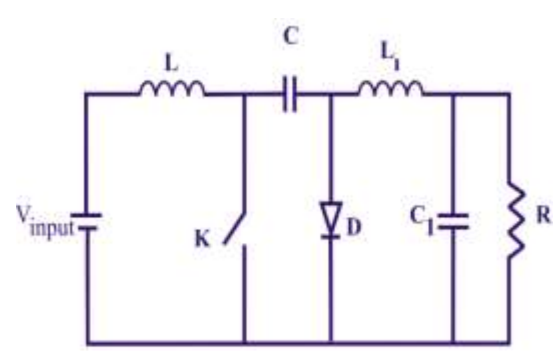


Fig.1. Cuk converter power circuit

By considering the inductor current and capacitor voltage as state variable, the state space analysis of the proposed cuk converter depicted in Fig.1 can be expressed mathematically as:

Case 1: When K is ON and D OFF

Apply KVL

$$V_{inpu} - L\,{dI_L}/{dt} = 0$$

$$L_1\,{dI_{L_1}}/{dt} + V_C + V_{C_1} = 0$$

$$C\,{dV_C}/{dt} - I_{L_1} = 0$$

$$C_1\,{dV_{C_1}}/{dt} - I_{L_1} + {V_{C_1}}/{R} = 0$$

In this mode of operation, the switch K is ON and diode will work on reverse biased operation so that the inductor L will store energy in the form of magnetic field and capacitor 'C' will discharge energy in the form of electric field. State space model becomes in case 1:

$$\begin{bmatrix} {dI_L}/{dt} \\ {dI_{L_1}}/{dt} \\ {dV_C}/{dt} \\ {dV_{C_1}}/{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & -1/L & 0 \\ 0 & 0 & 0 & -1/L_1 \\ 1/C & 0 & 0 & 0 \\ 0 & 1/C_1 & 0 & -1/RC_1 \end{bmatrix} \begin{bmatrix} I_L \\ I_{L_1} \\ V_C \\ V_{C_1} \end{bmatrix} + \begin{bmatrix} 1/L \\ 0 \\ 0 \\ 0 \end{bmatrix} [V_{input}] \qquad (1)$$

Case 2: K is OFF & D ON

In this mode of operation, the switch D will be conducting, so that the capacitor C_1 will be charged from supply.

$$L\,{dI_L}/{dt} - V_{input} + V_C = 0$$

$$L_1\,{dI_{L_1}}/{dt} + V_{C_1} = 0$$

$$C\,{dV_C}/{dt} - I_L = 0$$

$$C_1\,{dV_{C_1}}/{dt} - I_{L_1} + {V_{C_1}}/{R} = 0$$

State space model becomes in case 2

$$\begin{bmatrix} {dI_L}/{dt} \\ {dI_{L_1}}/{dt} \\ {dV_C}/{dt} \\ {dV_{C_1}}/{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & -1/L & 0 \\ 0 & 0 & 0 & -1/L_1 \\ 1/C & 0 & 0 & 0 \\ 0 & 1/C_1 & 0 & -1/RC_1 \end{bmatrix} \begin{bmatrix} I_L \\ I_{L_1} \\ V_C \\ V_{C_1} \end{bmatrix} + \begin{bmatrix} 1/L \\ 0 \\ 0 \\ 0 \end{bmatrix} [V_{input}] \qquad (2)$$

3. Proposed GA based Maximum power point trackers

Several MPPT methods have been used to track the peak power from the PV panels. The conventional P&O method of MPPT are unable to get the global maximum power point (MPP) under varying weather conditions [26]. In this paper natural evolution based GA for MPPT has been discussed to resolve the disadvantages of classical MPPT algorithms. It depends on heuristic search algorithm, which is used as optimization tool.

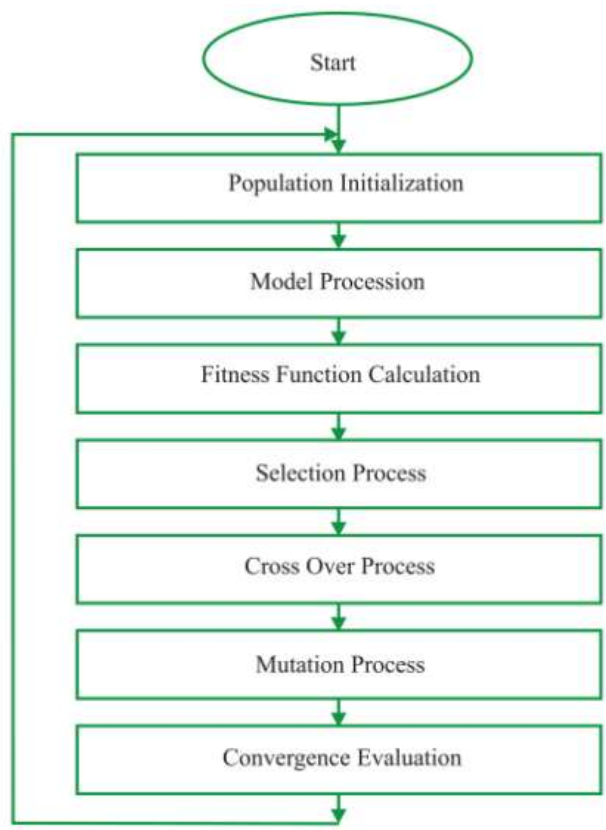


Fig.2. Step by step process of Genetic Algorithm

In case of multiple maximum power point on PV characteristics curve or for partial shading conditions. The conventional P&O method of MPPT algorithms are unable to work properly in first MPP. J. HOLLAND proposed the genetic algorithm in 1970, which is based on natural selection to make optimized potential solution. The specifications of PV modules have been encoded to binary which is treated as chromosomes. By the conversion of binary to real parameters, the chromosome fitness function is calculated.

GA is based on mainly three natural operators as selection, crossover and mutation. Selection is based on fitness function of chromosome by which we select two chromosomes from population. In crossover process and the new chromosome will produce after combination of two chromosomes. Moreover, genetic diversity can be calculated after comparison of present and next generation population. Fig 2 shows the step by step process of GA. MATLAB m-file is used to program the genetic algorithm for which 3 GB RAM and 3.5 GHz system has been used. Table 1 presents the specifications of GA parameters used in this experimentation.

Table1. Specifications of GA Parameters

S.N	GA Parameters	Value
1	Size of Population	4
2	Probability of Mutation	0.1
3	Probability of cross over	0.9
4	No. of iteration	4
5	Sampling Period	0.04

Genetic algorithm is based on principle of Darwin's survival of the fittest theory. Everyone in the population has been represented by some chromosomes, which has own fitness function. The heuristic optimized based search algorithm is applied to the chromosomes. Genetic algorithm is global search based optimization method and it does not depend on initial conditions. Therefore, it is capable to find global maximum power point (MPP).The GA based MPPT are robust, precise, has less damping oscillation, fast computational convergence speed and able to make optimal solution within a specific time interval. Based on the following mathematical relation, the sun insolation has appeared and initial population will get reset.

$$\left|V(N+1) - V(N)\right| < dV \tag{3}$$

$$\frac{\left|P_{PV}(N+1) - P_{PV}(N)\right|}{P_{PV}(N)} > dP \tag{4}$$

Where, dP=0.20, dV=0.5

Also, the mathematical relation between the position of chromosomes and output desired voltage at n iteration can be expressed as:

$$X^{n}{}_{Chromosome} = V^{n}{}_{desired} \tag{5}$$

The duty cycle of the power switch of cuk converter is derived mathematically as:

$$d^{n} = 1 - \frac{\text{Crossover output}}{\text{Chromosome Position}} \tag{6}$$

4. Hardware Structure and Results Discussion

For the verification of effectiveness of the proposed MPPT controller, a cuk converter based standalone PV system has been developed. The GA and P&O MPPT algorithms have been used for benchmark test. Fig.3 shows the practical setup block diagram of the proposed GA based MPPT using real time dSPACE DS 1104 Controller. BP315J PV panel, cuk converter, data acquisition system, dsp card and personal computer are used as major components. The A/D converter, voltage divider, and LTS25-NP current sensors have been used for the purpose of analog to digital conversion and measurement of PV voltage and current. The MATLAB/Simulink structured model is also run through data acquisition dSPACE real time control board. The duty cycle is obtained after connecting PV voltage and current to the GA based MPPT block. The obtained duty ratio is fed to the DS1104SL_DSP_PWM block for generation of gating signal to the power MOSFET. For overvoltage and over current protection purpose, 6N137 based opto-coupler has been employed. The BP315J PV panel has been used as a PV emulator and the different MPPT algorithms have been tested by applying the same irradiance profile using dSPACE board.

The control structure of GA based MPPT has been implemented using MATLAB/Simulink model interfaced with dSPACE DS 1104 control board is shown by Fig.4

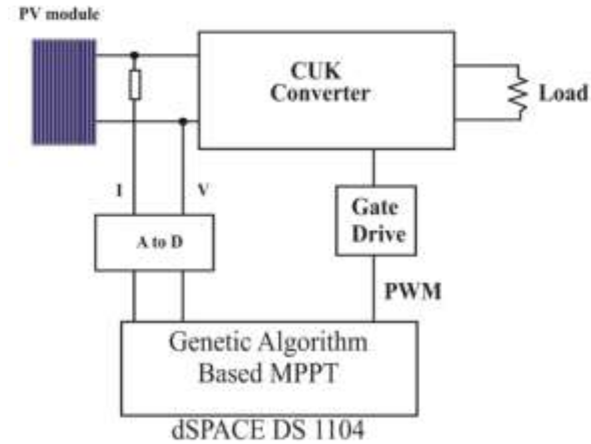


Fig.3. Practical hardware structure of GA based MPPT using dSPACE DS 11O4 interface

The generated duty ratio is directly fed to the DS1104SL_DSP_PWM block for getting PWM switching signal to power switch. The PWM gating signal has been operated at 20 KHz switching frequency. To perform the maximum power point tracking, the cuk converter has been designed physically. The MOSFET based driver circuit is constructed to trigger the power switch of cuk converter.A cuk power converter is adopted as interface between PV and load.

At variable ambient conditions, the behavior of the proposed PV system has been tested for proposed as well as classical P & O MPPT method. The performance of the proposed MPPT controller has been tested at 750 W/m^2 irradiance value. Fig.5 presents the experimental responses of PV voltage and current under steady state condition. It shows the negligible oscillations around MPP and able to track optimum power from the PV panel. As the level of irradiance varies abruptly, the proposed controller is able to achieve new MPP quickly.

Table2. Specifications of 200 W Kyocera KD200GXLPU PV panel

S.N	PV Panel Parameters	Value
1	Maximum Power	200 W
2	Max.Voltage	26.6 V
3	Max. current	7.52 A
4	Open circuit voltage	33.2 V
5	Open circuit current	8.36 A

The range of output signal from A/D converter which acts as an input to the dSPACE board should be -10 to +10.In MATLAB/Simulink model the internal value will be taken as 1 for +10 V signal and should be multiplied by 10 after obtaining from A/D converter. The high switching frequency noise has been removed by the application of filter. The maximum current limit obtained from dSPACE controller is 13mA, therefore the PWM signal cannot be fed directly to the power switch. Hence, an optocoupler has been employed to provide protection from overvoltage and over current. Table 2 portrays the design specifications of 200 W Kyocera KD200GXLPU PV panel used for experimentation.

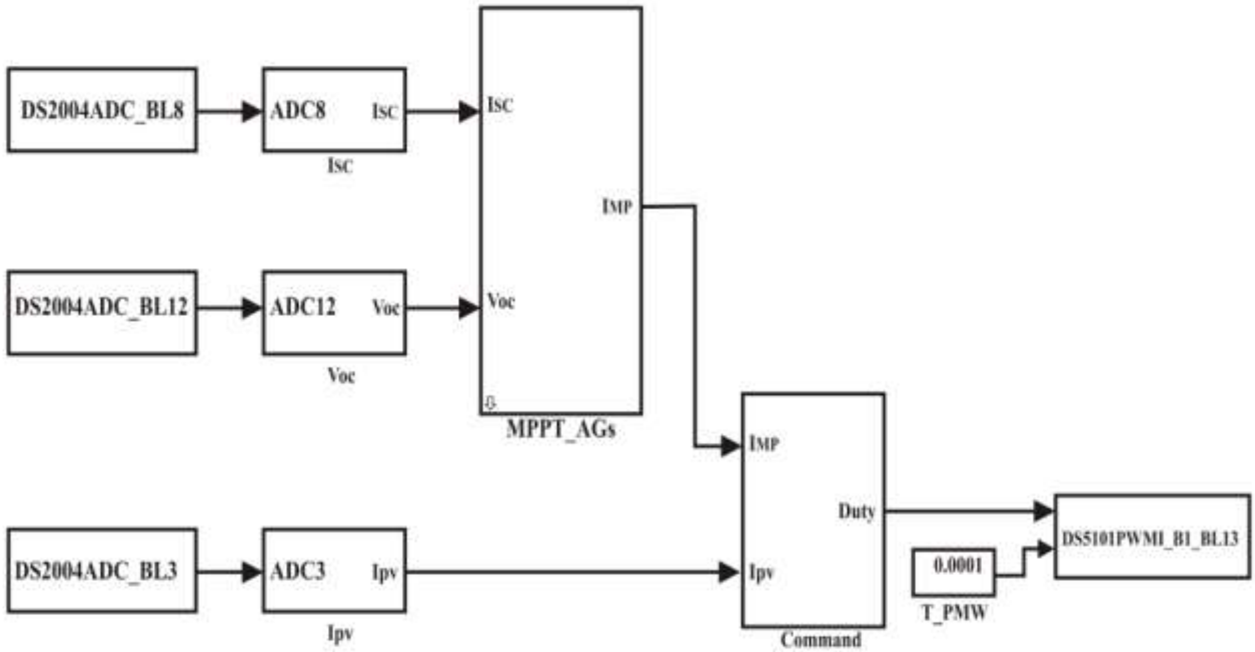


Fig.4. Control model of proposed MPPT using MATLAB/Simulink

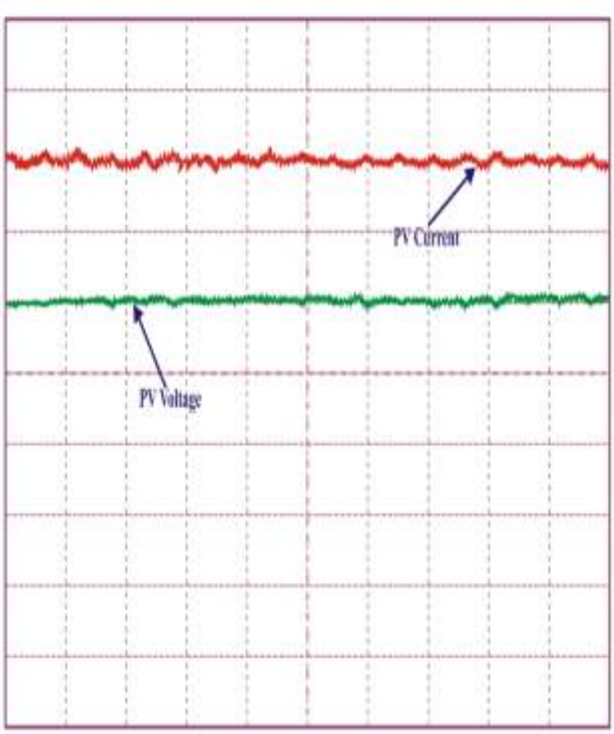


Fig.5. Experimental steady state responses

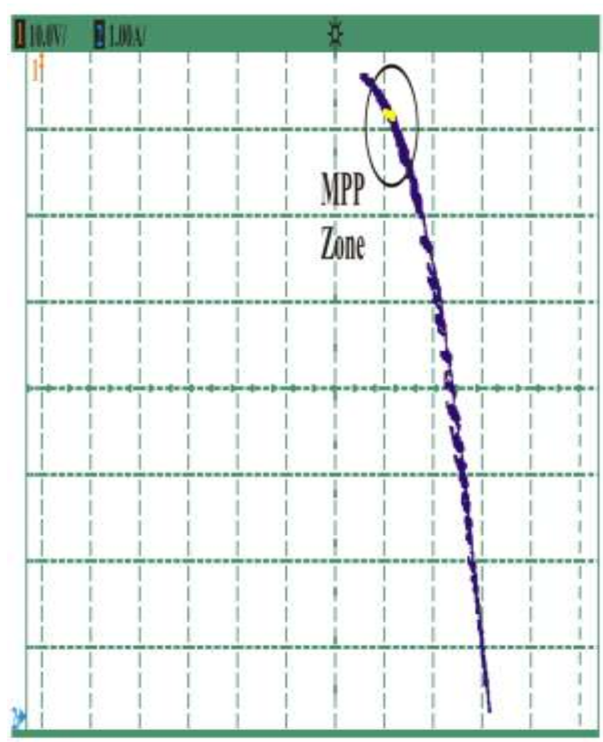
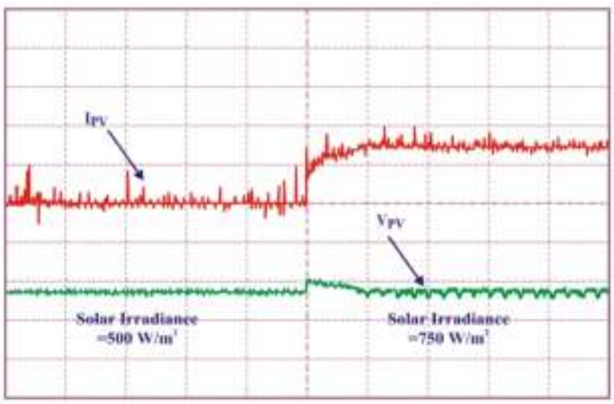
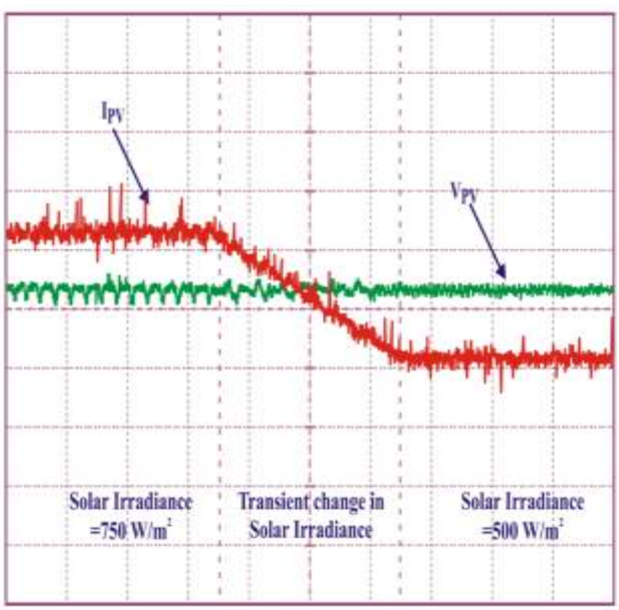


Fig.6. Practical V-I characteristics of the proposed system under steady state condition

Fig.6 depicts the experimental V-I characteristics of the proposed system under steady state conditions, which demonstrates the effective operation of MPP operating zone.

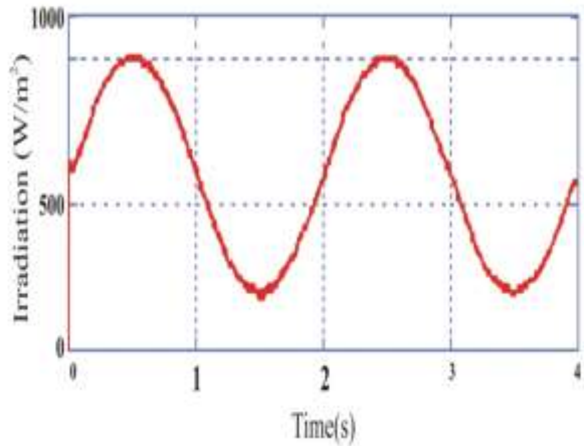


(a)

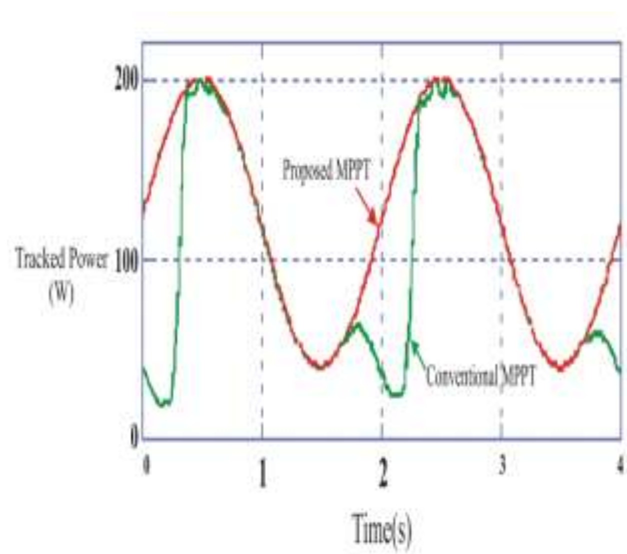


(b)

Fig.7. Practical results (a) during variation in irradiance level (b) Responses during transient in irradiance



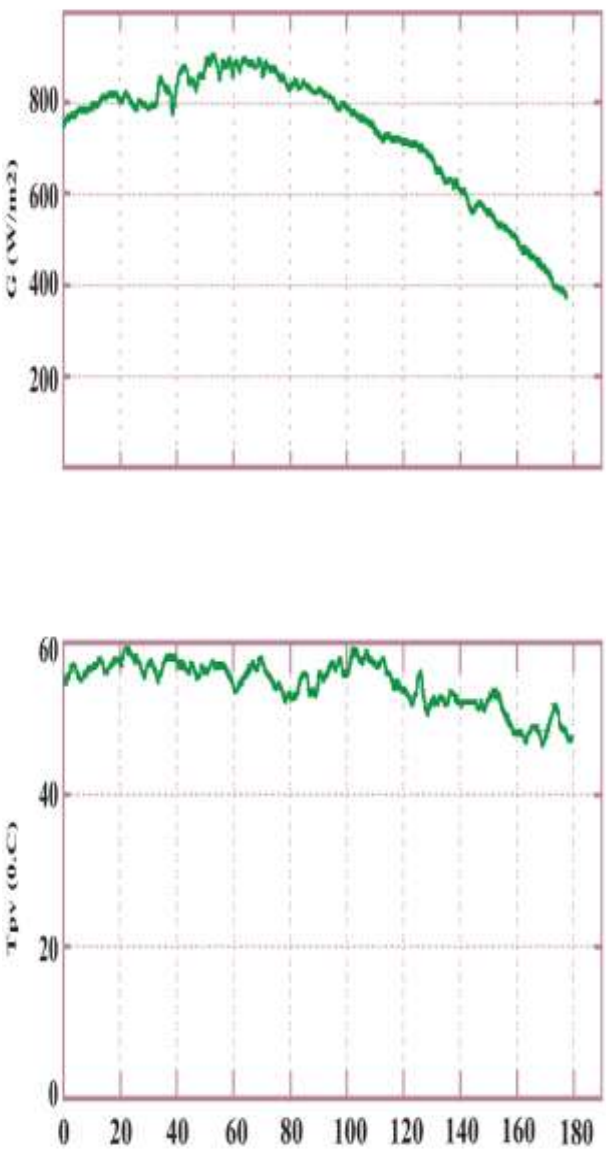
(a)



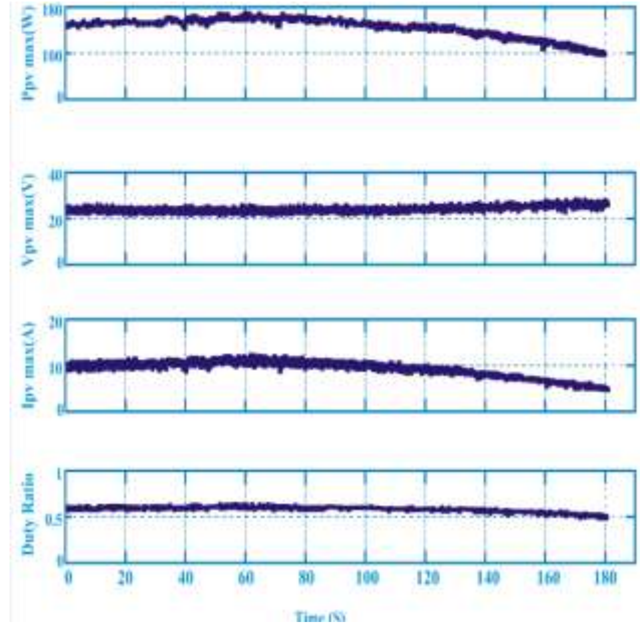
(b)

Fig.8. Practical results (a) Sinusoidal input irradiance level (b) Tracking power comparison

The practical responses of the PV voltage and current have been shown using Fig. 7, when irradiance level changes from 500 W/m^2 to 750 W/m^2 and under transient conditions. The practical results verify that the MPP is achieved rapidly under variable irradiance as well as in transient conditions. The experimental responses validate the rapid and accurate tracking operation of the proposed controller.



(a)



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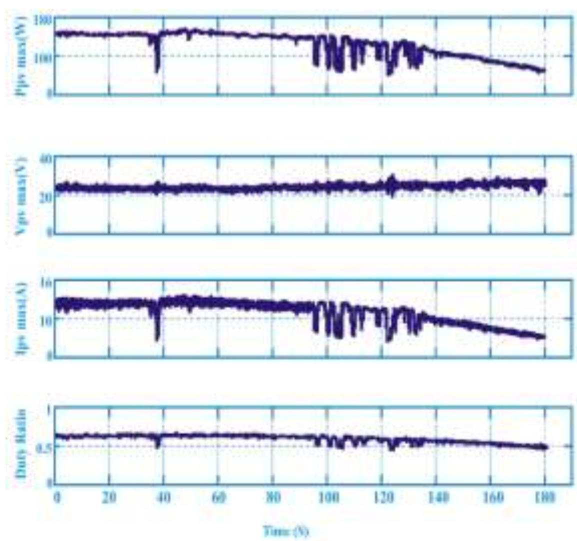


(c)

Fig.9. Experimental responses of (a) Variable irradiance and ambient temperature (b) with proposed MPPT control (c) with conventional P & O control

The proposed GA based MPPT controller is tested experimentally by applying sinusoidal irradiance profile, which is presented in Fig.8 (a). The experimental tracking power of the proposed Vs conventional P & O MPPT method has been explained by Fig 8. From practical results, it is clear that the proposed MPPT tracks the optimal power from the PV panel and lies in the MPP zone compared to the conventional P & O MPPT method.

Under changing environmental conditions, the proposed MPPT controller performs excellently which is explained by Fig.9 (b). It exhibits high tracked efficiency and stable operation under wide range of irradiance change. From practical responses, it is clear that the proposed system operates in peak power zone during variable weather conditions.

Moreover, the performance of the proposed MPPT method has been compared experimentally with conventional P & O control under variable irradiance and temperature. The tracking response of GA based MPPT method is faster compared to classical P & O MPPT algorithm. Fig.9 (b) & (c) shows the practical response of PV voltage, current, power and corresponding duty ratio using proposed and conventional MPPT controller. The GA based MPPT controller has accurate and precise power tracking ability compared to P & O MPPT method. The practical results validate the excellent performance of the proposed GA based MPPT controller under steady as well as dynamic conditions. Fig. 9(a) shows the experimental test conditions of variable irradiance and ambient temperature applied to MPPT controllers. The practical PV tracked voltage, current, power and corresponding duty cycle is obtained by the application of GA based MPPT algorithm, which has accurate and high tracked maximum power. However, the conventional P &O based MPPT methods have been also tested under these environmental conditions.

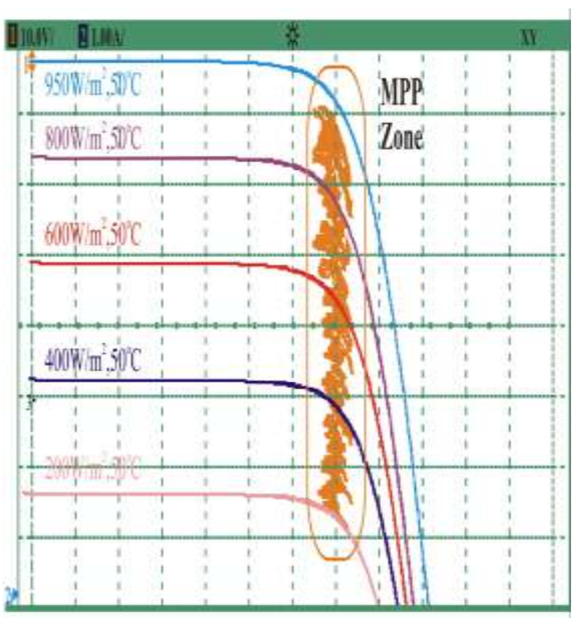


Fig.10 Experimental V-I characteristics of the proposed system under variable irradiance level

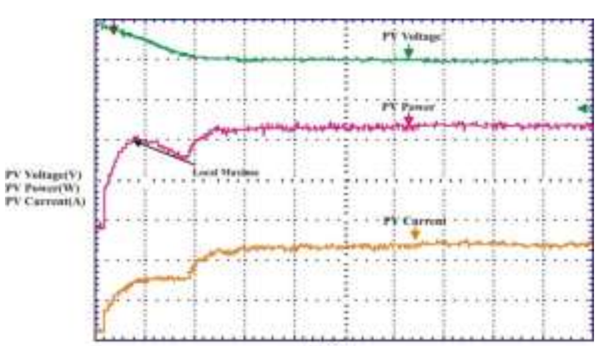
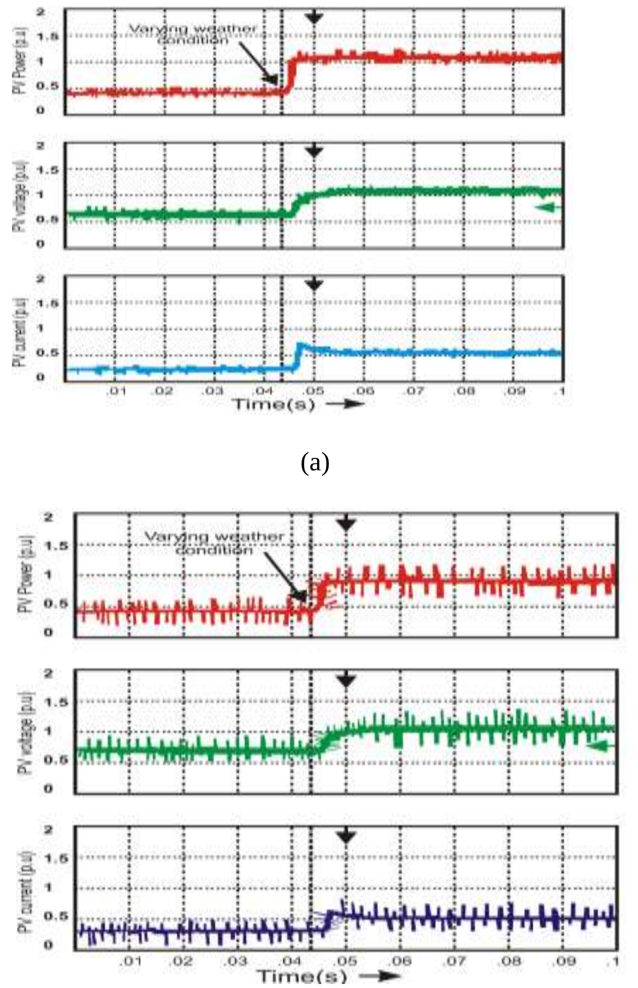


Fig.11. Experimental results of PV voltage, current and power during partial shading condition



(a)

(b)

Fig.12. Practical results of PV voltage, current and power (a) Proposed MPPT controller (b)Conventional P & O MPPT Controller

Fig. 9 (c) demonstrates that the conventional P & O MPPT control is unable to track maximum power with less accuracy and has high oscillation around MPP. The practical V-I curve of proposed PV system is presented by Fig. 10,which shows that the system operates always in peak power point region under variable irradiance.

I-V characteristics is found by programming the PV simulator and peak MPP operating point has been obtained with small oscillation in relatively low time interval under partial shading conditions. Fig 11 portrays the experimental responses of PV voltage, current and power during this condition.

The hardware responses using proposed GA based MPPT and classical P & O MPPT are depicted in Fig.12. From practical results, it is clear that the MPP and peak power zone has been obtained within a short time interval and has less oscillation around MPP compared to classical P & O MPPT method.

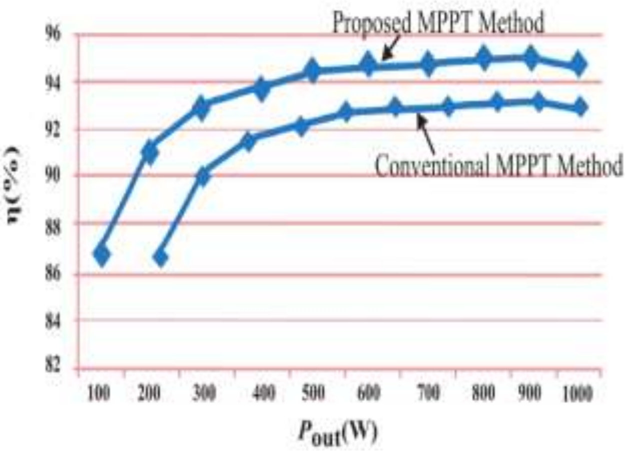


Fig.13. Practical tested efficiency curve of the proposed MPPT versus conventional P&O MPPT.

The practical tested efficiency curve of the proposed MPPT versus conventional P & O MPPT methods has been presented by Fig.13. From tracking curve, it is evident that the GA based MPPT has high power tracking ability compared to conventional P&O based MPPT method.

A hardware structure has been built which is shown in Fig.14 to verify the effectiveness of the proposed MPPT controller. It contains cuk power converter based MPPT controlled by GA algorithm using dSPACE DS 1104 controller interface. Also, a programmed dc supply based PV emulator is employed to plot the V-I characteristics of PV array. Moreover, a BP315J PV panel as a PV emulator is used and proposed GA with P&O MPPT algorithms have been tested by applying the same irradiance profile using real time dSPACE board.

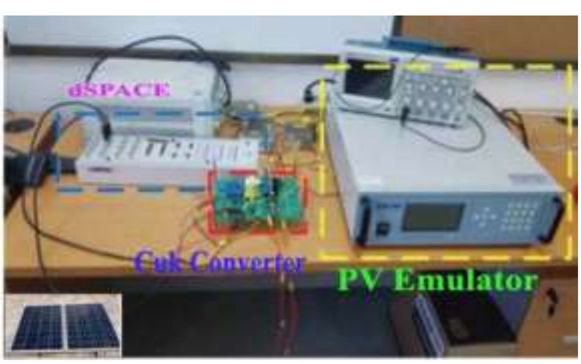


Fig. 14. Experimental developed GA based MPPT system using dSPACE control board

5. Conclusion

In this research paper, a genetic algorithm based maximum power point trackers has been implemented experimentally using dSPACE DS 1104 controller interface. The experimental results confirm that the proposed GA based MPPT algorithm is able to solve the multiple MPP problems associated with classical P&O algorithm. It has more power handling capability, low power losses, high tracking efficiency and zero steady state oscillation compared to conventional P&O MPPT algorithm.The practical responses verify that the proposed MPPT controller is working accurately and efficiently under variable irradiance and ambient temperature. Compared to conventional MPPT methods, the proposed GA based MPPT method has fast computational convergence speed, no divergence from MPP, accurate response time and high tracked efficiency under steady and dynamic operating conditions. For this purpose, a cuk converter has been employed due to its excellent buck-boost capability, negligible losses and better voltage regulation.

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