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Design of an Input and Output Linearization Based Enhanced Maximum Power Point Tracking

Jeyabalan.C, M.bhavani,

PG Scholar, Department of Power System Engineering, Anna University Regional Campus, Madurai, Tamil Nadu, India[1]

Assistant Professor, Department of Electrical and Electronics Engineering, Anna University Regional Campus, Madurai, Tamil Nadu, India[2]

ABSTRACT: An Enhanced maximum power point (MPPT) control algorithm is proposed for grid connected photovoltaic (PV) system. An advanced power control strategy by limiting the maximum feed in power of PV systems has been proposed, which can ensure a fast and smooth transition between maximum power point tracking and constant power generation (CPG), Regardless of the solar irradiance levels, high performance and stable operation are always achieved by the proposed control strategy. It can regulate the PV output power exact cancellation of the nonlinear dynamics in order to obtain the maximum point without stability problems, Experimental results have verified effectiveness of the proposed CPG control in terms of high accuracy, fast dynamic, and stable.

I. INTRODUCTION

Maximum Power point tracking (MPPT) operation is mandatory for grid connected PV systems in order to maximize the energy yield. Basically there are direct and indirect methods area proposed for MMP tracking. Direct methods operate through sensing input or output of the converter signals and directly adjust the duty cycle of the same converter. Indirect method operates in conjunction with a closed-loop control strategy and search for the MPP Point. Generally perturb and observe and incremental conductance are the two methods used for maximum power tracking. Closed loop controls such as the PID and fuzzy are used for the indirect maximum power point tracking.

The aim of MPPT is to regulate the actual operation voltage of PV panel to the voltage at MPP. For this purpose, MPPT adjusts the output power of inverter or DC converter .If the PV output voltage is higher than MPP voltage, then transferred power to the load or network is increased, otherwise, it is decreased. The main criteria taken into consideration in the selection of MPPT algorithms are summarized below.

(i) Ease of Implementation. Some techniques consist of analog circuits and others are digital. Sometimes digital MPPT algorithms may require software and programming.
(ii) The required number of sensors. Voltage measurement is usually easier and more reliable than current. Current sensors are also often expensive and cumbersome structure. The sensors measure the light level are not easy to find. Therefore, these features should be considered in MPPT design stage.
(iii) Due to a partial shading on PV, panels can affect the normal operation of the MPPT. If the selected algorithm is too sensitive, virtually MPPT that occurred by shading may be tracked. As a result of this, significant power losses may arise.
(iv) Determination of the cost of an MPPT algorithm is not easy before implementation. Accurate cost compassion depends on system features such as analog or digital, software and programming requirements, and number of sensors. Generally analog algorithms are cheaper than digital ones
(v) Different MPPT techniques are suitable for different applications. In each system, an algorithm may not give the same result.

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PMPPT represents the output power of PV system with MPPT, and Pm axis the output power at true maximum power point. It was obtained as a result of experimental studies that MPPT efficiency varies depending on cell temperature and fill factor. MPPT efficiency increases with temperature and only FF changing also affects the efficiency around 4% under constant temperature conditions. MPPT efficiency is associated with climatic conditions and features of geographic region where PV is system located. MPPT used to increase battery charger in PV systems with storage unit; the amount of this increase should be more than the amount the device itself losses. Otherwise, there is not any net income. Theoretical calculation model was developed to analyze benefits of MPPT under different climatic conditions. In practical MPPT algorithm was used in two PV systems located in different regions of a province, where they have distinctive climatic conditions. Eventually, it was determined that climate change can cause approximately 10% of differences between MPPT efficiencies, In the most general sense, MPPT techniques can be grouped under two headings as direct and indirect systems. The solution to this problem is that switching power converters can be used that is called as maximum power point tracker (MPPT). Thus, the continuous operation of photovoltaic panels at MPP can be provided. Generally in uniform conditions (absence of sudden shading or climate changes), using of MPPT is quite considerable increases in output power such as 20%–30%.

Basically, there are two different ways to achieve this operation

1) Direct methods, which are mainly focused on the MPP searching by using (sensing) input or output power converter signals and by adjusting directly the duty cycle of the same converter.
2) Searching Techniques in conjunction with a closed-loop Control Strategy

II. LITERATURE REVIEW

Renewable systems such as solar power experience a higher power variation since the panels exhibit a higher variation of solar irradiance that changes the output power of the panel, hence it is necessary to extract the available power to load, so MPPT techniques are said to be mandatory for PV systems, basically these techniques are based on the active and the passive power conversion based.

Among the PV extraction techniques:

1) Perturb & Observe, and
2) Incremental Conductance (P&O and IC, respectively) are the two popular techniques employed.

These techniques have been employed both as a direct method or in conjunction with traditional control strategies (usually a PI controller). The P&O direct method consists in disturbing the duty cycle of the DC/DC power converter, and evaluate if the power in the terminals of the PVM increases, or decreases, so then, define an action for the next step of the adjustment law. However, the problem with this method is that the system oscillates around the MPP, and as a consequence, some energy is wasted in this process, to enhance the traditional techniques the evaluation of the P&O Direct Method and P&O + PI Controller techniques for water pumping systems was recently reported. Meanwhile, the IC + PI Controller method is based on the fact that the first derivative of the power Ppv with respect to the steady-state voltage Vpv of the PVM is equal to zero in the MPP, since the mpp trackers require a fast dynamic response under sudden irradiation drops and load variations, a model considering uncertainty and the variations has to be deployed.

In paper [1] it has been an accurate model is essential when designing photovoltaic (PV) systems. PV models rely on a set of transcendental nonlinear equations which add to the model complexity. This letter implements a simple and easy-to-model approach for implementation in simulations of PV systems. It takes advantage of the simplicity of ideal models and enhances the accuracy by deriving a mathematical representation, capable of extracting accurate estimates of the model parameters, directly related to manufacturer datasheets.

In [2] this work, a photovoltaic (PV)-system maximum power point (MPP) tracking (MPPT) control strategy employing a predictive digital current-controlled converter implemented in conventional hardware resources is presented. Two current programmed controllers (finite-state predictive control and valley current control) have been integrated into a system with current- or voltage-oriented MPPT. The modifications applied to the perturb-and-observe algorithm enable the MPP tracker to interact rapidly with the controller accounting also for abrupt irradiance drops by

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considering voltage and current limitations. The implementation of digital control in PV systems entails significant advantages of speed and accuracy, although the controller converges correctly at the MPP under irradiance variations featuring fast dynamic response. The proposed controller scheme has been experimentally demonstrated on a digitally current-controlled boost converter delivering power from a PV system.

In [3] to [5] it is discussed Voltage-source inverter (VSI) topology is widely used for grid interfacing of distributed generation (DG) systems. However, when employed as the power conditioning unit in photovoltaic (PV) systems, VSI normally requires another power electronic converter stage to step up the voltage, thus adding to the cost and complexity of the system. To make the proliferation of grid-connected PV systems a successful business option, the cost, performance, and life expectancy of the power electronic interface need to be improved. The current-source inverter (CSI) offers advantages over VSI in terms of inherent boosting and short-circuits protection capabilities, direct output current controllability, and ac-side simpler filter structure. Research on CSI-based DG is still in its infancy. This work focuses on modeling, control, and steady-state and transient performances of a PV system based on CSI. It also performs a comparative performance evaluation of VSI-based and CSI-based PV systems under transient and fault conditions.

III. PROPOSED WORK

In terms of the algorithms, the CPG based on a Perturb and Observe (P&O-CPG) algorithm was introduced in single stage PV systems. However, the operating area of the CPG control is limited to be at the right side of the Maximum Power Point (MPP) of the PV arrays (CPP-R), due to the single-stage configuration. Unfortunately, this decreases the robustness of the control algorithm when the PV systems experience a fast decrease in the irradiance. This drawback applies also to other CPG algorithms presented, since all the control algorithms regulate the PV power P_{pv} at the right side of the MPP.

To tackle the above issues, a two-stage grid-connected PV is employed to extend the operating area of the P&O-CPG algorithm. By regulating the PV output power at the left side of the MPP (CPP-L), a stable CPG operation is always achieved, since the operating point will never “fall off the hill” during a fast decrease in the irradiance. Thus, the P&O-CPG algorithm can be applied to any two-stage single-phase PV system. This project is organized as follows: the operational principle of the P&O-CPG algorithm is discussed, where the dynamics of the P&O-CPG algorithm are analyzed. a high-performance CPG algorithm is proposed. Both the conventional and the proposed P&O-CPG algorithms are verified and compared experimentally.

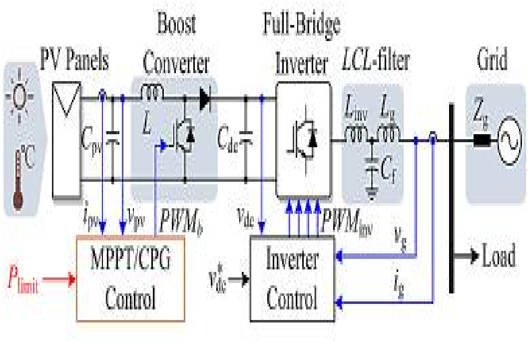

Fig.1 Hardware schematic and overall control structure of a two-stage single phase grid-connected PV system

The electrical power supplied by the photovoltaic (PV) array depends on insolation, temperature and load. On the other hand, the actual power produced by the PV array is not fully transferred to the load. Therefore, it is necessary to extract maximum power from PV array. Maximum Power Point Tracking (MPPT) is a power electronic system that extracts maximum power from PV system. MPPT varies the electrical operating point of the PV modules and enables them to deliver maximum available power. In this work, a new MPPT algorithm is designed that uses open circuit

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voltage and short circuit current, sampled from a reference PV Panel. Using these measurements the maximum power is been tracked from main panel without breaking the power transferred to load. A buck boost converter was used to match impedance between source and load to facilitate maximum power transfer. The proposed algorithm was checked for its performance in local environmental condition.

Out of different technologies available for harnessing the solar energy, photovoltaic (PV) is the simple and reliable technology which directly convert solar energy into electricity which is the most convenient form of energy for utilization. The output power from the PV system depends on PV cell efficiency, irradiation, cell temperature and load impedance. For given PV cell, extracting maximum power for given atmospheric condition, depends on the capability of the system operating close to maximum power point. The Maximum Power Point Tracking (MPPT) involves the adjustment of output voltage and/or current of the PV system for given load, irradiation and cell temperature. Tracking maximum power not only increases the power output, but also increases the life of the system. So far, different types of MPPT methods have been developed and employed. These methods can be differentiated depends on the sensors used, convergence speed, cost, range of effectiveness, implementation hardware requirements and popularity. Based on the approach used for generation of the control signal, these methods are categorized as online method, offline method and hybrid method.

Offline method is very simple and further classified into open circuit voltage (OCV) method and short circuit current (SCC) method. Open circuit voltage (Voc) method uses approximate linear relation between OCV and maximum power point voltage (Vmpp)at different environment conditions Equation (1). Short circuit current (Isc) method also uses approximate linear relation between SCC and maximum power point current (Impp) at different environment conditions Equation 1.

$$V_{mpp} \approx k_1 V_{oc} \qquad (1)$$

and

$$I_{mpp} \approx k_2 I_{sc} \qquad (2)$$

Where k_1 and k_2 are constants depend on the solar cell characteristics. Due to practical problems related measurement, the SCC method is more accurate and efficient than the OCV method. The main drawback of the offline method is load interruption occurring during measurement of I_{sc} or V_{oc}. Also, this method fails to predict the exact maximum power point using either the Equation (1) or Equation (2).

In online methods, the instantaneous values of the PV output voltage or current are used to generate the control signals. This includes perturbation and observation method (P&O), extremum seeking control method (ESC) and incremental conductance method (IncCond). In perturbation and observation method, PV system voltage or current is changed by applying a series of small and constant perturbations on a step-by-step basis until the power delivered is maximum. The problems associated with this method are amplitude of perturbation and rate of convergence. Extremum seeking control method (ESC) is a real-time optimization methodology for a nonlinear dynamic system with adaptive feedback, employed to track MPPT.

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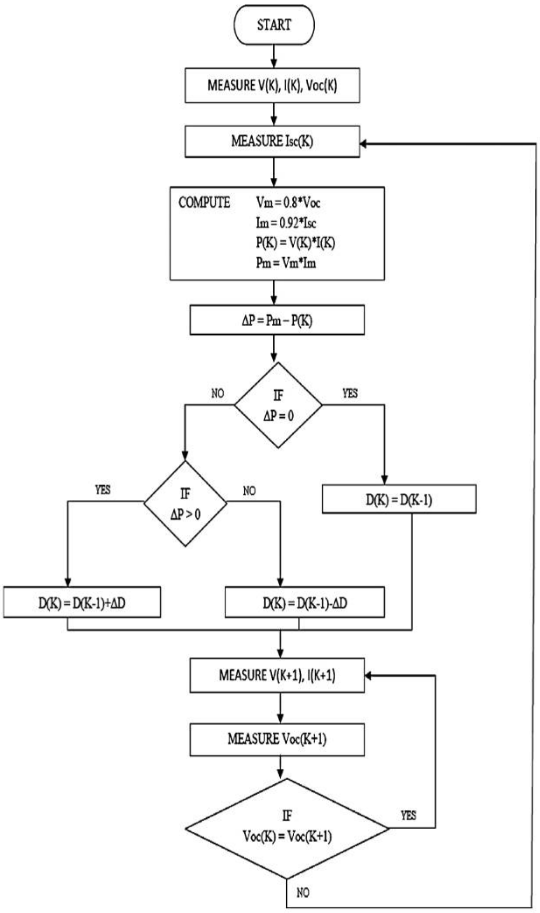

Fig.2 Flow chart of proposed MPPT algorithm

The disadvantages of the ESC method are its complexity in implementation and the evaluation of relatively low amplitude ignals. The incremental conductance (IncCond) method is based on the fact that the slope of the PV array power curve is zero at the MPP. The main drawback of this method is that it requires complex control circuitry. In hybrid method, both offline and online methods are used in sequence to locate the MPPT accurately to optimize the complexity. Offline method is used to locate the MPP approximately first, then online method is used to locate the point accurately.

It studied and compared the work done by different researchers on hybrid MPPT system with the combination of any on offline method (either OCV or SCC) and with any one online method (P&O or ESC or IncCond). A comprehensivepresentation was made by Bhatnagar and Nema on working principle of various MPPT techniques they compared each other in terms of some critical parameters like: number of variables used, complexity, accuracy, speed, hardware implementation, cost, tracking efficiency and so on.

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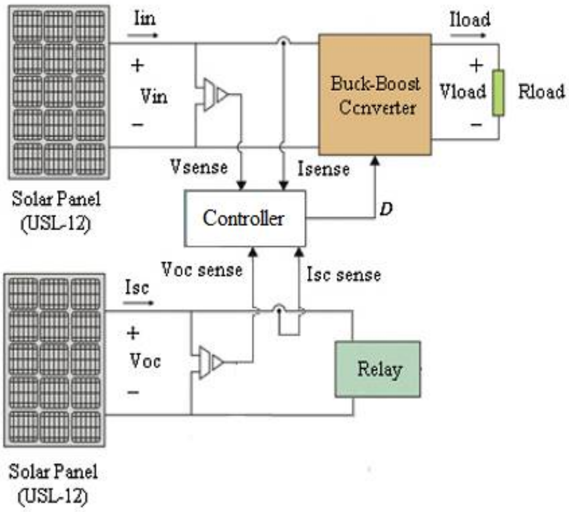

Fig. 3 Block diagram of experimental setup

In this new method, the new MPPT algorithm (Fig. 2) has been formulated, based on the concepts of open circuit voltage and short circuit current, to track the maximum power from PV panel. From the Equation.(1) and (2) the maximum power produced by the PV panel is given by the Equation (3). The following flow chart explains the algorithm used to track the MPP.

$$P_{max} = V_{mpp}I_{mpp} = k_1k_2V_{OC}I_{SC} = 0.736\ V_{OC}I_{SC} \quad (3)$$

One panel is used as reference panel to measure open voltage and short circuit.

Another panel is considered as main panel, where it supplies power to a resistive load connected to it for measurement. A DC–DC Buck–Booster converter (Fig. 3) is used to match the impedance. It also acts as an interface between PV panel and load, which adjusts the voltage level of the PV panel, according to the algorithm designed. According to buck–boost converters are reliable to find the MPP independently. The operating region of buck–boost converter is shown in Fig. 3

In order to control the operation of buck–boost converter, the MPPT algorithm was programmed in controller.

IV. RESULTS AND DISCUSSION

In order to validate the performance of the proposed voltage linearizer a modified approach in regulating the voltage response of the traditional MPPT systems a simulation model of the system is designed using plexim , the results of the linearizer and the traditional mode is compared to prove the internal stability of the system , The estimation and the experimental study is done to identify the variations of the controller when the irradiation variation happens, the following results in this chapter shows the stability of the converter under various loading and irradiation conditions.

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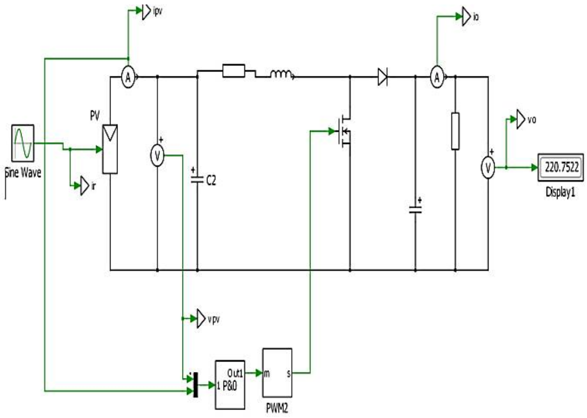

Fig. 4 Test system for the validation of the MPP scheme

Fig 4 Test system for the validation of the MPP scheme, contains the basic MPP controller and the solar input and converter scheme. The MPP tracking scheme is validated with various solar irradiance levels which the efficiency and the ripple ratio in the efficiency are to be compared.

The results are compared with the maximum power tracking schemes such as Petrub and observe and constant power control and the linearizing control which are validated and analysed in this chapter.

In order to validate the performance of the tracking schemes the following specifications are used

A. SOLAR PANEL

Table. 1 Specification of the solar panel

Max power	700W
Inductor L1	5e-6 H
Capacitors	1000Uf
Topology	boost
Number of switches	1

B. DC-DC CONVERTER

Table 2 Specification of the DC-DC converter

Max generated power	650W
Open circuit voltage	48V
Short circuit current	14A
Number of cells	22

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Case -1 : P&0 Maximum power point tracking

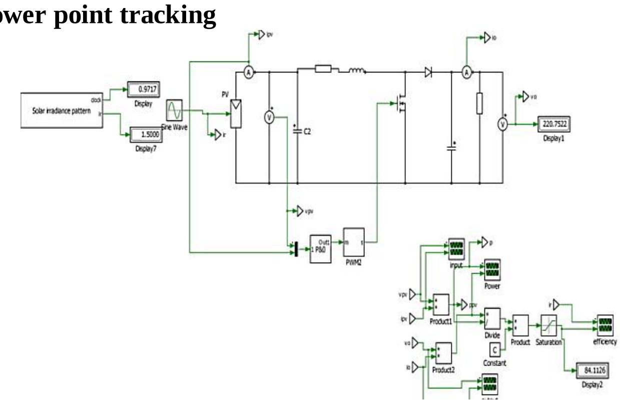

Fig. 5 Test circuit of the P&O controller

Fig. 5Test circuit of the P&O controller, consists a boost converter and solar cell module and the P&) tracker with the PWM generator , the PWM generations are done to obtain the maximum power point.

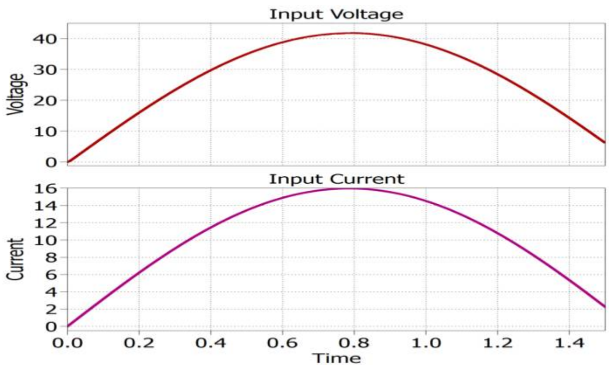

Fig. 6 Input voltage and current pattern

Fig 6 input voltage and current pattern the voltage is around 40V and the current is at 14 A.

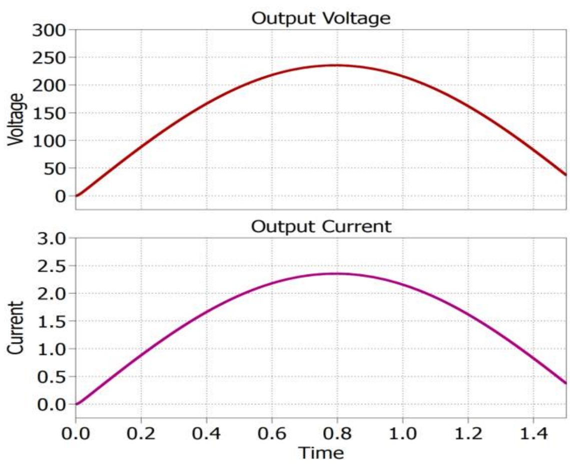

Fig. 7 Output voltage and current pattern

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Fig 7 Output voltage and current pattern the voltage is around 250V and the current is at 1.8 A.

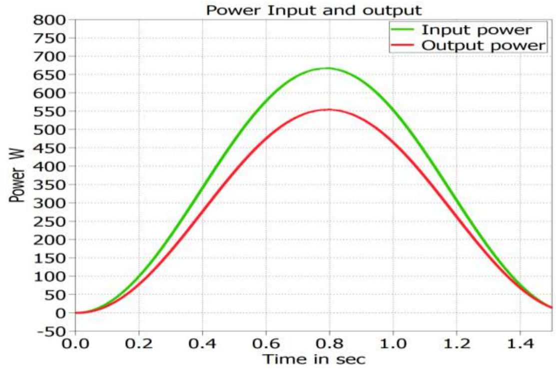

Fig. 8 Input and the output power patterns of the P&O tracking scheme

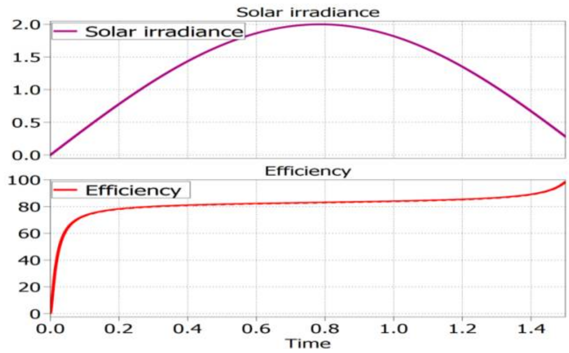

Fig. 9 Solar irradiance Vs efficiency

Fig 9 Solar irradiance Vs efficiency, the tracking efficiency lies around 79 % average and increases at tis maximum under the solar irradiance variations

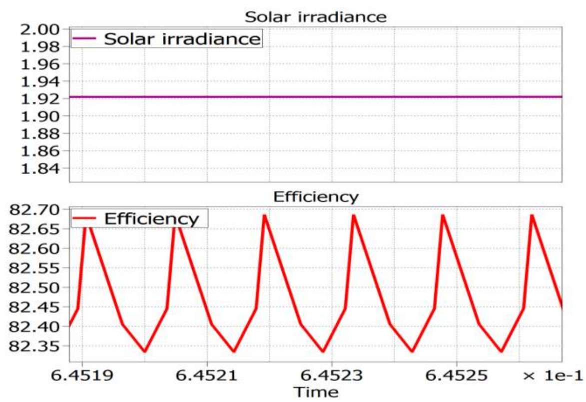

Fig. 10 Solar irradiance and efficiency

Fig 10 Solar irradiance and efficiency shows that the efficiency is around 82 % at the constant irradiance and also the efficiency has larger oscillations that usually happens at the MPP stage of the P&O due to its variation control, this is the objective key point for this project to eliminate.

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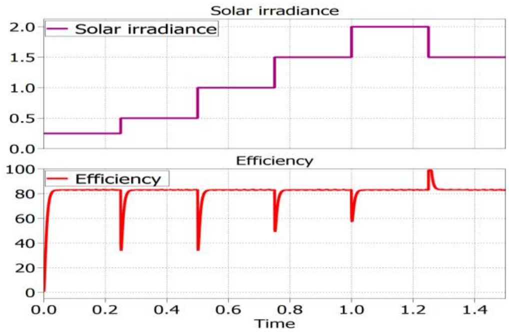

Fig. 11 Solar irradiance and efficiency

Fig 11 Solar irradiance and efficiency at the step change conditions of the solar pattern, the efficiency oscillates heavily under the step change conditions, and a larger spike at the efficiency is also observed.In order to eliminate the issues with the P&O maximum power tracking scheme a constant power control scheme is introduced, the constant power control scheme is used to limit the input power of the solar panel to its 90%, so that the oscillations of the power around the peak can be regulated.

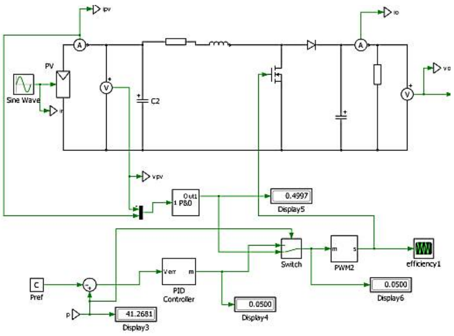

Fig. 12 Test circuit of the constant power control scheme

Fig 12 Test circuit of the constant power control scheme, that has the P&O tracker and also a analog based PID controller for maintaining input power, the input power is regulated to the set point mentioned at the P ref. The P&O control is used until the power reaches the Plimit and once the Plimit is reached the P&O control is transfeered to constant power control which a PID controller has a feed back loop to main the input power. Once the power is restricted to it (5 % of generation the oscillations can be redcued , which the wave forms below represents below

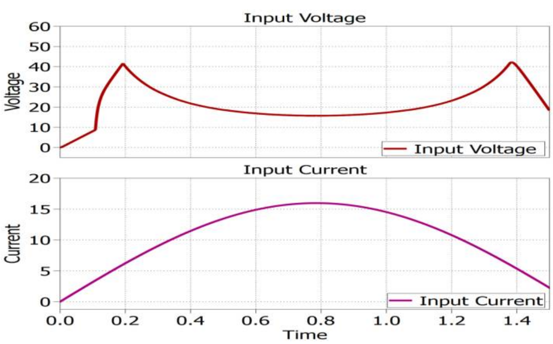

Fig. 13 The input current and voltage pattern of the scheme during the constant power control

Fig 13 The input current and voltage pattern of the scheme during the constant power control , once the constant set power is reached the voltage tends to reduce and the current increases.

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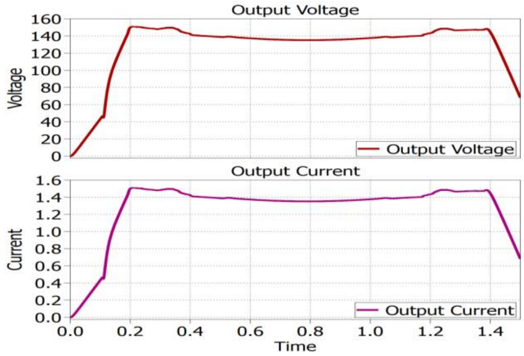

Fig. 14 The output current and voltage pattern in the constant power control

Fig 14 The output current and voltage pattern in the constant power control is shown which states that once the power set point is reached , the voltage and the current are set to a constant level.

Fig. 15 The output and input power pattern of the proposed schemes

Fig 15 The output and input power pattern of the proposed schemes shows that the input power set point is limited to 250 W and the constant power is limited to the set point , and the output power is tend to track the input limited power, this limitation minimizes the step vhanges in the pwm control , and thus the current ripple can be controlled to a set level , with lesser oscillations that brings the efficiency better.

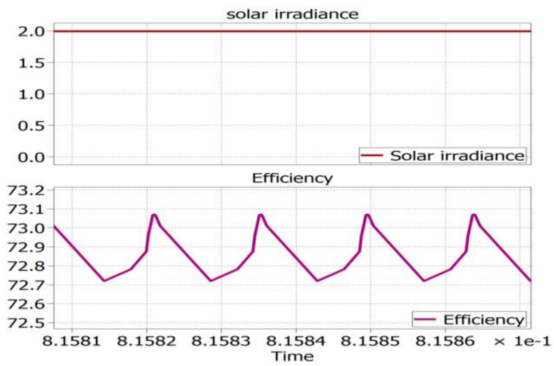

Fig. 16 Efficiency ripple at the constant irradiance level

Fig 16 Efficiency ripple at the constant irradiance level the ripple of the efficiency is lower as compared to the P&O controller , the constant power regulation has regulated the efficiency ripple to 0.04 points which is minimal .

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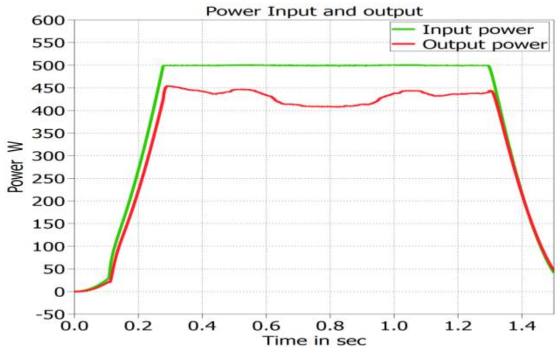

Fig. 17 500 W set point the control

Fig 17 Constant power control mode under the 500 W set point the control scheme is able to track the set point levels with out any distortion .

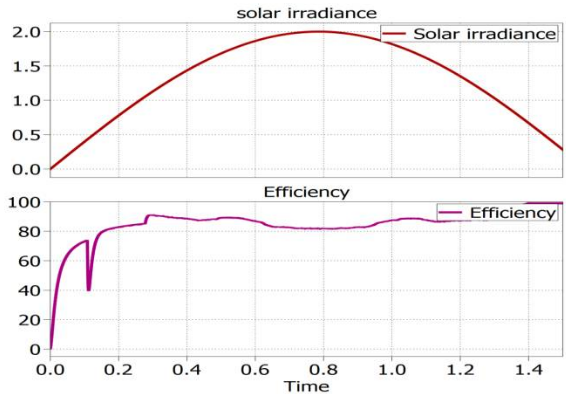

Fig. 18 Efficiency of the converter

Fig 18 Constant power control mode under the 500 W set point the control scheme is able to track the set point levels without any distortion , the efficiency of the converter is now aroud 90 %

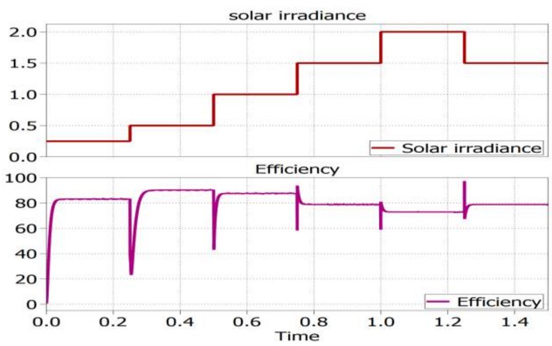

Fig. 19 Step change analysis of the irradiance levels

Fig 19 Step change analysis of the irradiance levels which has minimal transients as compared to the existing schemes

The Constant power control scheme is been validated with reference to the P&O scheme which has obtained a better efficiency , but the efficiency at the transition stages are lower and also the output control is not considered,

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hence a lingering control based on the input and the input power variations are added to improve the efficiency of the proposed converter

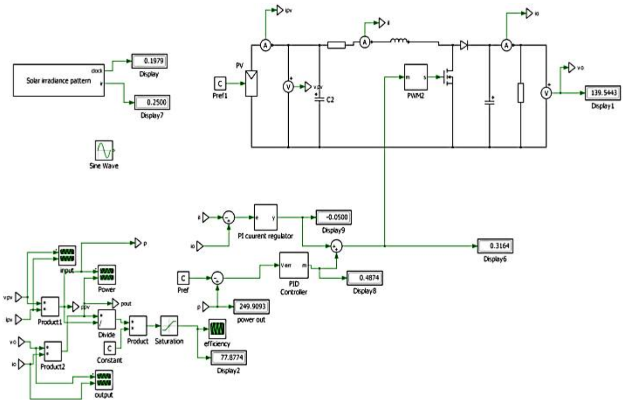

Fig. 20 Circuit simulation of the linearizer scheme

Fig20 Circuit simulation of the linearizer scheme which has a current regulator and a constant power controller to maintain the efficiency at its maximum.

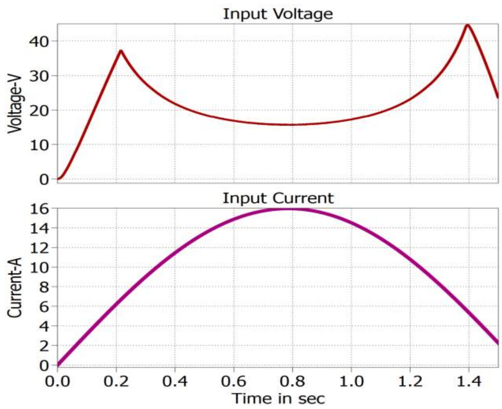

Fig. 21 Input voltage and current of the proposed scheme

Fig 21 Input voltage and current of the proposed scheme, the voltage is controlled to allow the maximum current in take.

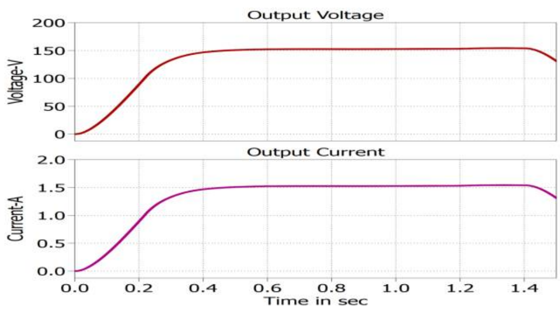

Fig. 22 Output voltage and current of the proposed scheme

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Fig 22 Output voltage and current of the proposed scheme , the voltage is regulated to a set point with out any distortions in the current.

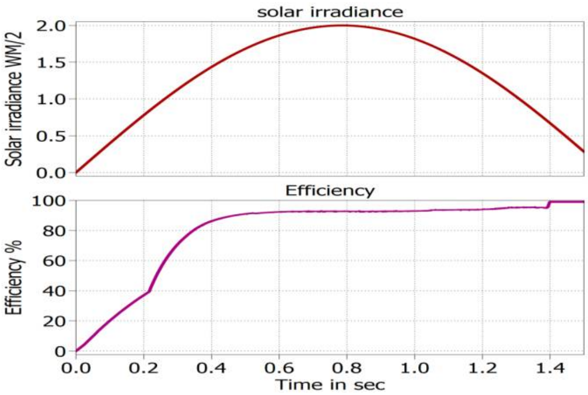

Fig. 23 Solar irradiance and efficiency

Fig 23 Solar irradiance and efficiency which is around 90 %

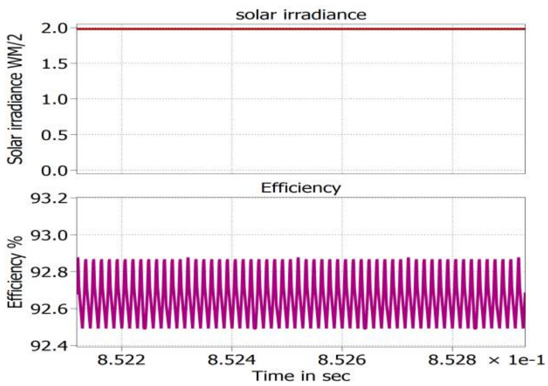

Fig. 24 Efficiency ripple at the constant irradiance level

Fig 24 Efficiency ripple at the constant irradiance level the ripple of the efficiency is lower as compared to the P&O controller and the constant power regulation has regulated the efficiency ripple to 0.02 points which is minimal then the constant control scheme.

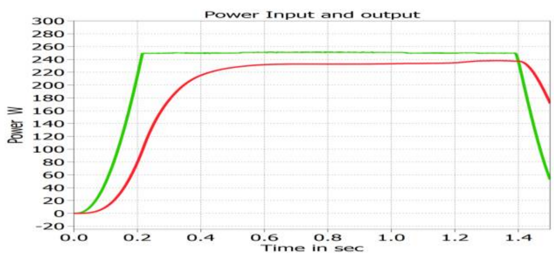

Fig. 25 Input and the output regulation of the scheme

Fig 25 Input and the output regulation of the scheme the input power is regulated to a set point with out any distortions in the output

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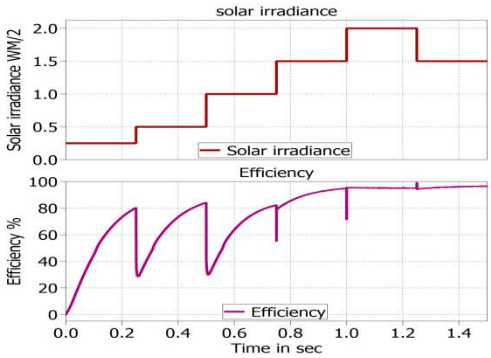

Fig. 26 Step change analysis of the irradiance levels

Fig 26 Step change analysis of the irradiance levels are minimal transients as compared to the existing schemes

V. CONCLUSION

Since MPPT algorithms used in PV systems are one of the most important factors affecting the electrical efficiency of system, since to maintain the efficiency of the under various environmental conditions , this project brings a robust input-output linearization controller as maximum power point tracking (MPPT) technique in a photovoltaic (PV) buck DC-DC converter. Due to the simpler control structure that brings a cascaded control which integrates the traditional MPPT systems aith the closed loop control which is able to track very fast irradiance changes. Meanwhile, the internal stability of the overall closed loop system is guaranteed for different load scenarios. The MPPT control system is validated through experimental results, where the closed-loop performance is evaluated under abrupt irradiance and set-point changes , the experimental results shows the mppt system has a better stability and roboustness over voltage control , that maintains the efficiency which makes the controller suitable for various DC applications that demand high efficiency.

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