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Two-diode model photovoltaic system with nonlinear MPPT controller for grid connected loads

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Abstract

This paper presents a nonlinear maximum power point tracking (MPPT) controller for two diode model photo voltaic system. In this technique MPPT operates in conjunction with a Z-source converter. This nonlinear MPPT gives duty cycle to converter switches in order to get maximum power from PV system. To improve transient and steady state conditions in both tracking and regulation, a nonlinear MPPT controller was designed. In this method oscillations around MPP are reduced and accuracy of MPP high. The effectiveness of proposed method investigated via MATLAB simulation and results are compared with perturb and observe (P&O) and incremental conductance (IC) method. This topology was extended to Grid connected loads through an additional inverter, simulated in MATLAB and observed the obtained results.

Key words—Maximum power point tracking, nonlinear control, photovoltaic, Grid connected PV.

1. Introduction

Now a days renewable energy sources have made significant progress in fulfilling the continuously growing energy demand. Among the renewable energy resources, the energy through the solar photovoltaic effect will be considered the most necessary and prerequisite sustainable resource because of the universal presence, large quantity, and sustainability of solar energy (S. Mekhilef 2011). The output characteristics of PV module depends on the solar irradiance, cell temperature and output voltage of PV module. Since PV module has nonlinear characteristics, it is necessary to model it and simulate for Maximum Power Point Tracking (MPPT) of PV system applications. A PV module generates small power, so the task of a MPPT in a PV energy conversion system is to continuously tune the system so that it draws maximum power from the solar array regardless of weather or load conditions. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. Here load is not constant so thevenin impedance depends on duty cycle of converter. MPPT methods could be sorted, into two classes, namely, the conventional and soft computing (SC) methods.

Among the conventional MPPT methods reported in the literature, the hill climbing (E. Koutroulis 2001), perturb and observe (P&O) (N. Femia 2005), and incremental conductance (IC) (M. A. Elgendy 2013) are mostly used due to their simple implementation and appropriate convergence speed. However, the oscillation around the MPP is the major weakness of theses algorithms. The oscillatory behavior around the MPP affects negatively the system efficiency due to energy losses. Moreover, under variable atmospheric conditions, these methods may be unable to keep working around the global MPP (N. Femia 2005). In order to minimize the oscillation, several attempts were made by reducing the perturbation step size (S. K. Kollimalla 2014). However, a smaller perturbation size reduces the tracking speed of MPP. In order to overcome the above-mentioned situation, the SC techniques, such as fuzzy logic controller (B. N. Alajmi 2013), the neural-network method (W. M. Lin 2011), genetic algorithm (A. Messai 2011), differential evolution (S. Taheri 2012, H. Taheri 2010), and particle swarm optimization (K. Ishaque 2012), have attracted much interest over the past years. Despite of their effectiveness, the SC algorithms are highly dependent on the complexity of computing programs. To derive accurate results, the SC techniques must have been trained using a large amount of measurements prior to its real-time operation in the MPPT control unit.

The operating point of the PV system, determined by the MPPT, can be controlled through a dc–dc converter. The dc–dc converter as an interface between the PV system and the load is equipped with the MPPT to achieve maximum energy from the PV panel. Over available dc–dc converters, the Z-source dc–dc converter offers a wider range of dc voltage and improves the system reliability (F. Z. Peng 2003). Recently, (Taheri 2015) proposed a nonlinear MPPT model, which is able to find accurately the MPP taking into account the PV system is connected to the load through a Z-source dc–dc converter. Despite of its effectiveness, the proposed model did not take into account the PV module model. Since the parameters of a PV model vary according to the position of the operating point on the PV characteristics, these parameters cannot be updated in new conditions. Hence, the MPPT controller tracks only the MPP based on the initial constant values of the PV module parameters.

In order to overcome the above-mentioned drawbacks, in particular, the oscillatory behavior and complexity of available MPPT algorithms, a nonlinear MPPT controller taking into account the two-diode model of the PV module is proposed. The primary goal of this paper is to improve the accuracy and speed of the MPPT in tracking the MPP and connected to grid loads. To achieve this objective, a nonlinear model of the Z-source dc–dc convertor is first proposed. This model is used for designing a nonlinear maximum power point tracker. Then, to improve the PV voltage regulation, a nonlinear PV voltage controller is designed. A two-diode model is used to represent an accurate behavior of the PV module. Furthermore, similar to the procedure used to establish a linearized equivalent circuit of a PV system, the PV model parameter is updated in each time interval Δt using simple linear algebraic equations. In addition, to further compare this proposed MPPT with conventional MPPTs, the P&O and IC methods are implemented, extended this PV model to grid connected loads through inverter and the results are discussed. Simulation results validate a considerable reduction of the steady-state oscillation at the MPP using the proposed technique, contrary to those obtained by the conventional P&O and IC techniques and accuracy of MPP improved.

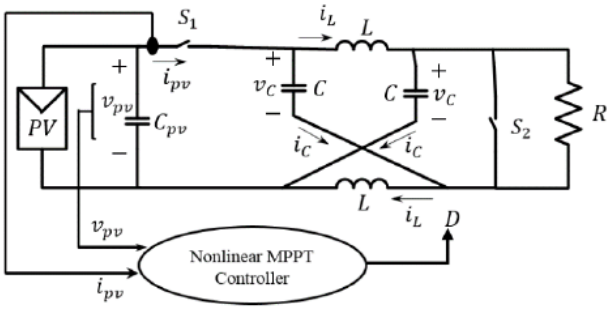


Fig 1 Topology of the proposed nonlinear MPPT system with a Z-source dc–dc converte

2. System Description and Modeling

In order to evaluate the capability of the proposed nonlinear MPPT method in tracking the MPP, a general topology of the PV system is employed as shown in Fig. 1. This topology comprises a PV array, a Z-source dc–dc converter, a resistive load, and a nonlinear MPPT controller. This topology can be extended to a grid-connected system through an additional inverter and a transformer.

In general, the *Z*-source dc–dc convertor can be used to improve the low PV terminal voltage to the higher output voltage at the dc bus. In other words, the *Z*-source dc–dc converter offers a wide range of required output voltage. Moreover, it acts as a protective buffer between the load and the PV system. In fact, the PV system is isolated from the load if a short circuit happens on the load side. On the other hand, the MPPT controller plays an important role in the performance of the dc–dc converter to achieve the MPP. The current and voltage of the PV array are measured by voltage and current sensors, respectively. These values are fed into the MPPT block to generate the reference voltage. Then, the reference value is compared with the terminal voltage of the PV array. Eventually, the duty cycle that controls the switches of the dc–dc converter is generated through a nonlinear controller. Hence, this paper more concentrated in designing the nonlinear MPPT and its controller.

The converter shown in Fig.1 consists of two switches S_1 and S_2, two identical inductors L and two identical capacitors C. The switches S_1 and S_2 are controlled by the duty cycles $1 - D$ and D, respectively, generated by the nonlinear MPPT controller. In other words, when the switch S_1 is activated the other one S_2 is deactivated and vice versa.

In order to obtain the nonlinear model of the MPPT, the nonlinear relationships between the voltage and current of the circuit elements taking into account the duty cycle are extracted using the KVL and KCL laws. The dynamics of inductor current i_L is obtained as

$$D = 0 : v_L = v_{pv} - v_C \quad (1)$$

$$D = 1 : v_L = v_C \quad (2)$$

The average value of $\overline{v_L}$ is

$$\overline{v_L(t)} = \int_0^D v_L(t)dt + \int_D^1 v_L(t)dt. \quad (3)$$

Eq (3) is zero if we consider $(di_L/dt) = 0$. It means i_L has no oscillation. Supposing $v_L(t) = L(di_L/dt) \neq 0$, we obtain

$$L\frac{di_L}{dt} = v_C D + (v_{pv} - v_C)(1 - D) \quad (4)$$

The dynamics of inductor current and capacitor voltage are simplified as follows:

$$\frac{di_L}{dt} = \frac{1}{L}(v_{pv} - v_C) + \frac{1}{L}(2v_C - v_{pv})D \quad (5)$$

$$\frac{dv_C}{dt} = \frac{1}{C}(i_{pv} - i_L) \quad (6)$$

Where v_{pv}, i_{pv}, v_c, v_L, and i_L represent the PV voltage, the PV current, the voltage across each capacitor, the voltage across each inductor, and the current of each inductor, respectively. The above-mentioned relations are used to design the nonlinear MPPT controller.

The circuit modeling of the PV devices plays an important role in optimizing power converter design, in studying the MPPT algorithms and also in simulating the PV system and its components. In fact, the PV model basically represents the nonlinear I–V and P–V characteristic curves. The most popular approach to model a PV module is to utilize the electrical equivalent circuit, which is primarily based on the single diode model, i.e., a current source in parallel with a diode (Y. T. Tan 2004). This type of model requires only three parameters to completely characterize the I–V curve, namely, short-circuit current (Isc), open circuit voltage (Voc), and diode ideality factor (a). An improvement of this model is fulfilled by the inclusion of one series resistance Rs (R. Chenni 2007). Although the model is still relatively simple, it exhibits serious deficiencies when subjected to high temperature variations. To overcome this drawback, an extension of the single diode model, which includes an additional shunt resistance, is suggested (M. G. Villalva 2009). Although some improvements are achieved, this model requires significant computing effort, since the parameters have been increased to five. Moreover, its accuracy deteriorates at low irradiance, particularly in the vicinity of the open circuit voltage. To improve the accuracy, a two-diode model consisting of an additional diode was proposed as shown in Fig. 2 (K. Ishaque 2011).

The output current of the module can be described through the following equation: [13]

$$I = I_{PV} - I_{d1} - I_{d2} - \left(\frac{V + IR_s}{R_P}\right) \quad (7)$$

$$I_{d1} = I_{01}\left[\exp\left(\frac{V + IR_s}{\alpha_1 V_{T1}}\right) - 1\right] \quad (8)$$

$$I_{d2} = I_{02}\left[\exp\left(\frac{V + IR_s}{\alpha_2 V_{T2}}\right) - 1\right] \quad (9)$$

Where I_{pv} is the current generated by the incidence of light, I_{01} and I_{02} are the reverse saturation currents of diodes, V_{T1} and V_{T2} are the thermal voltages of diodes, α_1 and α_2 represent the diode ideality constants.

The four parameters that need to be estimated are $I_{01} = I_{02} = I_0$, Rs , Rp, and IPV. The parameters I0 and IPV are obtained analytically. Only Rs and Rp need to be determined by iteration, i.e., Newton–Raphson method.

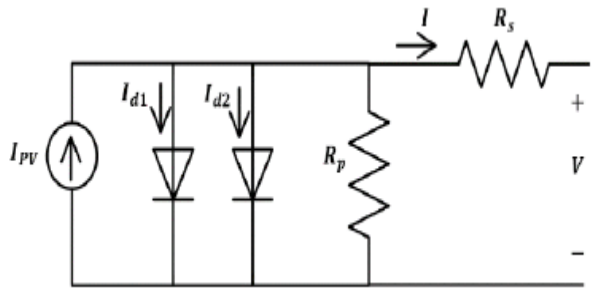


Fig 2 Two-diode model of a PV module

Unlike the previous similar models (the two-diode models) suggested by other researchers, the proposed paper requires the computation of only two parameters. In addition, it was found that the improved two-diode model is superior when subjected to irradiance and temperature variations. In particular, it exhibits excellent accuracy at lower irradiance conditions (M. G. Villalva 2009). This two-diode model is used for updating the unknown parameters ∝(t) and β(t).

3. Nonlinear MPPT Approach

The proposed nonlinear MPPT algorithm is based on the fact that the derivative of PV power with respect to voltage is zero at the MPP. Hence, the oscillation around the MPP can be eliminated. In fact, once the MPP is reached, the operation of the PV array is

maintained at this point. Therefore, the optimal voltage that is tracked by MPPT (at the MPP) can be determined using the following condition (Hamed Taheri 2017):

$$\left.\frac{dP_{pv}}{dv_{pv}}\right|_{v_{pv}=v_{pv}^{*}} = 0 \tag{10}$$

Where Ppv is the power generated by the PV, and v_{pv}^{*}, determined by the nonlinear MPPT, is the reference voltage at which the PV array is forced to operate. Hence, a MPPT model is proposed to obtain the reference voltage v_{pv}^{*} by solving the nonlinear equation presented in Eq (10). Thus, a model-based approach is used to design the nonlinear MPPT. Eq (10) can be presented using the following equation where α(t) and β(t) are the variables that should be updated as per operating conditions:

$$\frac{dP_{Pv}}{dv_{Pv}} = \alpha(t) + \beta(t) v_{Pv} \tag{11}$$

In order to achieve the objective, integral action signal Ω is defined as

$$\Omega = \int_0^t \left(\alpha(t) + \beta(t) v_{Pv}\right) dt. \tag{12}$$

The objective of the controller is that this variable Ω converges to zero. On the other hand, the power derivative will converges smoothly to zero when the integral action signal Ω is zero. To achieve the MPP, an exact input–output feedback linearization approach is adopted to solve the nonlinear equation. The deferential operation is applied to Eq (12) and it equals to a new variable *v* as the input signal v_{pv}^{*} appears as follows:

$$\frac{d\Omega}{dt} = \alpha(t) + \beta(t) v_{pv}^{*} = v \tag{13}$$

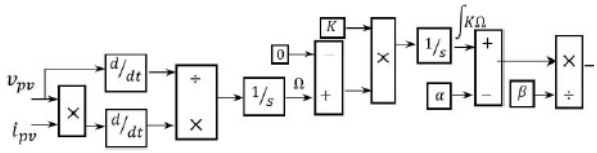


Fig 3 Model of a nonlinear MPPT design

The reference voltage v_{pv}^{*} could be reformulated as a function of the new variable *v* as:

$$v_{pv}^{*} = \frac{1}{\beta(t)}\left(v - \alpha(t)\right) \tag{14}$$

Proposing an integral control for the variable *v*, the optimal variable v_{pv}^{*} can be obtained as

$$v = k\int \Omega \tag{15}$$

$$v_{pv}^{*} = \frac{1}{\beta(t)}\left(k\int \Omega - \alpha(t)\right) \tag{16}$$

The proposed MPPT method that generates the reference voltage v_{pv}^{*} through the above relations leads to a model, shown in Fig.3

4. Nonlinear Controller Design

In order to harvest maximum energy from the PV array, the MPPT should ensure the PV system to operate at the MPP. To achieve this goal, the MPPT controls the operation of dc–dc converter through generating the updated duty cycle. The MPP is reached when the PV terminal voltage is equal to the voltage reference v_{pv}^{*}, determined by the MPPT. Thus, the design of a controller is required to generate the reference voltage, which corresponds to the MPP. A novel approach is used to control the terminal of the PV array indirectly. It can be achieved through adjusting the energy storage across the PV terminal by the following equation: [13]

$$E = \frac{1}{2} C_{pv} v_{pv}^{2} \tag{17}$$

The relationship between the energy and power in the circuit shown in Fig 1 can be written as

$$\frac{dE}{dt} = P_i - P_{pv} \tag{18}$$

Where Pi is the input power of z-source converter and Ppv is the power generated by PV module.

Assuming

$$Y = E \tag{19}$$

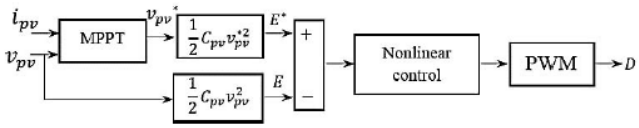


Fig 3.4 Model of a nonlinear MPPT controller

Then, taking the first and second derivative of Eq (19) leads to the following equation:

$$\frac{dy}{dt} = \frac{dE}{dt} = P_i - P_{pv} \tag{20}$$

$$\frac{d^2 y}{dt^2} = \frac{dP_i}{dt} - \frac{dP_{pv}}{dt} \tag{21}$$

The power dP_{pv}/dt can be calculated as

$$\frac{dP_{pv}}{dt} = \left(\frac{(i_{pv} - i_L) i_L}{C} + \frac{(v_{pv} - v_C) v_C}{L}\right) + \left(\frac{(2v_C - v_{pv}) v_C}{L}\right) D \tag{22}$$

$$D = \frac{-L}{(2v_C - v_{pv})v_C} \times \left(v_1 - \frac{dP_i}{dt} + \left(\frac{(i_{pv} - i_L)i_L}{C} + \frac{(v_{pv} - v_C)v_C}{L} \right) \right) \quad (23)$$

The auxiliary control v_1 in Eq (23) is utilized to stabilize the system. The nonlinear MPPT controller that produces the duty cycle to drive the dc–dc converter is shown in Fig 4. Thus, the nonlinear controller (based on exact input–output feedback linearization) operates based on the error obtained from the calculated energies E and E^* to force the dc–dc converter to work at the MPP.

5 Linear Controller Design for PV System

As explained in Section 4, the nonlinear system [consisting of *eq* (18) and *eq* (22)] can be linearized by the proposed nonlinear controller *eq* (23) through applying the following coordinate transformation in Z (S. Taheri 2015):

$$z^* = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix} * Z + \begin{pmatrix} 0 \\ 1 \end{pmatrix} * v_1 \quad (24)$$

Where v_1 is defined as the new auxiliary input of the controller. $Z=(z_1,z_2)^T=(E, P_{pv})^T$ is the state vector of the linearized system and y is the output that should be regulated. In fact, the nonlinear system obtained by *eq* (18) and *eq* (22) and the linearized system presented by *eq* (24) are related via a diffeomorphism. Thus, achieving the output of the above-mentioned linear system leads to the desirable output voltage of the PV terminal corresponding to the MPP. In order to facilitate the study of asymptotic tracking, the system equations are converted into the error state variable form e(t) as

$$e(t) = y(t) - y_{ref}(t) \quad (25)$$

Where *y(t)* is the real output and *y*ref *(t)* is the reference output

Through defining $e_1 = z_1 - y_{ref}(t)$ and $e_2 = z_2 - \left(\frac{(dy_{ref})}{(dt)} \right)$, the relationship between e_1 and e_2 can be obtained as

$$\frac{de_1}{dt} = \frac{dZ_1}{dt} - \frac{dy_{ref}}{dt} = e_2 \quad (26)$$

$$\frac{de_2}{dt} = \frac{dZ_2}{dt} - \frac{d^2 y_{ref}}{dt^2} = v_1 - y_{ref}(t) \quad (27)$$

The linear auxiliary law could be proposed to stabilize the system by the following expression:

$$v_1 = -K_{11}e_1 - K_{12}e_2 + \frac{d^2 y_{ref}}{dt^2} \quad (28)$$

Where the coefficients K_{11} and K_{12} are the controller gains.

eq (26) and *eq* (27) can be represented in the state space as

$$\frac{de}{dt} = \begin{pmatrix} 0 & 1 \\ -K_{11} & -K_{12} \end{pmatrix} e \quad (29)$$

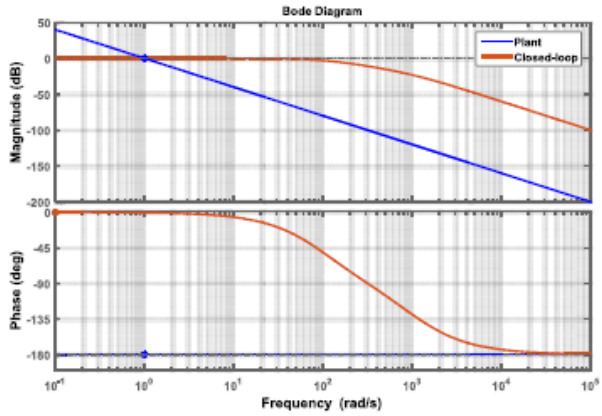


Fig 5 Frequency analysis of closed-loop system and the plant

The characteristic equation and the type of the output response of the system can determine the coefficients K11 and K12 as follows:

$$\Delta_d(s) = s^2 + 2\xi\omega_n s + \omega_n^2 \quad (30)$$

$$\Delta_d(s) = s^2 + K_{11}s + K_{12} \quad (31)$$

Therefore

$$\Delta_d(s) = \Delta_s(s) \rightarrow \begin{cases} K_{11} = \omega_n^2 \\ K_{12} = 2\xi\omega_n \end{cases} \quad (32)$$

Where ωn is the natural frequency and ξ is the damping ratio.

Fig. 5 shows frequency responses of the nonlinear controller system in closed-loop and the plant, implemented using MATLAB. The nonlinear controller gains (K_{11} =10^5 and K_{12} = 1100) are calculated using a natural frequency ωn = 316.23 and a damping ratio ξ = 1.74. These gains correspond to a phase margin of 150°, an infinite gain margin, and a bandwidth of 71 Hz. These characteristics guarantee asymptotic stability and good transient performance of the proposed system.

6. Adaption Mechanism

In order to track properly the MPP of a PV module, the proposed nonlinear MPPT model can be updated through the two-diode model and the Taylor series, inspired by the method presented in (A. D. Theocharis 2012). In fact, the derivation of the PV model offers a flexible approach for updating the parameter β(t) in Eq (11). Taking into account the initial operating point $(v(t_0), i(t_0))$ at the next time step ($t_0 + \Delta t$), the operating point changes to (v(t), i(t)). Through applying the Taylor series on Eq (7) around the point $(t_0, v(t_0), i(t_0))$, the PV current results in the following expression [14]:

$$i(t) = i(t_0) + \left.\frac{di(t)}{dv(t)}\right|_{v(t_0),i(t_0)} [v(t) - v(t_0)] \tag{33}$$

According to a common *I–V* characteristic of a PV system, the derivative of current with respect to voltage is negative.
Thus

$$\frac{di(t)}{dv(t)} < 0 \tag{34}$$

Hence, IC g_{pv0} at time t_0 can be presented as

$$g_{pv0} = -\left.\frac{di(t)}{dv(t)}\right|_{v(t_0),i(t_0)} \tag{35}$$

By substituting Eq (35) into Eq (33), following terms can be obtained:

$$i(t) = I_{pv0} - g_{pv0} v(t) \tag{36}$$

$$I_{pv0} = i(t) + g_{pv0} v(t) \tag{37}$$

The parameter g_{pv0} can be updated by the application of Eq (35) on Eq (7) as follows:

$$g_{pv0} = -\frac{dI_{pv}}{dv} + I_{01} \exp\left(\frac{V + IR_s}{\alpha_1 V_{T1}}\right)\left(\frac{1 + R_s \frac{dI}{dv}}{\alpha_1 V_{T1}}\right) + I_{02} \exp\left(\frac{V + IR_s}{\alpha_2 V_{T2}}\right)\left(\frac{1 + R_s \frac{dI}{dv}}{\alpha_2 V_{T2}}\right) + \frac{1 + R_s \frac{dI}{dv}}{R_p} \tag{38}$$

By defining

$$M = -I_{01} \exp\left(\frac{V + IR_s}{\alpha_1 V_{T1}}\right)\left(\frac{1}{\alpha_1 V_{T1}}\right) - I_{02} \exp\left(\frac{V + IR_s}{\alpha_2 V_{T2}}\right)\left(\frac{1}{\alpha_2 V_{T2}}\right) - \frac{1}{R_p} \tag{39}$$

Eq (38) can be rewritten as

$$\frac{dI}{dv} = \left(1 + R_s \frac{dI}{dv}\right) * M \tag{40}$$

$$g_{pv0} = \frac{M}{1 - R_s M} \tag{41}$$

The parameter g_{pv0} can be updated as per the computed values at $(t_0, v(t_0), i(t_0))$.

Since the main purpose of the proposed model is to calculate the updated value of the parameters ∝(t) and β(t), the following procedure based on the derivative of power P_{pv} with respect to voltage is used as:

$$P_{pv.} = v_{pv} i_{pv} \tag{42}$$

$$\frac{dP_{pv}}{dv_{pv}} = i_{pv} + v_{pv} \frac{di_{pv}}{dv_{pv}} \tag{43}$$

By comparing Eq (43) with Eq (11), the parameters ∝(t) and β(t) can be obtained as

$$\begin{cases} \alpha(t) = i_{pv} \\ \beta(t) = -g_{pv0} \end{cases} \tag{44}$$

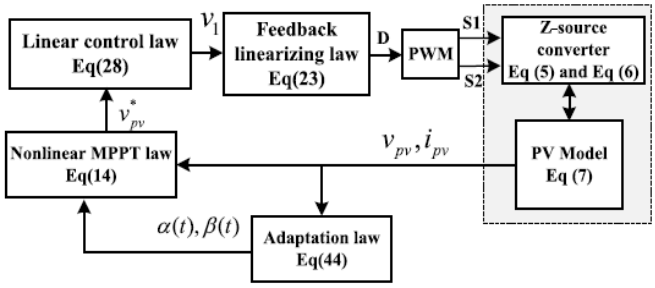


Fig 6 General block diagram for the proposed control system

Therefore, the parameter ∝(t) is the online measurement of PV current (ipv), and β(t) is the update of $-g_{pv0}$. The aforementioned control systems along with relevant equations are summarized in Fig 6.

7 Grid-Connected PV-Inverter Control Strategy

The control scheme of the grid-connected PV inverter is shown in Fig.7. In order to decouple the active and reactive power controls, the synchronous rotating d-q reference frame is applied for developing the controllers. A synchronous reference frame phase-locked loop (SRF-PLL) is used to synchronize the *d*-axis with the grid-voltage vector.

The *d*-channel current loop allows the control of active power that is supplied by the PV inverter (Baburaj Karanayil 2014). The reactive power is controlled by the *q*-axis current controller. To minimize the inverter power losses, unity power factor at the output of the inverter is desirable. Hence, a null reference I^*_q for the reactive current loop is chosen. The *id* and *iq* current references are generated by the outer control loops imposed by the dc voltage and reactive power references, respectively.

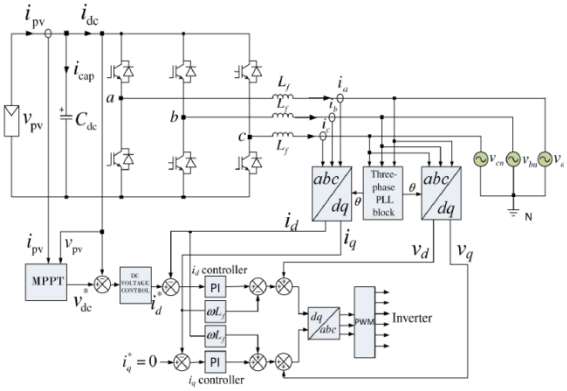


Fig 7 Three-phase grid-connected PV inverter with its control based on the dq coordinates

Two inner control loops regulate the *id* and *iq* currents, where the coupling currents are compensated by feed-forward terms as it can be observed in Fig.7. An outer voltage loop maintains the PV array's voltage close to a desired reference V^*_{dc}, which is calculated by the MPP tracking (MPPT) algorithm to extract the maximum power from the PV array.

8. Results and Discussion

To verify the effectiveness of the proposed MPPT, a detailed model of the *Z*-source converter with its proposed nonlinear MPPT controller is implemented in the MATLAB. The system parameters are given in Table 1.

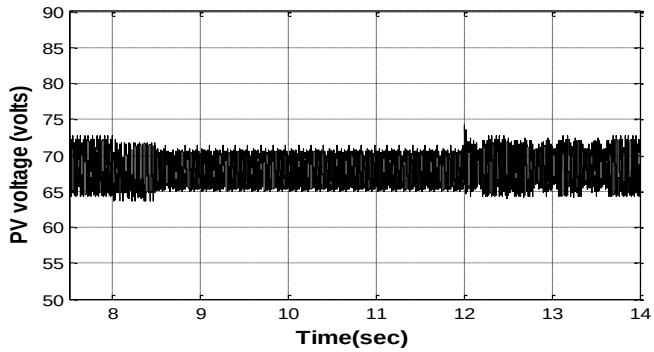
Table 1 Parameters of Z-source converter

Z-source inductance, L	1mH
Z-source capacitance, C	1300µF
PV panel terminal capacitance, C_{pv}	680µF
Load resistance, R	80Ω
Switching frequency	10KHz
MPP voltage at 1000W/m^2, 25^{0}C	70V
MPP power at 1000W/m^2, 25^{0}C	173W

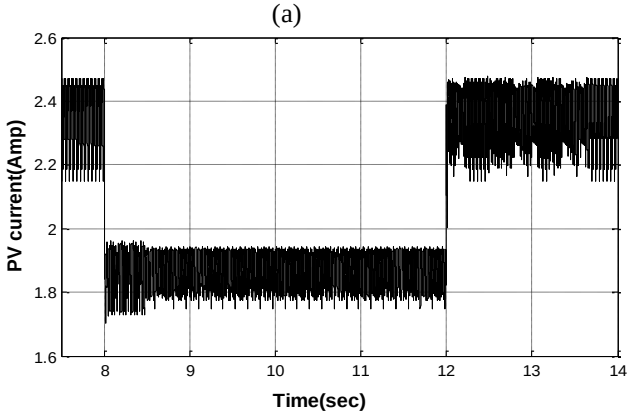
A string of four PV modules (KYOCERA KC40T) is used in simulation. The PV module specification is given in Table 2 under standard test conditions. In order to evaluate the performance of the proposed MPPT, an insolation step change is applied to the PV system. Initially, the PV array receives the sun insolation 1000 W/m2. Then, it is stepped down to 800 W/m2, and finally, it is stepped up to its initial state

Table 2 PV module specifications

Maximum Power, P_{max}	43W
Maximum Power Voltage, V_{mpp}	17.4V
Maximum Power Current, I_{mpp}	2.48A
Open Circuit Voltage, V_{oc}	21.7V
Short Circuit Current, I_{sc}	2.65A
Temperature Coefficient of V_{oc}	-8.21×10^{-2}V/^{0}C
Temperature Coefficient of I_{sc}	1.06×10^{-3}A/^{0}C



(a)



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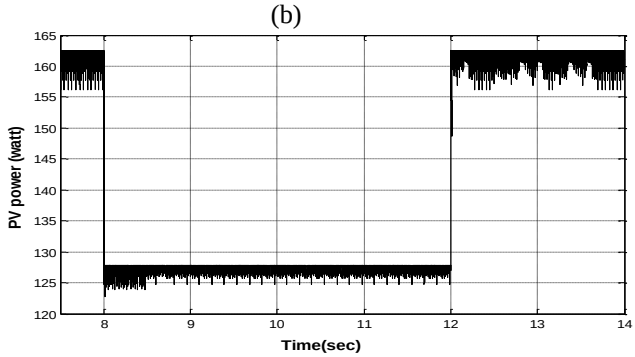
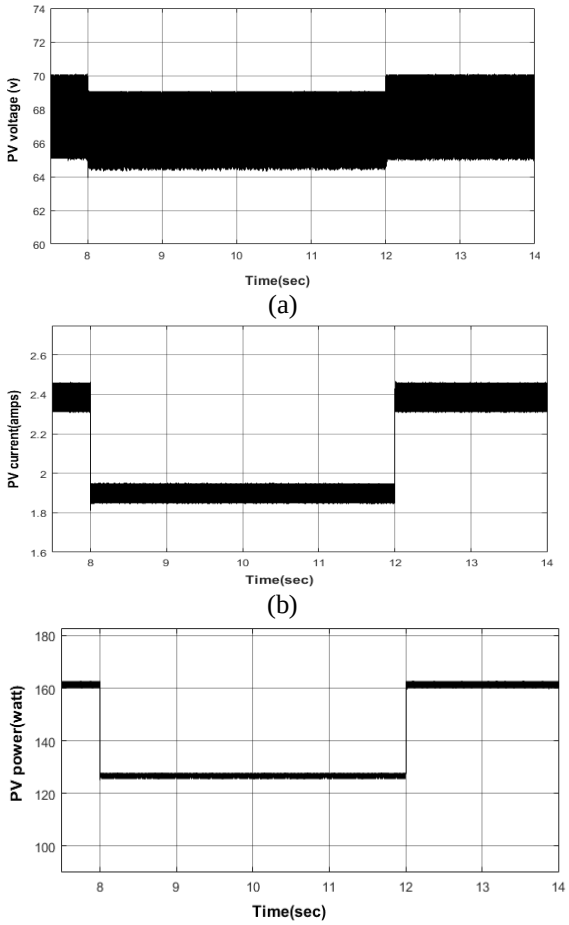


(c)

Fig 8 Results obtained by the P&O method. (a) PV voltage. (b) PV current. (c) PV power.

To highlight the capability of the proposed nonlinear MPPT algorithm, the behavior of the well-known P&O and IC methods in tracking the MPP is numerically studied under the above-mentioned solar insolation pattern. The simulation results for the voltage, current, power, and duty cycle of the switch (control action signal) obtained using the P&O and IC methods are shown in Figs 8 and 9. As stated in the literatures, the results validate that these conventional methods track the peak of the PV array system, but they do not contribute into the transience of the system. Moreover, with these conventional MPPT techniques, the measured voltage, current, and power oscillate around the MPP. The oscillation can be reduced by employing a smaller size of the voltage perturbation. However, this alternative would slow down the MPPT speed, particularly under large environmental fluctuation.



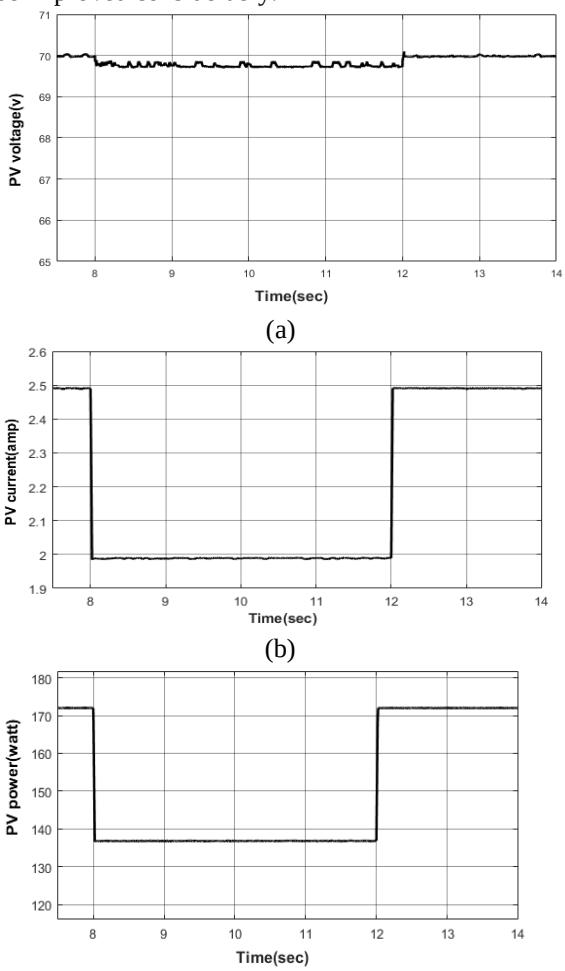
(c)

Fig 9 Results obtained by IC MPPT method. (a) PV voltage. (b) PV current. (c) PV power.

The simulation results, obtained by the proposed MPPT, are shown in Fig.10 under similar solar insolation pattern. The results affirm that once the MPP of the PV is tracked under the step change tests, the oscillation around the MPP is significantly reduced; consequently, a decrease in the power loss can be obtained. Therefore, the results confirm that the proposed nonlinear MPPT controller outperforms the conventional technique as the steady state oscillation is reduced adequately, the transient regime is improved, and the accuracy and speed of the tracking process are enhanced independently without affecting inversely each other.

Table 3 shows the comparison between the P&O, IC, and proposed nonlinear MPPT methods. There is a tradeoff between speed and accuracy using P&O and IC. Higher perturbation results in higher speed, lower accuracy, and higher MPP oscillation. Here P&O and INC MPPT are not attain rated maximum power that is 173 watts but propose MPPT method reaches the 170 watts.

The proposed MPPT offers a method that speed and accuracy of the MPP tracking are handled independently while the MPP oscillation is minimized. A Z-source dc–dc converter is suggested as an interface between the PV array and the load, since it overcomes the limitations of a conventional dc–dc converter, and the reliability of the system can be improved considerably.



(c)

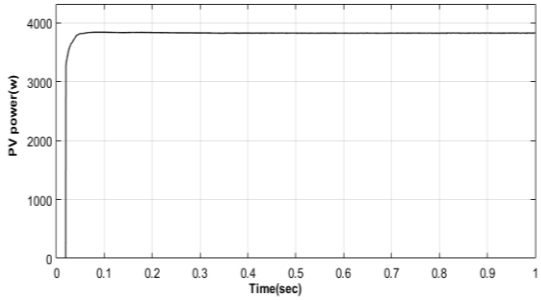
Fig 10 Results obtained by the nonlinear method. (a) PV voltage.(b) PV current. (c) PV power.

As can be seen from Table 3, the conventional P&O and IC techniques are unable to converge the exact MPP while the proposed MPPT can reach the MPP successfully. In addition, the tracking time as well as the MPP oscillation is adequately improved through the proposed method.

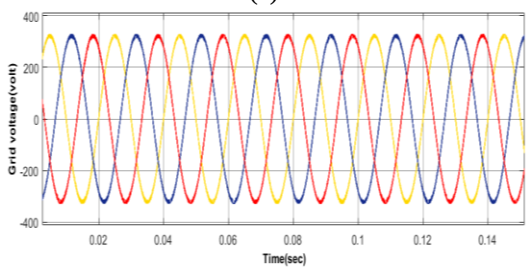
Table 3 MPPT comparison

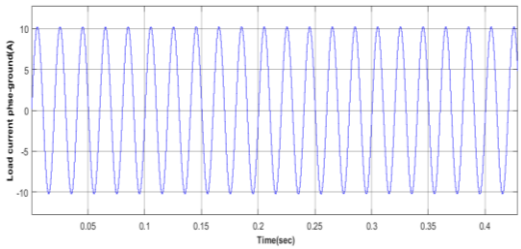
MPPT Methods	Speed	MPP Accuracy	MPP Oscillation
Proposed MPPT	High	99%, High	< 2 V, Low
P&O	Low	95%, Low	8V, High
IC	Low	97%, Medium	4.5V, High

The 4 kw PV array provides the input to the three-phase inverter and the output is connected to the 415 V, 50 Hz grid. Here 3KVA 0.9 pf load connected to grid. The output wave forms of PV power, grid voltage and load current are shown in fig 11. In this PV system 24 series cells are arranged in 3 parallel combinations therefore the voltage at MPP is 24 times the rated voltage at MPP and current at MPP is 3 times the rated current at MPP.



(a)





(b)

(c)

Fig 11 Grid connected proposed system (a) PV power (b) grid voltage (c) load current

9 Conclusion

In this paper a two diode model based nonlinear maximum power point tracking controller was described along with an adaptation mechanism to draw maximum energy from PV panels. A nonlinear input–output feedback linearization technique is used to design a nonlinear PV voltage controller. A Z-source dc–dc converter is used in between the PV array and the load, since it overcomes the limitations of a conventional dc–dc converter, and the reliability of the system can be improved considerably. The simulation results obtained from the proposed nonlinear MPPT controller and the conventional P&O and IC methods are compared. The proposed technique overcomes the existing problems for the conventional MPPTs. Simulation results show that the proposed nonlinear MPPT method is the best one over the conventional P&O and IC algorithms, since not only the steady state oscillation is greatly decreased but also the dynamic response in MPP tracking process is improved as the nonlinearity of the system is taken into account. This proposed model has connected to grid through inverter. Ac loads are connected in ac side and observe the load current wave forms, pv power and inverter output at the time of grid connection. It shows proposed MPPT gives more pv power than conventional MPPT's.

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