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COMPARATIVE STUDY OF STANDALONE SPV FOR ENVIRONMENTAL CONDITION OF RAJASTHAN

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Abstract— *This paper presents performance of a photovoltaic electric energy stand alone generating system interfaced with various power electronics converter. It also presents theoretical studies of photo-voltaic and modeling techniques using equivalent electric circuits. It also deals with the analysis, design and control of a power standalone solar photovoltaic (SPV) generating system. Various maximum power point tracking techniques are being reviewed and are compared with each other for different application's specification. In this work we have reviewed Perturbation and Observation (P&O) method, IncrementalConductance (I&C) Method and Modified Regula Falsi Method (MRFM) for maximum power point tracking (MPPT). The various MPPT algorithms and control methods are being investigated and discussed. The matlab simulation is carried out for analysis with various converters. A standalone PV system with Input voltage 20 – 48 V, Output voltage 110V, and maximum output power 250W has been designed for the verification purpose. The model of PV system and converter has been simulated in MATLAB. A comparison has been drawn through simulation for system with and without MPPT in terms of total energy produced per day. The results confirm that MPPT can considerably increase the efficiency and the performance of PV system as compared to the system without MPPT. The simulation results obtained are compared for maximum output, voltage regulation. In this work we have used fly back, cuk buck boost converter for extracting maximum power from SPV system. The stand alone PV system thus obtained has been tested under conditions of high temperature and high irradiance virtually on software environments. Converter are modeled and simulated through coding in Matlab. The result show that for given temperature and irradiance and time period a standalone PV energy generation system gives more output with fly back converter.*

I. INTRODUCTION

Rajasthan is blessed with two critical resources that are essential to solar power production: high level of solar radiation per square meter and large amounts of adjacent, relatively flat, undeveloped land. It is apparent from the map below that the western states have the highest levels of solar radiation. The most intense solar radiation in the India is located in Rajasthan.

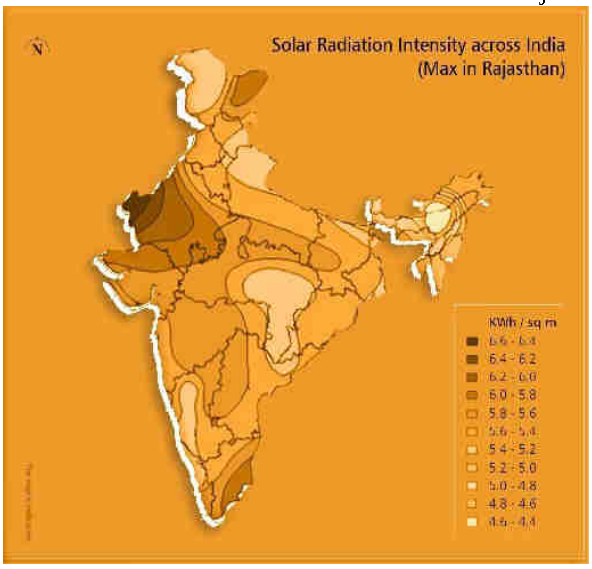

Fig. 1 Map of solar radiation levels in India

Rajasthan is uniquely placed to tap solar radiations with 300-330 clear sunny days and average daily solar incidence of 5-7kWh/m^2 that is comparable to Deserts of California, Nevada, Colorado and Arizona. The total desert area in the State is 208,110sq.kms. 60% of the land is arid and semi-arid land in the State.

Throughout Rajasthan throughout the summer months one per year generally there remains to be a lack of 30% of energy demand from customers which is not attained by simply its very own sources and should not keep tempo together with the swift rise in strength demand. In addition, regarding 60 % in the human population day-to-day lives using some 60,000 towns tossed through the state. Most of these towns tend to be considerably from your country's power company regarding television broadcasting wrinkles as well as, for their compact human population, it is almost always never fiscally helpful to be connected the whole village towards grid. Solar power offers the prospective proficient throughout Rajasthan which obtained levels of photovoltaic the radiation in the year. Throughout Rajasthan photovoltaic PV tissue may be used to change solar panel technology into electricity which may be used to ask for the battery to offer lighting style at night. Solar panel made power can be utilized right to water pump, to perform the admirers, with regard to lighting style, radio as well as television. Solar is actually an alternative energy source of information prospective obtainable in the country. The following source of information can be used as a superb alternative to fossil fuels because of areas. Solar power source of information blueprints with regard to profitable use with regard to household apps as well as strength remote control towns during these areas. Resulting from this system would be to boost interpersonal, health benefits as well as supply regarding fundamental facilities regarding life. PV photovoltaic (SPV) devices change sunlight right into electricity. Little power program will allow the home owner to obtain several as well as a bunch of their each day power demand from customers automatically top , swapping day time unwanted power for the strength desires at nighttime employing SPV age group , if it's held by battery power back-up. A new SPV power program may be used to crank out electricity as an approach regarding dispersed age group (DG) with regard to out of the way areas.

II. DESIGN, SIMULATION AND ANALYSIS

In this chapter I have presented design and simulations of MPPT. It discusses about and flyback and Cúk converter design. First of all components have been selected, than design and choice of the MPPT sampling rate has been validated through MATLAB simulations. A comparative study has been done between various MPPT algorithm using MATLAB simulations. Than by considering a resistive load the functionality of MPPT will be verified with flyback and Cuk converter. At the end of this chapter comparisons between systems equipped with different MPPT and coupled with the two converters is provided.

For this work I have considered PV module "PV-MLU250HC" manufactured by "MITSUBISHI ELECTRIC" with the following specification, which are able to work at high temperature conditions as like in Rajasthan.

Specification	Maximum Power (Watt)	Open Circuit Voltage (V_{oc})	Short Circuit Current (I_{sc})	Voltage at MPPT (Vmpp)	Current at MPPT (Impp)	No. of Cells in Series	Normal operating cell temperature
Value	250	37.6	8.79	31	8.08	20	45.7

The converters are designed according to the following specifications: Input voltage 20 – 48 V, Output voltage 110V, and maximum output power 250W.

Comparison of MPPT Techniques

The three MPPT algorithms, perturbation and optimization (P&O), Incremental and Conductance (InC) and modified Regula Falsi algorithms (MRFA), discussed in chapter 5 are implemented in MATLAB simulations and tested for their performance. Since the purpose is to make comparisons of the considered algorithms, each simulation contains only the PV model and the algorithm in order to isolate any influence from a converter or load.

MATLAB scripts for this section are given in appendix. The algorithms are tested with actual irradiance data provided. Simulations use set of data, which is the measurements of a sunny day in April in Jodhpur, Rajasthan. The data contain the irradiance measurements taken every two minutes for from morning 7 am to 9 am. On a sunny day, the irradiance level changes gradually since there is no influence of cloud. MPP tracking is supposed to be easy.

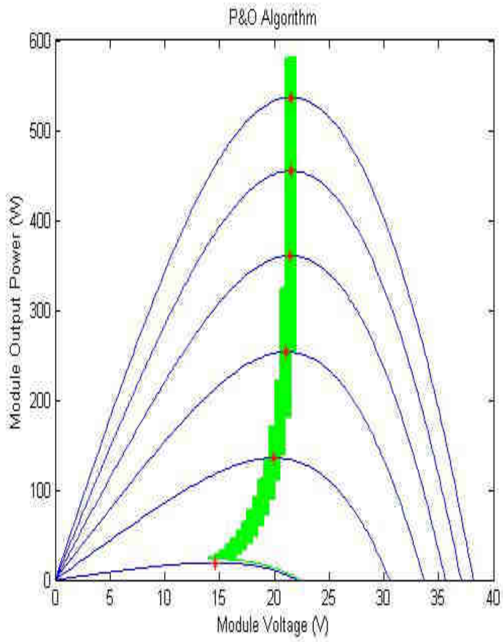

Fig. 2 MPP tracking by P&O algorithms on a sunny day.

As shown in Fig.2,3,4. all three algorithms locate and maintain the PV operating point very close to the MPPs (shown in red asterisks) without much difference in their performance. Fig. 6.1 ,6.2.6.3 shows the trace of PV operating points for (6.1)P&O algorithm and (6.2) Inc-Cond algorithm (6.3) MRFA algorithm. For all the three algorithms, the deviations of operating points from the MPPs are obvious when compared to the results of a sunny day. Among the three algorithms, the MRFA algorithm is supposed to outperform the other two algorithm under rapidly changing atmospheric conditions.

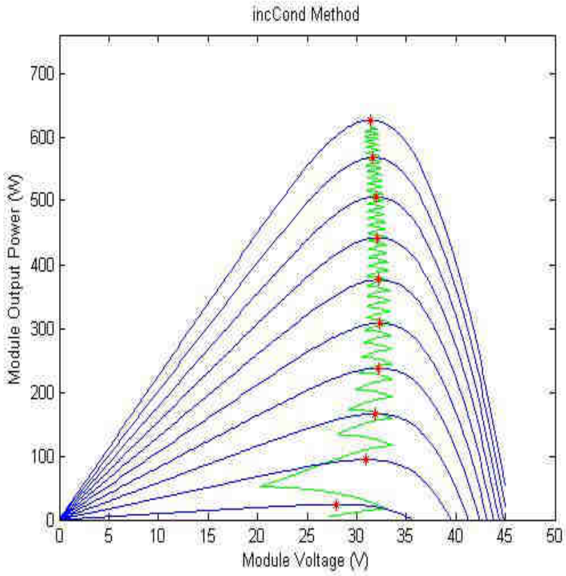

Fig. 3 MPP tracking by Inc-Cond algorithms on a sunny day.

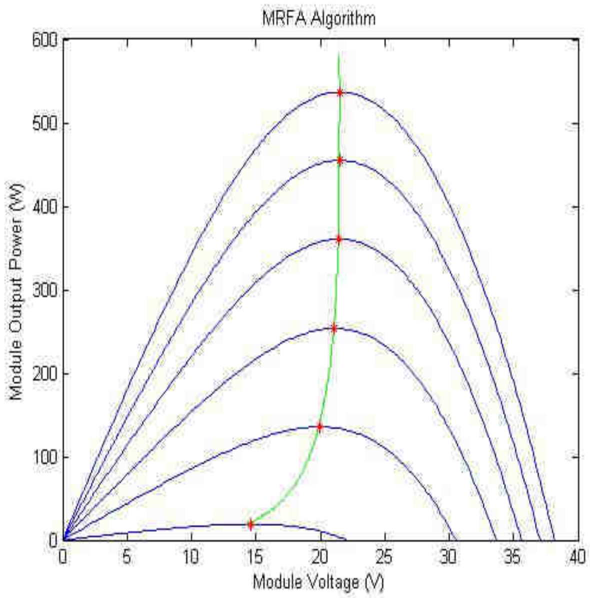

Fig. 4 MPP tracking by MRFA algorithms on a sunny day.

In order to make a better comparison, total electric energy produced during a 2-hour period is calculated and tabulated in Table 6.2

	P&O Algorithm	IncCond Algorithm	MRFA Algorithm
Total Energy (simulation)	320.3666	318.6716	320.7406
Total Energy (theoretical max)	320.8361	320.8361	320.8361
Efficiency	99.85%	99.33%	99.97%

Total electric energy produced with the MRFA algorithm is narrowly larger than that of the Inc-Cond algorithm and P&O algorithm. The MPP tracking efficiency measured by {Total Energy (simulation)} ÷ {Total Energy (theoretical max)} ×100% is still good in the cloudy condition for both algorithms, and again it is narrowly higher with the MRFA algorithm. The irradiance data are only available at two-minute intervals, thus they do not record a much higher rate of changes during these intervals. The data may not be providing a truly rapid changing condition, and that could be a reason why the two results are so close. Also, further optimization of algorithm and varying a testing method may provide different results. The performance difference among the three algorithms, however, would not be large. There is a study showing similar results. The simulation results showed the efficiency of 99.85% for the P&O algorithm, 99.33% for the inc-Cond algorithm and 99.97% for the MRFA algorithm.

Cuk Converter Design

The basic principle and working and voltage transfer function of Cuk Converter is already explained in chapter 5. Now we design a Cuk converter based on the specification as given below. After calculation of component values, the design is simulated in MATLAB.

Specification	Input Voltage (*Vs*)	Input Current (*Is*)	Output Voltage (*Vo*)	Output Current (*Io*)	Maximum Output Power (*Pmax*)	Switching Frequency (*f*)	Duty Cycle (*D*)
Value	20-48	0-8	110	0-8	250 W	50K Hz	0.1<D<0.65

Component Selection

a) Inductor Selection

The inductor sizes are decided such that the change in inductor currents is no more than 5% of the average inductor current. The following equation gives the change in inductor current.

$$\Delta i_L = \frac{V_s.D}{L.f} \qquad (6.1)$$

where: Vs is the input voltage, D is the duty cycle, and f is the switching frequency. Solving this for L gives:

$$L = \frac{V_s.D}{\Delta i_L . f} = \quad (6.2)$$

Assume that the worst current ripple will occur under the maximum power condition. Under this condition, the average current (I_{L1}) of the input inductor (L_1) is 8 A, and the ripple current is 5% of I_{L1}.

$$\Delta i_{L_1} = 0.05.I_{L1} = 0.3A \quad (6.3)$$

Thus, from the equation (6.2):

$$\Delta i_{L_1} = 0.05.I_{L1} = =2.4 \quad (6.4)$$

Similarly, the value of the output inductor (L_2) is calculated as follows.

$$\Delta i_{L2} = 0.05.I_{L2} = 0.3A \quad (6.5)$$

$$L_2 = \frac{V_s.D}{\Delta i_{L2} . f} = 1.5mH \quad (6.6)$$

To make parts procurement easier, the output can use the same inductor size as one in the input.

b) Capacitor Selection

The design criterion for capacitors is that the ripple voltage across them should be ess than 5%. The average voltage across the capacitor (C_1) is, from the equation (5.2), $V_{c1} = V_s + V_o$= 45 + 110 = 155V, so the maximum ripple voltage is Δv_{c1} = 0.05 × 155 = 7.75V.

The equivalent load resistance is:

$$R = \frac{V_o^2}{P_o} = \frac{110^2}{250} = 48.4\Omega \quad (6.7)$$

The value of C_1 is calculated with the following equation:

$$C_1 = \frac{V_o.D}{R.f.\Delta v_{c1}} = 2.9326\text{e-}06 \quad (6.8)$$

The value of the output capacitor (C_2) is calculated using the output voltage ripple equation (the same as that of buck converter).

$$\frac{\Delta v_o}{V_o} = \frac{1-D}{8.L_2.C_2.f^2} \quad (6.9)$$

Solving the above equation for C_2 gives:

$$C_2 = \frac{1-D}{8.L_2.\Delta v_o / V_o . f^2} = 55.6\text{mf} \quad (6.10)$$

c) Diode Selection

Schottky diode should be selected because it has a low forward voltage and very good reverse recovery time (typically 5 to 10ns). The recurrent peak reverse voltage (V_{RRM}) of the diode is the same as the average voltage of capacitor (C_1), thus V_{RRM} = 82 V. Adding the 30% of safety factor gives the voltage rating of 107 V. The average forward current (I_F) of diode is the combination of input and output currents at the SW off, thus it is $I_D = I_{L1}+I_{L2}$ = 16 A. Adding the 30% of safety factor gives the current rating of 20.8A.

d) Switch Selection

Power-MOSFETs are widely used for low to medium power applications. The peak voltage of the switch (SW) is obtained by KVL on the circuit shown in Fig. 5.3.

The voltage of SW could go up to 56 V by the specification. Adding the 30% of safety factor gives the voltage rating of 73 V. The peak switch current is the same as the diode. Thus, adding the 30% of safety factor gives the current rating of 10.4 A.

Fly-back Converter Design

A flyback converter is a simplest topology of isolated DC-DC converter because it has only one switch, one transformer and there is no inductor at output stage. In the flyback converter, during on time of the switch, the energy is stored in the flyback transformer while the load current is supplied by the output capacitor and during off time of the switch, the stored energy in the flyback transformer is delivered as the load current and to the capacitor for charging. In the flyback converter, the duty cycle is restricted up to 50%. This is due to time required to empty the flyback inductor flux to the output capacitor. The different components of the flyback converter are designed using basic equations. Table 6.4 shows the design equations for the proposed flyback converter. Here this flyback converter is designed with a 100 kHz switching frequency in DCM operation. The solar PV panel supplies at 20 – 48 V with a little variation in the voltage to the converter, where it converts it to 110 V DC. Using equations given in Table 6.4, the parameters are calculated for the flyback converter at rated power of 250W.

Name of	Component Equation for Flyback	Calculated Value
Turns Ratio	$n = \frac{N_2}{N_1} = \frac{\eta D_{max} V_{in}}{(1-D_{max})V_o}$	1/11
Magnetizing Inductance	$L_{in(max)} = \frac{V_{in} D_{max}}{f \Delta i_{L_m}}$	1.2Mh

Output Capacitance	$C_o = \frac{V_o.D_{\max}}{f.R_L.\Delta v_c}$	11µF
Switching Frequency	f	100kHz

Considering, f (Switching Frequency of converter switches)=100kHz, L_m (magnetizing Inductance)=1.2µH, V_o(output voltage)=110 V, V_{in}(Input voltage)= 20-48 V, C_o (output capacitance, $n=N_2/N_1$ (turns ratio for flyback transformer), P_{max} (maximum output power)=250W, D_{max}(maximum duty cycle for operation in DCM)=0.5, η=90%, Δv_c (allowed ripple voltage across the output capacitor) =1% of rated output voltage = 1.1 V.

III. SIMULATIONS WITH RESISTIVE LOAD

The simulation results in section 6.1 have shown that there is no great advantage in using the more complex Inc-Cond algorithm, and the P&O algorithm provides satisfactory results even in the cloudy condition. On the other hand MRF algorithm is fastest among the three and searched the MPPT voltage fast with sharp and stable point of reference at MPP. But, the selection of the P&O algorithm permits the use of the output sensing direct control method which eliminates the input voltage and current sensors.

The simulated system consists of the "PV-MLU250HC" PV model, the ideal converters, the MPPT control, and the resistive load. The MATLAB function that models the PV module is given by the following function whose coding given in appendix A.

function [I] = MLU250HC(V,G,TC) (6.11)

The function, "MLU250HC", calculates the module current (I) for the given module voltage (V), irradiance (G in KW/m^2), and module temperature (T in C^0). The operating point of PV module is located by its relationship to the load resistance (R) as:

$$R = \frac{V}{I} \quad (6.12)$$

The irradiance (G) and the module temperature (T) for the function are known variables, thus it is possible to say that I is the function of V hence I = f(V). Substituting this into the equation (6.12) gives:

$$V - R.f(V)=0 \quad (6.13)$$

Knowing the value of R enables to solve this equation for the operating voltage (V). MATLAB uses fzero function to do so, back to the equation (6.12) gives the operating current (I).

The following flowchart, shown in Fig. 6.4, explains the operation of the simulated system.

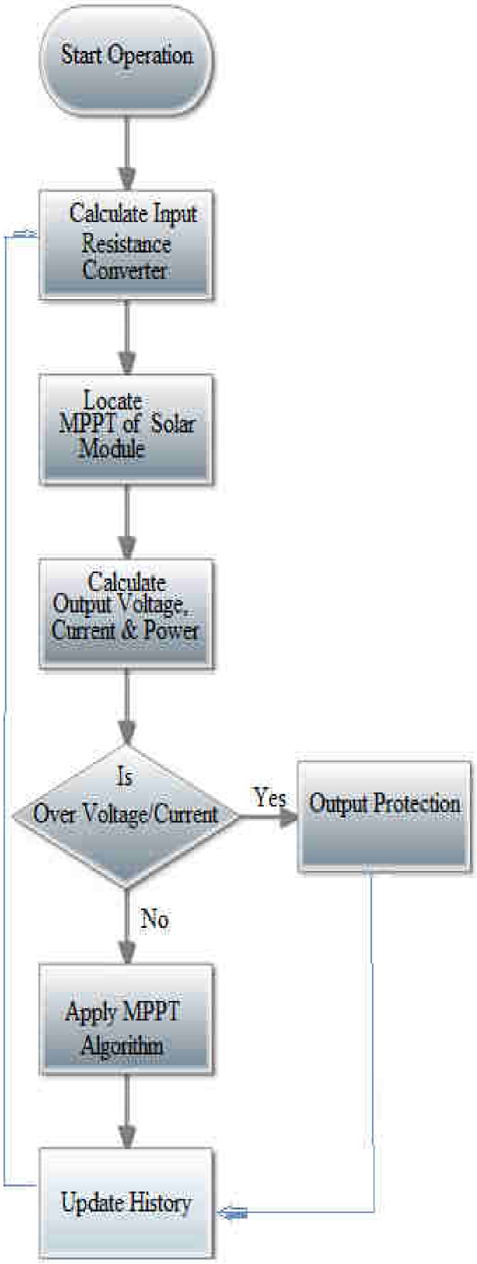

Fig. 5 Operation algorithm of SPV with power conditioning converter.

Simulation stand-alone PV system with Cuk converter

For the simulation of standalone PV energy generation system, we will use MRFA algorithms to calculate reference voltage for the converter operation. As in section 6.2 we have found that MRFA algorithms calculate stable and more accurate MPPT reference voltage with less number of iterations. So it is fast in calculation.

For a Cuk converter relation between a constant output voltage and variable input voltage as described as in section 5.2 is re-written here

$$\frac{V_o}{V_s} = \frac{D}{1-D} \quad (5.10)$$

And current at output is given by

$$\frac{I_{L1}}{I_{L2}} = \frac{D}{1-D} \quad (5.11)$$

Now, duty cycle is varied according to reference voltage calculated by MPPT tracking algorithm for keeping output voltage constant so the household loads may be supplied directly or battery load may be charged.

A matlab simulation codes has been written and presented in appendix for the SPV generation system interfaced to household resistive load via Cuk converter.

Simulation conditions are:

- Output Voltage = 110V constant
- MPPT technique employed MRFA technique
- Load = 6 ohm resistive
- Interfacing converter is Cuk converter
- Clear weather condition on some summer day for morning 2 hours when temperature as well as irradiation rises continuously in western Rajasthan.

Result:
Average power obtained = 314.0585 Watt

Simulation stand-alone PV system with Fly-back converter

For the simulation of standalone PV energy generation system, we again ues MRFA algorithms to calculate reference voltage for the converter operation. As described in section 6.2 we have found that MRFA algorithms calculate stable and more accurate MPPT reference voltage with less number of iterations. So it is fast in calculation.

For a flyback converter relation between a constant output voltage and variable input voltage as described as in section 5.3 is re-written here

$$V_o = V_s \frac{D}{1-D}\left(\frac{N_2}{N_1}\right) \quad (5.17)$$

And output current for given duty ratio, input and output voltages is given by

$$I_o = \frac{V_s D}{(1-D)^2 R}\left(\frac{N_2}{N_1}\right)^2 \quad (5.18)$$

For fly-back converter also a matlab simulation codes has been written and presented in appendix for the SPV generation system interfaced to household resistive load via fly-back converter.

Simulation conditions are same as were kept for Cuk converter:

- Output Voltage = 110V constant
- MPPT technique employed MRFA technique
- Load = 6 ohm resistive
- Interfacing converter is fly-back converter
- Clear weather condition on some summer day for morning 2 hours when temperature as well as irradiation rises continuously in western Rajasthan.

Result:

Average power obtained = 322.1569

IV. CONCLUSION

In this paper we have presented the performance of a photovoltaic electric energy stand alone generating system interfaced with various power electronics converter. In this we have also presented theoretical studies of photo-voltaic and modelling techniques using equivalent electric circuits. We have also dealt with the analysis, design and control of a power standalone solar photovoltaic (SPV) generating system. Here, we have reviewed Perturbation and observation (P&O) method, Incremental Conductance (I&C) method and a new Modified Regula Falsi Method (MRFM) method for maximum power point tracking (MPPT). The matlab simulation is carried out for analysis with two most popular converters found in literature survey for our state weather conditions of high temperature and high irradiance power per unit area. A comparison has been drawn through simulation for system with various MPPT in terms of total energy produced for given time. The results confirm that MRFA MPPT can considerably increase the efficiency and the performance of PV system as compared to the system with other MPPT techniques. Further we employed two most popular converter Cuk and fly-back converter in our SPV system. With fly-back converter we obtained higher average power with all other conditions kept same. So obviously fly-back converter will be better choice for conditions of Rajasthan in stand-alone SPV system.

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