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Research Article

High Performance MPPT Approach for Off-Line PV System Equipped With Storage Batteries and Electrolyzer

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ABSTRACT. The current publication is directed to achieve a high-performance stand-alone PV system having the capability of tracking maximum output power, providing fixed output DC voltage, and attaining efficient system utilization, under different irradiation levels. A new maximum power point tracking (MPPT) approach integrating the incremental conductance algorithm and fuzzy logic control, and enhanced with PI-controller, was proposed to track maximum power. To provide fixed output DC voltage and approaching full system utilization, the PV system is equipped with a battery bank, electrolyzer; as a dump load, and buck-boost converter, with two controllers. The results of the proposed MPPT technique; modified incremental conductance (MINC), are compared with the corresponding results of three prevalently implemented MPPT algorithms: perturbed and observed (P&O), modified variable step-size P&O (VSZ-PO) and the ordinarily incremental conductance (INC). The highest output power, best tracking efficiency and best output power response are achieved by utilizing the proposed MPPT method. The results of the output voltage response and electrolizer on/off states confirm the ability of the PV scheme to provide fixed DC voltage and attain efficient system utilization, under varying irradiances.

Keywords: Photovoltaic, MPPT, Battery bank, Electrolyzer, Fuzzy logic.

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1. Introduction

People's lifestyles and their comfort levels are changing drastically towards the increased demand for electricity consumption. This trend constitutes a great challenge for power system investors to invest in the power generation system which can meet the expected future demand expansions (Al-Refai, 2014). Unfortunately, most of the current power generation systems worldwide are based on conventional fossil fuel energy resources, like oil and natural gas (Bose, 2013). These resources are limited in nature which could be depleted in the near future. Moreover, their operation involves harmful emissions to the environment, and their prices are fluctuating depending on various political and economic issues (Bose, 2010). In contrast, renewable energy resources, like solar and wind, are abundant, sustainable, and environmentally friendly Pazheri *et al.,* (2014); Ahmadi *et al.* (2018); Bhukya and Kota (2018).

Nowadays, photovoltaic (PV) generators are of great interest in many parts of the world due to the advantages of utilizing solar energy for power generation (Khatibi *et al.,* 2019). The PV-based generation systems could be mainly divided into on-grid and off-grid schemes (Maleki *et al.,* 2016). On-grid indicates that the PV system is connected to the grid, while the off-grid means that the PV system is operating solely Blaabjerg *et al.* (2006); Pavlović *et al.* (2010). Storage elements, like battery bank or supper capacitors, are usually required for off-grid PV configurations to ensure a continuous supply for the load Li *et al.* (2009); Yokoyama *et al.* (2011). The main applications of stand-alone (off-grid) PV schemes are electrification of remote buildings, water pumping, transportation, mobile applications, and satellite systems Mohammadnezami *et al.* (2015); Sebastian *et al.* (2016); Ahmadi *et al.* (2018).

A PV generator is an attractive electric energy source because of the solar energy merits. However, the efficiency of PV panels in converting solar energy to electric power is relatively low, typically in the range of 12% to 30% (Sera *et al.,* 2007). In addition, the variations in the solar irradiation, panel temperature, and load are adversely affecting the PV system efficiency in a non-linear manner (Chandel *et al,* 2015). Therefore, tracking the maximum possible power from a PV generator, under the variations in atmospheric and load conditions, is highly demanded to improve the conversion efficiency. The system of maximum power point tracking (MPPT) is basically a DC chopper equipped with a control system to adjust the chopper duty-cycle Subudhi and Pradhan (2013). The behaviour of a MPPT technique can be assessed based on its tracking efficiency, which can be realized as the ratio of the practical tracked output power of the PV array to its theoretical output power, for the same time interval (Tafticht *et al,* 2007).

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Over the last years, the issue of achieving maximum power extraction from the PV array has attracted the attention of many researchers worldwide. Therefore, a great number of papers deal with the implementation of various MPPT methods have been published Yeong-Chau *et al.* (2001); Pandey et al. (2008); Berrera *et al.* (2009); Mummadi (2010); Qiang and Tong (2010); Revankar *et al.* (2010); Chim *et al.* (2011); Mei *et al.* (2011); Alajmi *et al.* (2013); Babaa *et al.* (2014). Maximum power point trackers are competing in terms of different factors such as simplicity, sensor requirements, cost, tracking efficiency, and convergence speed (Enrique et al., 2010). Perturbed and observe (P&O), Incremental conductance (INC) and modified variable step-size P&O (VSZ-PO) algorithms are the most utilized trackers in the PV based systems Metry *et al.,* 2017; Naick *et al.* (2017); Bhukya and Kota (2018); Javed *et al.* (2018).

The output voltage and power of a PV array are expected to vary due to natural variations in the atmospheric conditions. Therefore, off-grid PV systems are usually equipped with storage batteries to overcome the shortage in the generated power Thang *et al.* (2015); Bhattacharyya and Samanta (2018). To achieve fixed DC link voltage and proper power flow modes under the variations in atmospheric conditions, the PV system has to combine power conditioners, with the needed control Karthikeyan and Gupta (2017); Saxena *et al.* (2017).

In this paper, a new MPPT algorithm (MINC) is proposed for off-grid PV system. This MPP tracker combines both INC and Fuzzy Logic Control (FLC) algorithms and enhanced with PI controller. To confirm the validity of utilizing the MINC approach, a comparison with P&O, INC, and VSZ-PO has been made. The PV system performance is improved by maintaining the DC link voltage fixed and reaching efficient system utilization, even under rapid irradiation level changes. This improvement is achieved by enhancing the system with a battery bank, electrolyzer (dump load), and DC chopper, with two controllers.

2. Photovoltaic Generation System

This section provides the basic principles concern with the PV array including the mathematical model and the effects of the atmospheric variations (irradiance and temperature) on the I-V and P-V characteristics of the PV-generator**.** The second part of this section describes the investigated PV system in detail.

2.1 Principles of the Photovoltaic Array

The basic element of a photovoltaic array is the solar cell. It directly converts the sunlight to electricity (Vastav *et al.,* 2016). To acquire more voltage and current, the cells are combined to form a panel (module). Panels are connected together either in series or in parallel to obtain an array, which can meet the electrical needs. The buildup structure of these components is presented in Fig. 1 (Vastav *et al.*, 2016).

A Single-diode model or two-diode model is used to represent the behavior of a solar cell (Liu *et al.*, 2005). The two configurations are shown in Fig. 2. Single-diode model has a simple configuration, which leads to less complex mathematical expression, and can provide accurate results Kim and Choi (2010); Bhukya and Kota (2018). Using the single diode model, the I-V relationship and the thermal potential V_T of a PV panel can be given in equations (1) and (2), respectively Liu *et al.,* (2005); Khatibi *et al.* (2019); Premkumar *et al.* (2020).

The behavior of a PV-generator is strongly affected by the solar irradiation level and the ambient temperature (Premkumar *et al.* 2020). The current-voltage (I-V) and voltage-power (P-V) characteristics of the PV generator, under various irradiation levels and fixed temperature, are illustrated in Fig. 3. As can be observed, increasing the irradiation level causes the current to linearly increase, but the voltage is slightly increasing. As a result, the output power increases with irradiation level. The I-V and P-V characteristics, under different temperature settings and fixed irradiation level, are demonstrated in Fig. 4. It can be noticed that the increase in the ambient temperature causes a decrease in the open circuit voltage and very small increase in the current. Consequently, the array output power will decrease with an increase in temperature level.

$$i = I_{ph} - I_o\left(e^{\frac{v+iR_s}{n_s V_T}} - 1\right) - \frac{v+iR_s}{R_{sh}} \tag{1}$$

$$V_T = \frac{AKT_{stc}}{q} \tag{2}$$

2.2 The Proposed PV generation Scheme

The main power source in the proposed PV generation system is the PV array. The PV system is equipped with a battery bank to feed the load if the generated power from the main source is insufficient to cover the load demand and at the same time the state of charge (SOC) of the battery bank is higher than 80%. To achieve the features of fixed DC link voltage and improved system utilization, under solar irradiation changes, a buck-boot DC/DC converter, with two controllers, and electrolizer (dump load) are combined with the PV system.

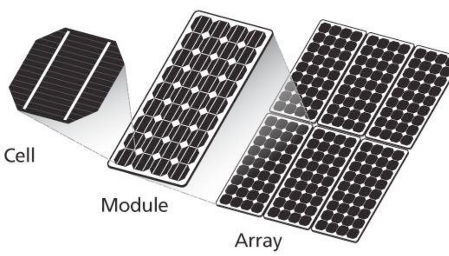
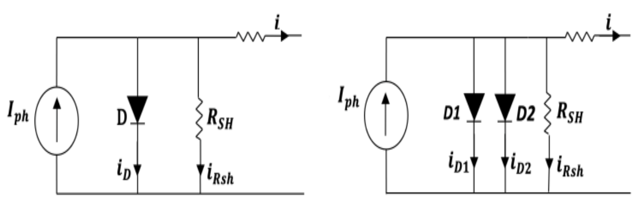


Fig. 1 PV cell, Module and array (Vastav et al., 2016)



(a) (b)

Fig. 2 Solar cell models: (a) single-diode circuit (b) two-diode circuit

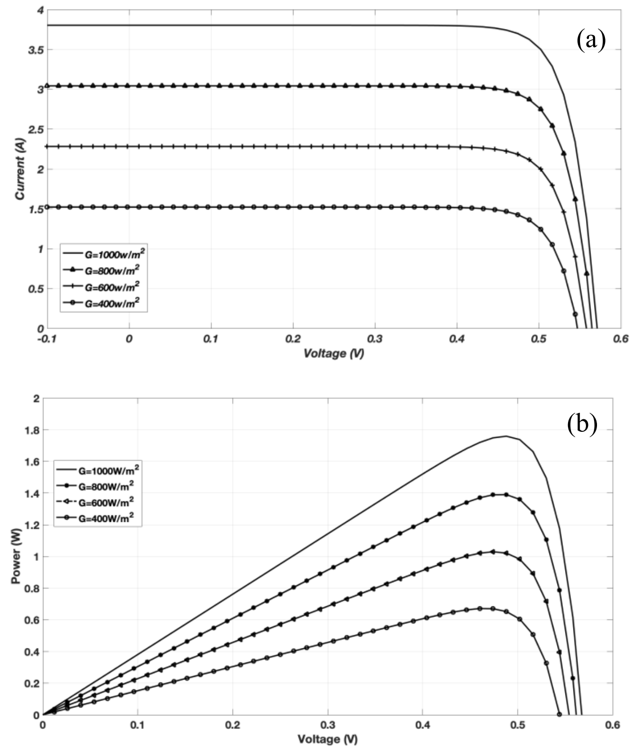


Fig. 3. (a) The current-voltage relationship of the PV array for various irradiation levels and constant temperature level, (b) The Power-Voltage relationship of the Photovoltaic array for various irradiation levels and constant temperature settings.

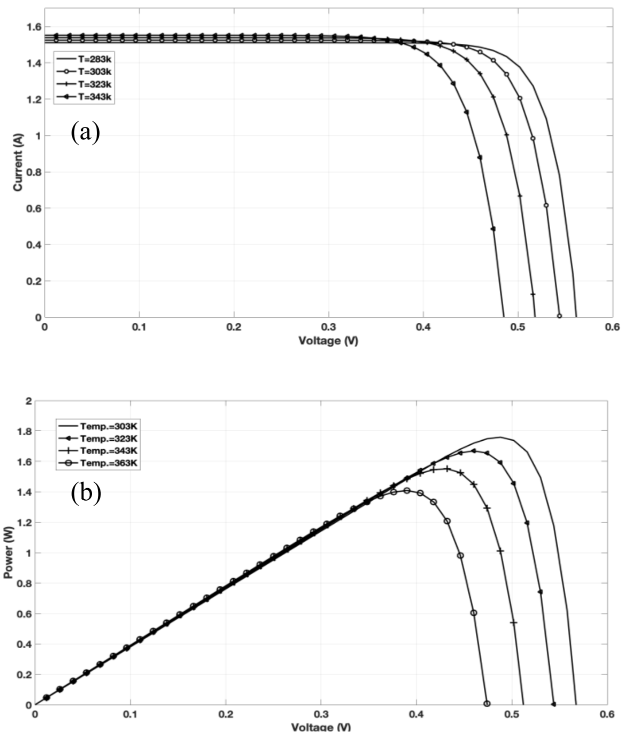


Fig. 4. (a) The current-voltage relationship of the Photovoltaic array for variable temperature and constant irradiance, (b) The Power-Voltage relationship of the Photovoltaic array for variable temperature and constant irradiance

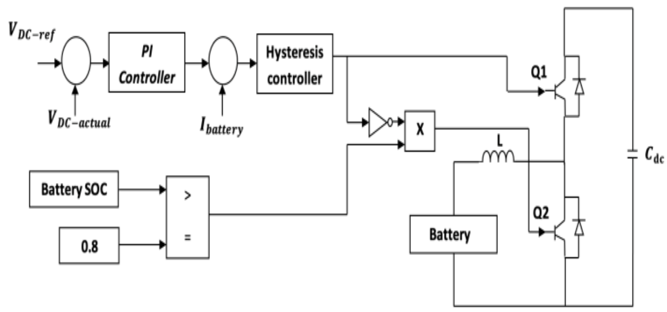


Fig. 5 The control scheme for the operation of the buck-boost converter

The control scheme for the operation of the buck-boost DC chopper is represented in Fig. 5 Berrera *et al.* (2009); Qiang and Tong (2010). The actual DC link voltage is subtracted from the reference set value to generate the deviation error signal, which is input to the PI-controller. The output control signal from the PI-controller represents the reference battery current signal. Subtracting the actual battery current from this reference signal will produce the error signal which is fed to the hysteresis controller. The output control signal from the hysteresis controller represents the switching command (duty cycle) for switch S1 or/and switch S2 of the converter, depending on the SOC of the battery bank.

3. The Proposed MPPT Approach

Incremental conductance (INC) algorithm is one of the well-known maximum power trackers and usually it runs with constant step size (Kharb *et al.*, 2014). With fixed step size, it is very difficult to achieve fast transient response with minimized steady state oscillations (Javed *et al.* 2018). The proposed MPPT scheme integrates INC algorithm and fuzzy logic control to acquire proper adjustment for step size. Consequently, fast transient response and reduced fluctuations around the point of maximum power will be achieved. The proposed approach is enhanced with PI controller to accelerate the response and minimize the percentage overshoot. The PI-controller gains are adjusted using Zeigler-Nichols approach (Singh and Singh, 2014). the schematic diagram of the proposed MPPT is shown in Fig. 6.

The output current and voltage of the PV array are fed to INC block to produce the error (E), which is processed to provide the change of error (ΔE). This process is mathematically represented in equation (3). The two parameters E and ΔE are fed to the fuzzy-logic controller, which provides the modulation signal. This signal is compared with the reference signal to provide proper switching command for the boost chopper. As a result, fast speed response in tracking the maximum power point, with minimized fluctuations around this attained point, will be achieved. Detailed description of the INC method and fuzzy logic control approach are given in next subsections.

$$\Delta E = E(n) - E(n-1) \tag{3}$$

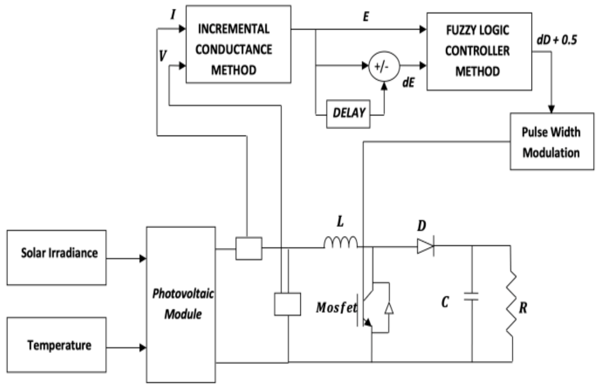


Fig. 6 The schematic of the proposed MPPT scheme

3.1 Incremental Conductance (INC) Algorithm

Incremental conductance algorithm is based on the concept that maximum power point (MPP) is attained when the rate of change of the power output with respect to the output voltage is zero (Yun *et al.,* 2004). This condition can be mathematically represented by the following equation:

$$\frac{dP}{dV} = \frac{d(I.V)}{dV} = \mathrm{I} + \mathrm{V}(\frac{dI}{dV}) = 0 \qquad (4)$$

On the array power-voltage characteristic, the slope is zero (*dP/dV*=0) at the MPP, positive on its left-hand side (LHS) and negative on the right-hand side (RHS) Subudhi and Pradhan (2013). From equation 4, ΔI / ΔV may be given by:

$$\frac{\Delta I}{\Delta V} = -\frac{I}{V} \qquad (5)$$

Equation 5 represents the case at the MPP. For all operating points located on the LHS of the MPPT, (ΔI/ΔV) > (-I/V). On the other hand, (ΔI/ΔV) < (-I/V) for all operating points located to the RHS of the MPP. Consequently, the MPP can be tracked by comparing the instantaneous conductance (I/V) with the incremental conductance (ΔI/ΔV). The INC algorithm is demonstrated by the flow chart shown in Fig. 7 (Diva and Kavitha, 2013). The Simulink model of the INC algorithm given in Fig. 8 which can be explained through two stages. In the first stage, the current and voltage of the PV array are fed to the model to produce the conductance I/V and the incremental conductance ΔI/ΔV. In the next stage, I/V is compared with ΔI/ΔV to give the error signal. This signal is then subjected to two consecutive comparison via two cascaded switches to provide the output.

3.2 Fuzzy Logic Control

Fuzzy logic control (FLC) has been widely used in various applications due to its several advantages. First, the controller can be tuned to control complicated nonlinear system having several inputs. Second, an exact system mathematical model is not required to implement FLC (Esram and Chapman, 2007). There are various techniques which can be used to perform fuzzy interface process. Mamdani method is widely utilized for control engineering applications because it is the most computationally efficient approach (Bai *et al.,* 2006). Mamdani method performs the fuzzy interface process in four steps: Fuzzification, knowledge base, interface engine and defuzzification Mobaied (2008); Iancu (2012); Ocran *et al.* (2005).

The general structure of the fuzzy interface system is demonstrated in Fig. 9. The first process in FLC is fuzzification. During this stage, the fuzzifier transforms crisp input variables into fuzzy inputs through membership functions. These inputs are then represented using linguistic rules, for example “if x and y, then z”. The fuzzy inference engine processes these data to obtain the desired fuzzy outputs (Soufi *et al.* (2014). The last interface process to achieve the desired FLC objective is defuzzification. It is accomplished through the defuzzifier which converts the fuzzy outputs into numerical values.

In the present work, the error and change of error (E, ΔE) are the input variables to FLC. After the accomplishing of all required processes, the desired output from the final interface process is the duty cycle (ΔD). The membership functions of the inputs (E, ΔE) and output (ΔD) are presented in Fig. 10. The implemented fuzzy rules in the present work are given in Table 1. The triangular shape is chosen to represent the membership functions because it is the most popular and widely used shape. The degree of membership function lies in the range of [0 1]. As can be noticed in Table 1, the selected number of membership functions for each input is five and consequently the inference rules of the fuzzy logic controller are twenty-five rules.

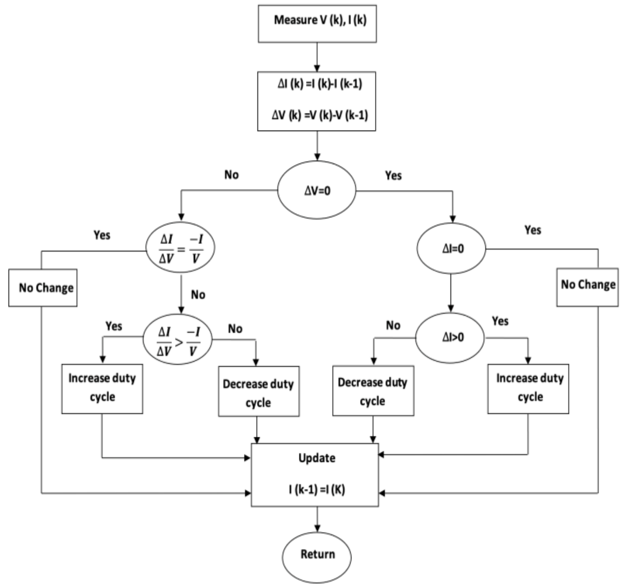


Fig. 7 Flowchart of the INC algorithm

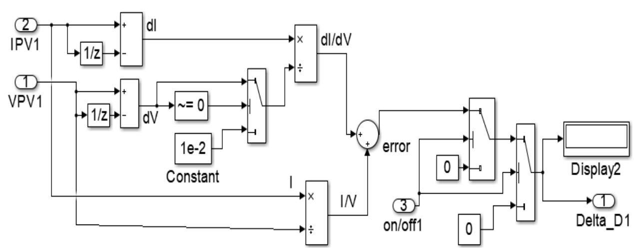


Fig. 8 The Simulink model of INC algorithm

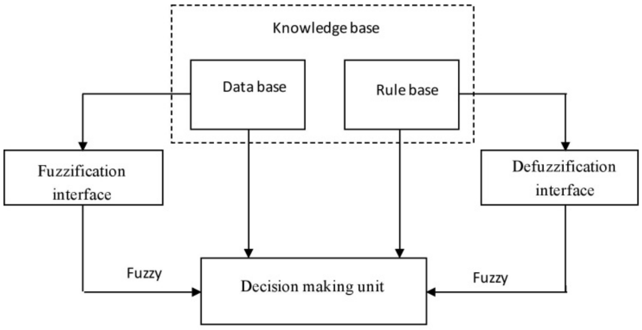


Fig. 9 General structure of fuzzy interface system

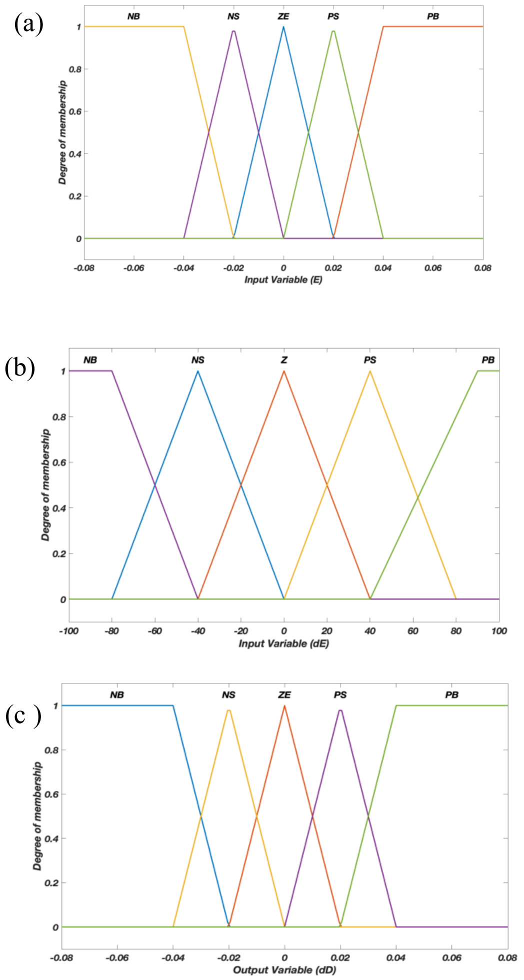


Fig. 10. (a) Membership function of the input variable; error (E), **(b)** Membership function of the input variable; changes of error (ΔE), **(C)** Membership function of the output variable; change of duty cycle (ΔD).

Table 1
Fuzzy rules base for MINC controller

ΔE \ E	NB	NS	ZZ	PS	PB
NB	ZZ	ZZ	NS	PS	PB
NS	ZZ	ZZ	ZZ	PS	PB
ZZ	NB	NS	ZZ	PS	PB
PS	NB	NS	ZZ	ZZ	ZZ
PB	NB	NS	PS	ZZ	ZZ

4. Results and Discussion

The parameters of the implemented PV array in the proposed standalone photovoltaic system are presented in Table 2. The integrated system components, including a MPPT algorithm, have been simulated in Matlab/Simulink platform. The system performance with MINC (the proposed approach), P&O, INC or VSZ-PO algorithm, under the same conditions, is investigated. The assessment is carried out under the operation of fixed irradiation level as well as variable irradiation level. The capability of the proposed PV scheme in achieving fixed DC voltage and reaching efficient system utilization, under various irradiation levels, is also tested.

The obtained output power results using P&O, INC, VSZ-PO and MINC (the proposed approach) MPPT methods are presented in Fig. 11. The system output power without MPPT is also shown in the figure. The PV generator is assumed to operate under fixed irradiance of 1000 W/m^2, constant temperature of 25^{o}C, and feeding a resistive load of 48 Ω. It can be observed that VSZ-PO has better dynamic performance and less oscillations, compared with P&O or INC method. This improvement is due to the use of variable step size, which is not the case for P&O or INC approach. However, INC method provides the highest steady output power compared with P&O and VSZ-PO methods. It is suitable to say that none of the three methods can provide high output power with minimized oscillations.

Based on the comparison made between the proposed MINC method in one hand and P&O, INC or VSZ-PO on the other hand, tremendous improvements in the PV system behaviour during both transient and steady-state situations has been achieved with MINC approach. It provides fast and smooth dynamic response, minimized steady-state oscillations and high steady-state output power. The computed tracking efficiency of the proposed MPPT technique reaches 99.3%, which is higher compared with that of P&O, INC or VSZ-PO.

To assess the behaviour of the output power for each of the four mentioned MPPT algorithms under rapid irradiation changes, the irradiance profile with great changes shown in Fig. 12 is considered. This profile is fed as input to the Simulink model of the proposed PV scheme and an individual simulation is run for each MPPT algorithm. The results of the output power tracked by P&O, INC, VSZ-PO and MINC MPPT algorithms are presented in Fig. 13. It can be observed that the MINC (proposed MPPT approach) possess the best performance features compared with P&O, INC and VSZ-PO techniques. It can respond very fast, under the rapid change in solar irradiation, to reach the steady state final value with no oscillations.

Table 2
The parameters of the tested solar array

Parameter	value	Unit
Maximum Power	230	W
Open circuit voltage	37	V
Short circuit current	8.3	A
No. cells per module	60	-
No. parallel strings	5	-
No. series strings	6	-
Current at maximum power point	7.72	A
Voltage at maximum power point	29.8	V

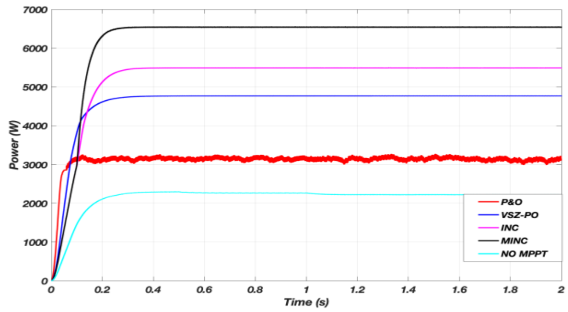


Fig. 11 The system output power using P&O, INC, VSZ-PO and MINC algorithms under fixed irradiation level operation

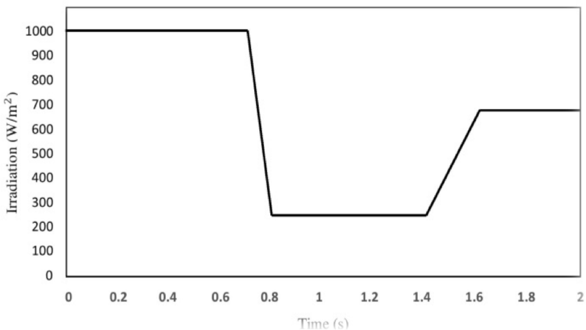


Fig. 12 The considered irradiance profile

The proposed algorithm also provides the highest steady-state output power, compared with other three algorithms. The other assessment criteria used to evaluate the performance of proposed MPPT method in comparison with the three commonly used MPPT approaches is the tracking efficiency. It is ratio of the real tracked PV output power, by a MPPT technique, to the theoretical computed one, under the same irradiation level. The irradiation levels used in the current investigation are 1000, 650 and 250 W/m^2. The obtained theoretical power output results for these irradiances are 6583, 3180 and 1085 W, respectively. The results of the tracking efficiency for the algorithms are given in Table 3. As can be noticed, the maximum tracking efficiency is achieved when implementing the proposed MPPT approach. The results presented in Fig. 11 and Fig. 13 as well as those given in Table 3 confirm the validity of the proposed MPPT approach in achieving high performance PV system.

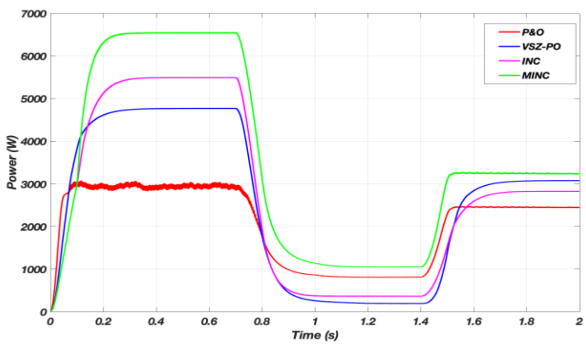


Fig. 13 Output power of the P&O, INC, VSZ-PO and MINC MPPT methods under different irradiation levels

Table 3
The computed tracking efficiency of MPPT techniques

Irradiance (W/m^2)		1000	650	250
Tracking Efficiency	MINC	99.3%	98.1%	97.7%
	P&O	44.1%	73.9%	65.4%
	INC	84.5%	73.9%	36%
	VSZ-PO	73.4%	94.8%	33%

Two attractive features in the performance of the proposed PV scheme are also examined. These features are the system capability to maintain the DC link voltage fixed and the ability to approach efficient utilization of the system components, under varying irradiation level. The assessment is carried out by feeding the irradiance profile of Fig. 12 to the PV system model and then SIMULINK simulations are run for the examined cases.

The output DC voltage of the PV scheme when excluding the storage means and the controllers is shown in Fig. 14. As can be seen the output DC voltage is changing in response to the variations in solar irradiation. Therefore, feeding most of the load types could be impossible or the solution to adjust the voltage will not be an easy task. The results of this test confirm the importance of the proposed PV system structure to achieve fixed output DC voltage under the variation in solar irradiation.

The output DC voltage of the proposed PV scheme under different solar irradiation levels is shown in Fig. 15. As can be observed the output DC voltage remains fixed for the whole solar profile period. Moreover, it possesses the features of fast dynamic response, with reduced percentage overshoot, and no oscillations during the steady state condition.

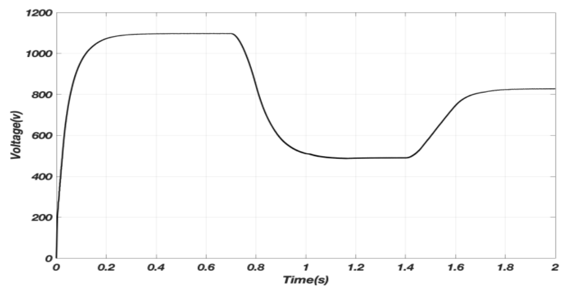


Fig. 14 The output DC voltage of PV system when excluding the storage means and the controllers

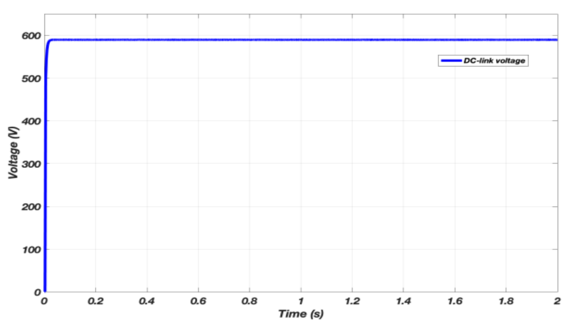


Fig. 15 The DC link voltage of the PV system enhanced with storage battery bank and ON/OFF controller

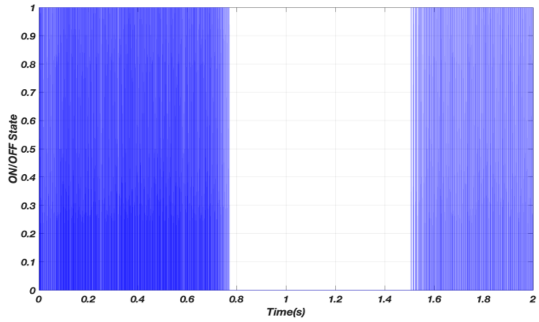


Fig. 16 The ON/OFF states of the electrolyzer under the different solar irradiation levels

The results presented in Fig. 16 shows the electrolyzer on/off states under the variation in the solar irradiation (Fig. 12). It can be noticed that the electrolyzer is ON in the first intervals (0 – 0.78) s, OFF in the second interval (0.78 – 1.54) s and again ON in the third interval (1.54 – 2) s.

During the first interval, the solar irradiation is high enough leading to extra PV generated power exceeds the load demand and the power for charging the batteries, if the SOC of the battery bank is less than 80%. The excess generated power enables the electrolizer to turn on. In the second interval, the electrolizer is OFF because the solar irradiation level is low and therefore the PV generated power is insufficient to supply the load. In the third interval, the solar irradiation level is moderate enabling the PV array, with the help of the battery bank, to produce power exceeds the load demand. The excess power causing the electrolyzer to turn ON again. It can be stated that the proposed PV scheme has the capability to manage the modes of power flow between the system components reaching efficient system utilization, under varying solar irradiation level.

5. Conclusion

The implementation of a new high performance maximum power point tracking (MPPT) approach, which integrates P&O and INC and enhances with PI controller, for standalone photovoltaic system, enhanced with a battery bank and electrolyzer, has been evaluated. Based on the comparison made with P&O, INC and VSZ-PO, the highest output power and maximum tracking efficiency, even under rapid changes in solar irradiation, are acquired with the proposed algorithm. In addition, it leads to a high-performance output power response during dynamic and steady state conditions. The capability of the proposed PV configuration to achieve fixed DC link voltage and attain efficient system utilization, under varying solar irradiation level, was also assessed. The obtained results confirm the attainment of these two features properly.

Nomenclature

A	The diode quality factor, usually 1<A<2
DC	Direct current
ΔE	Change of error
$E(n)$	Error of the current sample
$E(n-1)$	Error of the previous sample
FLC	Fuzzy logic control
i	Array output current
INC	Incremental conductance
I_o	Saturation current of a solar cell
I_{ph}	Solar cell photo generated current
K	Boltzmann's constant (1.38E-23 J/K)
LHS	Left hand side
MINC	Modified incremental conductance
n_s	Number of cells (or modules) connected in series
P&O	Perturb and Observe
PV	Photovoltaic
q	Electron charge (1.6E-19 C)
RHS	Right hand side
R_s	Solar cell series resistance
R_{sh}	Shunt resistance of a solar cell
SOC	State of charge
T_{stc}	Cell temperature under standard test condition
v	Array terminal voltage
VSZ	Variable step size
V_T	Thermal potential of the PV panel

References

Ahmadi, M., Ghazvini, M., Sadeghzadeh, M., Nazari, M., Kumar, R., Naeimi, A., Ming, T. (2018). Solar power technology for electricity generation: A critical review. Energy Science &Engineering, 6 (5), 340-361. doi: 10.1002/ese3.239

Alajmi, B., Ahmed, K., Finney, S., Williams, B. (2013). A maximum power point tracking technique for partially shaded photovoltaic systems in micro grids. *IEEE Transactions on Industrial Electronics*, 60(4), 1596-1606. doi: 10.1109/tie.2011.2168796

Al-Refai, M. (2014). Matlab/Simulink simulation of solar energy storage system. *International Journal of Electrical, Computer, Electronics and Communication Engineering*, 8(2), 297-302.

Babaa, S., Armstrong, M., Pickert, V. (2014). Overview of Maximum Power Point Tracking Control Methods for PV Systems. *Journal of Power and Energy Engineering*, 2, 59-72. doi.org/10.4236/jpee.2014.28006

Bai, Y., Zhuang, H., Wang, D. (2006). Advanced fuzzy logic technologies in industrial applications. Springer, UK, 17-36; doi.org/10.1007/978-1-84628-469-4

Berrera, M., Dolara, A., Faranda, R., Leva, S. (2009). Experimental test of seven widely-adopted MPPT algorithms. In 2009 IEEE Bucharest Power Tech (pp. 1-8); doi: 10.1109/PTC.2009.5282010

Bhattacharyya, S., Samanta S. (2018). DC link voltage control based power management scheme for standalone PV systems. In 2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES) (pp. 1-5); doi: 10.1109/PEDES.2018.8707904

Bhukya, M., Kota, V. (2018). A Novel PandO$_T$-Neville's Interpolation MPPT Scheme for Maximum PV System Energy Extraction. Int. Journal of Renewable Energy Development, 7 (2), 251-260. doi.org/10.14710/ijred.7.3.251-260

Blaabjerg, F., Teodorescu, R., Liserre, M., Timbus A. (2006). Overview of Control and Grid Synchronization for Distributed Power Generation Systems. *IEEE Transactions on Industrial Electronics*, 53(5), 1398-1409; doi: 10.1109/TIE.2006.881997

Bose, B. (2010). Global warming: energy, environmental pollution, and the impact of power electronics. *IEEE Industrial Electronics Magazine*, 4(1), 6–17; doi: 10.1109/mie.2010.935860

Bose, B. (2013). Global energy scenario and impact of power electronics in 21st century. *IEEE Transactions on Industrial Electronics,* 60(7), 2638-2651; doi: 10.1109/tie.2012.2203771

Chandel, S., Naik, M., Chandel, R. (2015). Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. *Renewable and Sustainable Energy Reviews,* 49, 1084-1099; doi.org/10.1016/j.rser.2015.04.083

Chim, C., Neelakantan, P., Yoong, H., Teo, K. (2011). Fuzzy Logic Based MPPT for Photovoltaic Modules Influenced by Solar Irradiation and Cell Temperature. In 2011 UkSim 13th International Conference on Computer Modelling and Simulation; Cambridge (pp. 376-381); doi: 10.1109/UKSIM.2011.78

Diva, C., Kavitha, B. (2013). Simulation of a solar MPPT charger using CUK converter for standalone application. *International Journal of Electrical, Electronics and Computer Systems (IJEECS)*, 1(1), 2347-2820.

Enrique, J., Andújar, J., Bohórquez, M. (2010). A reliable, fast and low cost maximum power point tracker for photovoltaic applications. *Solar energy*, 84(1), 79-89; doi.org/10.1016/j.solener.2009.10.011

Esram, T., Chapman, P. (2007). Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques. *IEEE Transactions on Energy Conversion,* 22 (2), 439- 449. doi: 10.1109/tec.2006.874230

Iancu, I. (2012). A Mamdani Type Fuzzy Logic Controller. In: Fuzzy Logic - controls, concepts, theories and applications. IntechOpen; doi: 10.5772/2662

Javed, K., Ashfaq, H., Singh, R. (2018). An improved MPPT algorithm to minimize transient and steady state oscillation conditions for small SPV systems. Int. Journal of Renewable Energy Development, 7 (3), 191-197. doi.org/10.14710/ijred.7.3.191-197

Karthikeyan, V., Gupta R. (2017). Varying phase angle control in isolated bidirectional DC–DC converter for integrating battery storage and solar PV system in standalone mode. *IET Power Electronics,* 10(4), 471-479; doi: 10.1049/iet-pel.2016.0162

Kharb, R., Shimi, S., Chatterjic, S., Ansari, Md. (2014). Modeling of solar PV module and maximum power point tracking using ANFIS. *Renewable and Sustainable Energy Reviews,* 33, 602–612; doi.org/10.1016/j.rser.2014.02.014

Khatibi, A., Astaraei, F., Ahmadi, M. (2019). Generation and combination of the solar cells: A current model review. Energy Science & Engineering, 7(2), 305-322. doi: 10.1002/ese3.292

Kim, W., Choi, W. (2010). A novel parameter extraction method for the one-diode solar cell model. *Solar Energy* , 84(6), 1008–1019; doi.org/10.1016/j.solener.2010.03.012

Li, C-H., Zhu, X-J., Cao, G-Y., Hu, M-R. (2009). Dynamic modeling and sizing optimization of stand-alone photovoltaic power systems using hybrid energy storage technology. *Renewable Energy,* 34 (3), 815-826; doi.org/10.1016/j.renene.2008.04.018

Liu, Y-H., Leou, R-C., Cheng, J-S. (2005). Design and implementation of a maximum power point tracking battery charging system for photovoltaic applications. *2005 IEEE Russia Power Tech*; St. Petersburg, Russia, 1-5; doi: 10.1109/PTC.2005.4524349

Maleki, A., Pourfayaz, F., Ahmadi, M. (2016). Design of a cost-effective wind/photovoltaic/hydrogen energy system for supplying a desalination unit by a heuristic approach. Solar Energy, 139, 666-675. http://dx.doi.org/10.1016/j.solener.2016.09.028

Mei, Q., Shan, M., Liu, L., Guerrero, J. (2011). A Novel Improved Variable Step-Size Incremental Resistance MPPT Method for PV Systems. *IEEE Transactions on Industrial Electronics*, 58(6), 2427-2434; doi: 10.1109/TIE.2010.2064275

Metry, M., Shadmand, M., Balog, R., Abu-Rub, H. (2017). MPPT of photovoltaic systems using sensorless current-based model predictive control. *IEEE Transactions on Industry Applications,* 53(2), 1157–1167; doi: 10.1109/tia.2016.2623283

Mobaied, M. (2008) Fuzzy logic speed controllers using FPGA technique for three-phase induction motor drives. Master thesis, The Islamic University, Gaza.

Mohammadnezami, M., Ehyaei, M., Rosen, M., Ahmadi, M. (2015). Meeting the electrical energy needs of a residential building with a wind-photovoltaic hybrid system. *Sustainability*, 7 (3), 2554-2569. doi:10.3390/su7032554

Mummadi, V. (2010). Control of TI-SEPIC Converter for Optimal Utilization of PV Power. In India International Conference on Power Electronics 2010 (IICPE 2010). (pp. 1-5); doi: 10.1109/IICPE.2011.5728087

Naick, B., Chatterjee, T., Chatterjee, K. (2017). Performance analysis of maximum power point tracking algorithms under varying irradiation. Int. Journal of Renewable Energy Development, 6 (1), 65-74. doi.org/10.14710/ijred.6.1.65-74.

Ocran, T., Cao, J., Cao, B., Sun, X. (2005). Artificial Neural Network Maximum Power Point Tracker for Solar Electric Vehicle. *Tsinghua Science and Technology*, 10(2), 204-208; doi: 10.1016/S1007-0214(05)70055-9

Pandey, A., Dasgupta, N., Mukerjee, A. (2008). High Performance Algorithms for Drift Avoidance and Fast Tracking in Solar MPPT System. *IEEE Transactions on Energy Conversion*, 23(2), 681-689; doi: 10.1109/TEC.2007.914201

Pavlović, T., Radonjić, I., Milosavljević, D., Pantić, L. (2012). A review of concentrating solar power plants in the world and their potential use in Serbia. *Renewable and Sustainable Energy Reviews*, 16, 3891-3902. doi.org/10.1016/j.rser.2012.03.042

Pazheri, F., Othman, M., Malik, N. (2014). A review on global renewable electricity scenario. *Renewable and Sustainable Energy Reviews*, 31, 835-845; doi.org/10.101/j.rser.2013.12.020

Premkumar, M., Kumar, C., Sowmya, R. (2020). Mathematical modelling of solar photovoltaic cell/panel/array based on the physical parameters from the manufacturer's datasheet. *Int. Journal of Renewable Energy Development*, 9 (1), 7-22. doi.org/10.14710/ijred.9.1.7-22.

Qiang, F., Tong, N. (2010). Complex-method-based PSO algorithm for the maximum power point tracking in photovoltaic system. In 2010 Second International Conference on Information Technology and Computer Science (pp. 134–137); doi: 10.1109/ITCS.2010.39

Revankar, P., Thosar, A., Gandhare, W. (2010). Maximum Power Point Tracking for PV Systems Using MATLAB/SIMULINK. In 2010 Second International Conference on Machine Learning and Computing (pp. 8-11); doi: 10.1109/ICMLC.2010.54

Saxena, N., Singh, B., Vyas, A. (2017). Single-phase solar PV system with battery and exchange of power in grid-connected and standalone modes. *IET Renewable Power Generation,* 11(2), 325-333; doi: 10.1049/iet-rpg.2016.0143

Sebastian, W., Subhash, K., Reinhard, M. (2016). Financial Viability of Grid-connected Solar PV and Wind Power Systems in Germany. *Energy Procedia*, 106, 35-45; doi.org/10.1016/j.egypro.2016.12.103

Sera, D., Teodorescu, R., Rodriguez, P. (2007). PV panel model based on datasheet values. In 2007 IEEE International Symposium on Industrial Electronics. (pp. 2392-2396); doi: 10.1109/ISIE.2007.4374981

Singh, A., Singh, R. (2014). Load-Frequency Controller of electrical Power plant using Ziegler Nichols (ZN) tuning controller. *IJISET - International Journal of Innovative Science, Engineering & Technology*, 1(6), 2348–7968.

Soufi, Y., Bechouat, M., Kahla, S., Bouallegue, K. (2014). Maximum power point tracking using a fuzzy logic control scheme for photovoltaic system; In 2014 International Conference on Renewable Energy Research and Application (pp. 902-906); doi: 10.1109/ICRERA.2014.7016515

Subudhi, B., Pradhan, R. (2013). A comparative study on maximum power point tracking techniques for photovoltaic power systems. *IEEE Transactions on Sustainable Energy*, 4(1), 89-98; doi: 10.1109/TSTE.2012.2202294

Tafticht, T., Agbossou, K., Doumbia, M. (2007). A new MPPT method for photovoltaic systems used for hydrogen production. *The COMPEL International Journal of Computation and Mathematics in Electrical*, 26(1), 62-74; doi: 10.1108/03321640710713976

Thang T., Ahmed, A., Kim, C., Park J. (2015). Flexible system architecture of stand-alone PV power generation with energy

storage device. *IEEE Transactions on Energy Conversion,* 30(4), 1386 – 1396; doi: 10.1109/TEC.2015.2429145
Vastav, B., Nema, S., Swarnkar, P., Rajesh, D. (2016). Automatic Solar Tracking System using DELTA PLC. In 2016 *International Conference on Electrical Power and Energy Systems* (pp. 16-21); doi: 10.1109/icepes.2016.7915899
Yeong-Chau, K., Tsorng-Juu, L., Jiann-Fuh, C. (2001). Novel maximum power-point- tracking controller for photovoltaic energy conversion system. *IEEE Transactions on Industrial Electronics,* 48(3), 594–601; doi: 10.1109/41.925586
Yokoyama, R., Hida, Y., Koyanagi, K., Iba, K. (2011). The role of battery systems and expandable distribution networks for smarter grid. *In IEEE General Meeting Power& Energy Society* (pp. 1-6); doi: 10.1109/N/A15735.2011
Yu, G., Jung, Y., Choi, J., Kim, G. (2004). A novel two-mode MPPT control algorithm based on comparative study of existing algorithms. *Solar Energy,* 76(4), 455-463; doi.org/10.1016/j.solener.2003.08.038