Avrupa Bilim ve Teknoloji Dergisi
Özel Sayı 47, S. 73-78, Ocak 2023

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
Special Issue 47, pp. 73-78, January 2023

Research Article

Synthesis of Voltage PID Controller to Improve INC- MPPT Algorithm for Cascade Regulation of KC200GT Panel-Based Solar System

Siham Aissani [1*], Mohcene Bechouat [2], Moussa Sedraoui [3], Sami Kahla [4], Toufik Amieur[5]

[1*] Université 8 Mai 1945 Guelma, *Guelma, Algeria* , *Département Électronique et Télécommunications/ Laboratoires des Télécommunications LT de Guelma*, (ORCID: 0000-0002-4900-2336), aissanisiham24@gmail.com

[2] *Université de Ghardaïa, Algeria*, *Département d'automatique et d'électromécanique, Faculté dessciences et de la technologie,*(ORCID: 0000-0002-0434-4324), mohcene.oui@gmail.com

[3] Université 8 Mai 1945 Guelma, *Guelma, Algeria* , *Département Électronique et Télécommunications/ Laboratoires des Télécommunications LT de Guelma*, (ORCID: :0000-0002-4590-2249), sedraoui.moussa@univ-guelma.dz,

[4] Research Center in Industrial Technologies (CRTI) Algiers /Algeria. *Guelma,Algeria Guelma, Algeria*, (ORCID: 0000-0002-7596-3739), samikahla40@yahoo.com

[5] *Département de Génie Électrique /Université de Larbi Tebessi Tebessa, Algeria*, (ORCID : 0000-0003-0870-5446), amieur.to@gmail.com

(2nd International Conference on Innovative Academic Studies ICIAS, January 28 - 31, 2023)

(**DOI:** 10.31590/ejosat.1244902)

ATIF/REFERENCE: Aissani, S., Bechout, M., Seraoui, M., Kahla, S. & Amieur, T. (2023). Synthesis of Voltage PID Controller to Improve INC- MPPT Algorithm for Cascade Regulation of KC200GT Panel-Based Solar System. *European Journal of Science and Technology*, (47), 73-78.

Abstract

This paper proposes the Maximum Power Point Tracking MPPT method based on the Incremental Conductance INC algorithm. The primary goal is to prevent the ripple problem that is occurred in the output responses of the solar panel system. This last includes the KC200GT panel system, while using it to supply a resistive load throughout the DC-DC boost converter. This goal is reached through respecting the two following steps. First, the INC algorithm modified so that it produces an optimal reference voltage rather than a duty cycle control, which is often utilized in the standard INC-MPPT control strategy for controlling the switch button of the DC-DC boost converter. Second, the solar system behavior is modeled by the linear small-signal model for the design of the voltage PID controller. At each sample, a voltage discrepancy is generated as a result of comparing the previous reference voltage to the one delivered by the KC200GT panel where the introduction of the voltage PID controller becoming indispensable. These two steps create the development of a novel strategy that is afterwards known as improved INC-MPPT. The performance assessments of the proposed strategy are carried out by simulation using MATLAB®/SIMULINK software, and the obtained results reveal the crucial importance of including the voltage PID controller to overcome the ripple issue, occurred when applying the standard INC-MPPT control strategy.

Keywords: PV system; DC-DC Boost Converter; Maximum Power Point Tracking MPPT; INC algorithm.

[*] Corresponding Author: *aissanisiham24@gmail.com*

1. Introduction

Maximum Power Point Tracking MPPT techniques are typically used in solar systems to extract the maximal power output of KC200GT panels where the Maximum Power Point MPP must be continually followed, regardless of the current climatic conditions like the absolute temperature and the solar irradiation. The MPPT issue has been addressed in several aspects in the literature [1, 2].

Among them, the INC-based algorithm is the most often used one since it is the easiest to implement in the real-world applications [3]. Accordingly, in energy solar domain, many researchers have worked to develop MPPT algorithms methods [4]. They presented a large number of simulations and experimental tests to control the switch of the buck chopper. In addition, they employed a proportional-integral PI controller whose corresponding pulse-width modulation (PWM) has been implemented directly in the buck converter [5]. The experimental results also demonstrated that the incorrect manual selection of the fixed-step size, whether large or small in standard INC-MPPT control strategy is well overcome. This can be accomplished by changing it to a variable-step size that was generated automatically to update the existing duty cycle control, regardless the changing of the two previous climatic conditions. In the same direction, the high-performance adaptive Perturb and Observe P&O algorithm was introduced through [6] in 2011. This enabled the MPP tracking in PV- based micro-grids. To improve the oscillation performances around the MPP, the real-time adaptive control was implemented under a variety of weather conditions. As a result, two main drawbacks that directly affect the required control have appeared, especially in the event of gradual variation of solar irradiation and absolute temperature. Accordingly, the operating point of the preceding system has oscillated around the MPP, resulting in a loss of a more or less important of the available energy. Besides, the INC algorithm can be confusing when the atmospheric conditions change rapidly.

In this paper, it will be illustrated that the negative effects associated with the second drawback mentioned above can be significantly improved. This will be possible by including a voltage PID controller in the inner loop of the overall control system where the output voltage, which is needed to power the resistive load, will be well stabilized. This control design is called also cascade regulation where the MPPT algorithm is operated indirectly, i.e., for a cascade voltage regulation (with respect to a cascade current regulation), the MPPT algorithm must be modified to provide a reference voltage (with respect to a reference current) where it is compared with the actual array voltage (with respect to the actual array current). The resulting voltage discrepancy (with respect to currant discrepancy) must be reduced as much as possible using a voltage PID controller (with respect to current PID controller). In fact, the preceding indirect control mode based on the P&O algorithm has recently attracted many scientists.

Among them, Kollimalla & Mishra (2014) developed the indirect P&O-MPPT control strategy the current regulation of the PV panel under solar irradiation variation using a proposed reference current disturbance. Accordingly, the current PI controller proves better power performances over the ones provided by the standard P&O-MPPT control strategy [7]. Also, Harrag & Messalti (2015) generated a variable step-size for the P&O-MPPT control strategy using the genetic algorithm [8]. Accordingly, the Proportional-Integral- Derivative controller is included for the cascade voltage regulation, providing thus a fast tracking behavior in the presence of several weather conditions. In addition, Babki & Al-Thabiti (2022) proposed a closed-loop system based on a small-signal model for voltage regulation. They were used either, a Proportional controller, equipped with a low-pass filter or a PI controller where its parameters have been designed through applying the Ziegler-Nichols method based on root locus approach [9]. Accordingly, the simulation results show that the proposed control strategy offers better stability characteristics over the one provided by the standard one. Finally, Lasheen et al., (2017) proposed an adaptive reference voltage-based technique for panel, which has been exposed to a radiation profile characterizing by a fast rate of change [10]. With respect of all preceding works, the new control strategy in this paper has two indispensable stages. In the first one, the system mathematical model is of the global solar system is designed using the small- signal principle. Afterward, the MPPT-based INC algorithm is modified, in which an optimal reference voltage is generated through the existing values of solar irradiance and absolute temperature. Finally, the optimal update of the existing duty cycle control is ensured by the proposed-stabilized voltage controller, whose parameters are determined by the trial-and- error approach, which is available in MATLAB® software. The given simulation results by the proposed control strategy will confirm that the desired is captured, even during a rapid variation of the solar irradiance. The remainder of the paper will be organized as follows: The introduction is presented in section1.The equivalent electrical circuit model description is given in section 2. The typical solar power system, modeled by the linear small-signal model is reviewed in Section3. Section4 will be focused on the synthesis of the voltage PID controller, used in the improved INC-MPPT control strategy. The simulation results are shown in section5. Finally, conclusions are drawn in Section 6.

2. Modeling of KC200GT panel.

In general, the modeling of the actual behavior of the *KC200GT* panel is often performed using an equivalent electric circuit having a specific number of diodes, resistors connected between them in series and other resistors connected between them in parallel. Hence, the electrical circuit can be shown in Fig. 1:

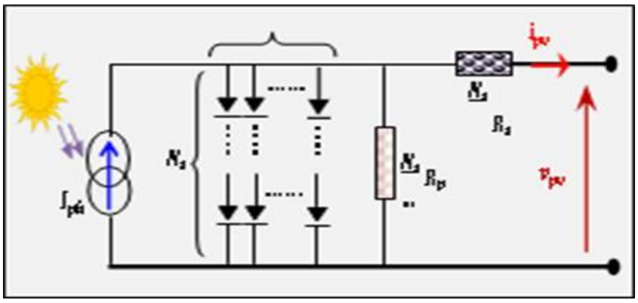


Fig.1 Equivalent-electrical circuit used for modeling the KC200GT panel

According to Fig.1, the nonlinear characteristic $I - V$ of the *KC200GT* panel is derived through expressing predicted PV current. I_{pv} It is defined by [11,12]:

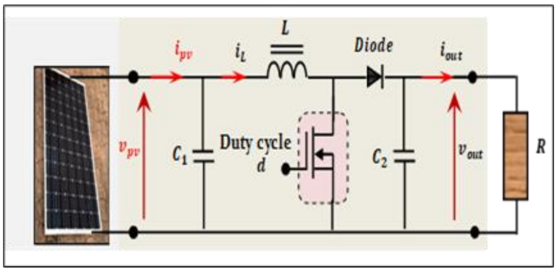
$$I_{pv} = N_p I_{ph} - N_p I_0 \left[exp\left(\frac{q\left(\frac{V_{pv}}{N_S} + \frac{R_s I_{pv}}{N_p}\right)}{a N_c K T} \right) - 1 \right] - \frac{\frac{N_p V_{pv}}{N_S} + R_s I_{pv}}{R_p} \quad (1)$$

I_{pv} : Solar cell current (A).

I_{ph} : Light generated current (A).
I_O : Diode saturation current (A).
q : Electron charge (1.6×10-19 C).
K : Boltzmann constant (1.38×10-23 J/K).
T : Cell temperature in Kelvin (K).
V_{pv} : Solar cell output voltage (V).
R_S : Solar cell series resistance (Ω).
R_p : Solar cell shunt resistance (Ω).
N_c : The number of series cells.
N_w : The number of series strings.
N_p : The number of parallel strings.
a : Diode ideality factor.

3. Modeling of global soLlar system

In general, most real-world applications require more power than the one generated by the basic KC200GT panel. Therefore, the introduction of the DC-DC boost converter becomes essential between it and the electrical device to be powered. Therefore, Fig.2 shows the equivalent electrical circuit describing the interconnection system including the KC200GT panel, the DC-DC boost converter and the resistive load.



The small-signal principle is applied for the linearization step of the preceding nonlinear state-space representation. This aim is achieved through applying some steps, described in [13]. Fig.2.Interconnection system including the KC200GT panel, DC-DC boost connverter and the resistive load

From Fig.2, the power required to supply the resistive load is highly dependent on the proper voltage regulation that is provided by the switch (transistor) control of the *DC-DC* boost converter. Here, the appropriate voltage *PID* controller must be provided the optimal duty cycle control which then send as a Pulse Width Modulation *PWM* signal having the prefixed frequency f. As a result, the controler-synthesis of desired controller requires a prior linear model that associates the output *PV* voltage V_{pv} with the input control d. Accordingly, the corresponding nonlinear state-space representation is given by [13]

$$\begin{aligned} \dot{V}_{pv} &= \frac{1}{C_1}.I_{PV} - \frac{1}{C_1}.I_L \\ \dot{I}_L &= \frac{1}{L}.V_{pv} - \left(\frac{1-d}{L}\right).V_{out} \\ \dot{V}_{out} &= \left(\frac{1-d}{C_2}\right).I_L - \frac{1}{R.C_2}.V_{out} \end{aligned} \tag{2}$$

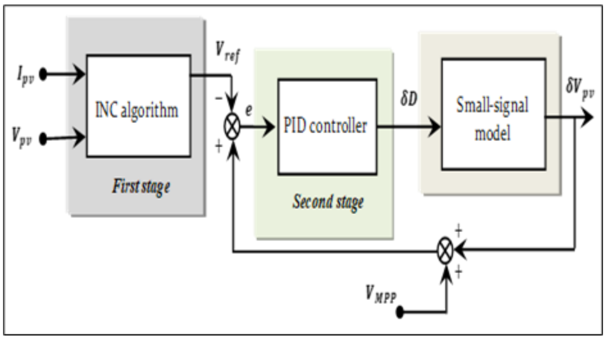
Fig.3. General scheme of the improved $INC - MPP$ control strategy

Therefore, the resulting linear state-space representation is given by

$$\begin{bmatrix} \delta\dot{V}_{pv} \\ \delta\dot{I}_L \\ \delta\dot{V}_{out} \end{bmatrix} = \begin{bmatrix} -\frac{1}{R_{eq}C_1} & -\frac{1}{C_1} & 0 \\ \frac{1}{L} & 0 & \frac{1-D_{MPP}}{L} \\ 0 & \frac{1-D_{MPP}}{C_2} & -\frac{1}{RC_2} \end{bmatrix} \begin{bmatrix} \delta V_{pv} \\ \delta I_L \\ \delta V_{out} \end{bmatrix} + \begin{pmatrix} 0 \\ \frac{-V_{outMPP}}{L} \\ -\frac{I_{LMPP}}{C_2} \end{pmatrix} \delta d \tag{3}$$

4. Synthesis of voltage PID controller

The indirect implementation of the previous control strategy, which brings out the new improved *INC-MPPT* control one, is realized in two different steps. In the first step, the *INC* algorithm will be adapted, in which the reference voltage V_{ref} is computed using the existing *PV* voltage and PV power. This last is compared by the actual *PV* voltage, providing the voltage error in each sampling time. This error must be minimized in the second stage by the synthesized *PID* controller whose parameters are designed through the linear small-signal model that is given by ''(3)''. The general scheme of the improved control strategy is shown in Fig.3 as below



According to Fig.3, it is clear to see that the reference voltage is generated according to the following modified flow- chart, described in Fig.4 as below

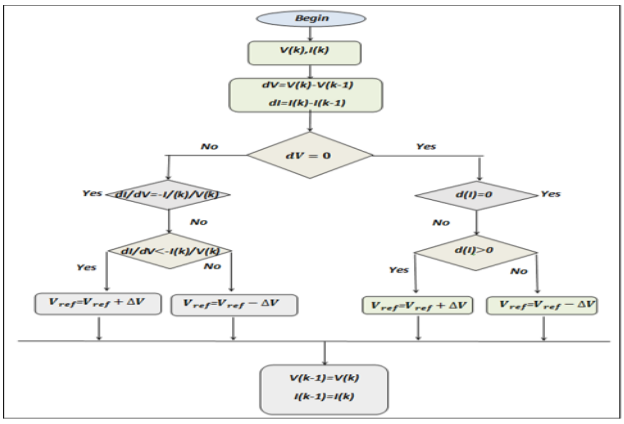


Fig.4. Modified flow-chart used to generate the reference voltage in theimproved INC-MPPT control strategy

5. Results and Discussion

To demonstrate the effectiveness of the improved INC-MPPT control strategy, the package of MATLAB®/SIMULINK is used. Here, the solar system parameters are summarized in TABLE.I Indeed, The transfer function describing the small-signal model is computed using ''(3)''. This last associate the duty cycle input variation with the PV voltage output . It is given by

$$F(s) = \frac{1.6827e08\,(s+3.333)}{(s+1.835)\,(s\text{^}2 + 63.84s + 5.334e06)} \qquad (4)$$

Starting from the preceding transfer function, the synthesis step of the voltage *PID* controller is performed using the *PidTuner* function of *MATLAB*® software. Hence, the tuning parameters are performed using the time domain specification, whose setting parameters are given by

- *Response time* : $1.008 \cdot 10^{-3}$
- *Transient behavior*: 0.5
- *PID structure*: *PIDF*
- *PID form* *Parallel*

The resulting transfer function $K_{PID}(s)$ is given by

$$K_{PID}(s) = 0.0103 + \frac{5.207}{s} + \frac{2.002 \times 10^{-5}s}{1 + 1.65 \times 10^{-6}s} \qquad (5)$$

Table 1.Solar system parameters used in simulation resul

		Parameter	Value	Unit
KC200GT panel		I_0	9.825×10^{-8}	*A*
		I_{sc}	8.214	*A*
		V_{oc}	32.9	*V*
		a	1.3	-
		R_p	415.405	Ω
		R_s	0.221	Ω
		N_c	54	-
		N_s	1	-
		N_p	1	-
	Simplified circuit	V_{eq}	51.597	*V*
		R_{eq}	3.3242	*Ω*
	PV Parameters given at MPP	V_{MPP}	26.3	*V*
		$V_{out_{MPP}}$	316.34	*V*
		I_{MPP}	7.61	*A*
		D_{MPP}	0.91686	-
DC − DC boost converter	L		0.4	*mH*
	C_1		4700	*μF*
	C_2		1200	*μF*
Resistive load	R		500	*Ω*

The Power-Voltage, i.e., (P-V) characteristic of the KC200GT panel is shown in Fig.5 for some varying solar irradiances and absolute temperature. Therefore, it is clear to see that the maximum power at Standard Test Condition STC (i.e., T=25℃ and G=1000W/m^2) is equal to P_max=200.1 W, which is supplied at the PV voltage V_MPP=26.3 V . This peak power is reduced as a function of the reduction, especially of the solar irradiance value. Indeed, the main target is to design the voltage PID controller, by which the dynamic MPP should be well kept up despite any change in the climatic conditions. To verify the controller performances, the preceding two climatic conditions are chosen according the profile given

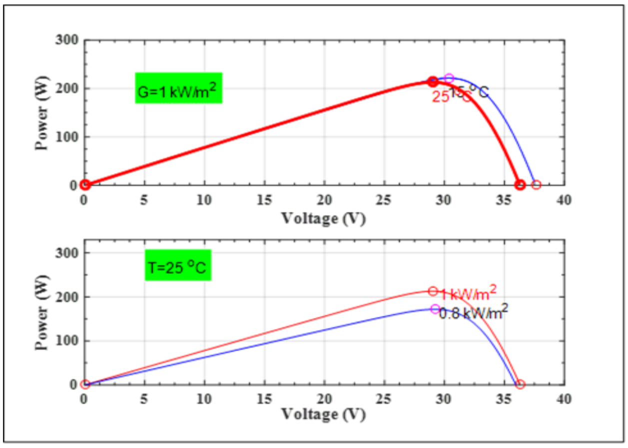


Fig.5. $(P-V)$ characteristic of KC200GT panel

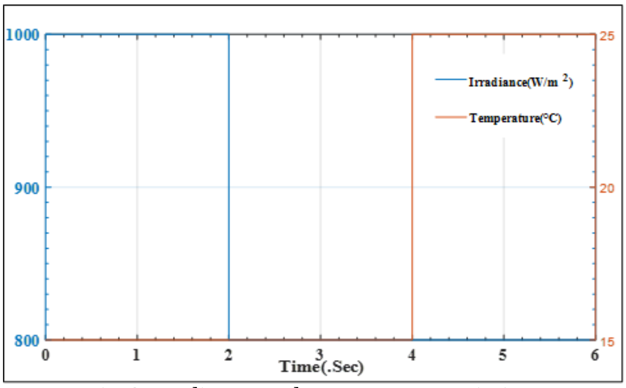


Fig.6.Irradiance and temperature variation

As a result, the tracking dynamic of the reference voltage, vided by the modified INC algorithm, for the improved INC-MPPT control strategy is given by Fig.7 as below

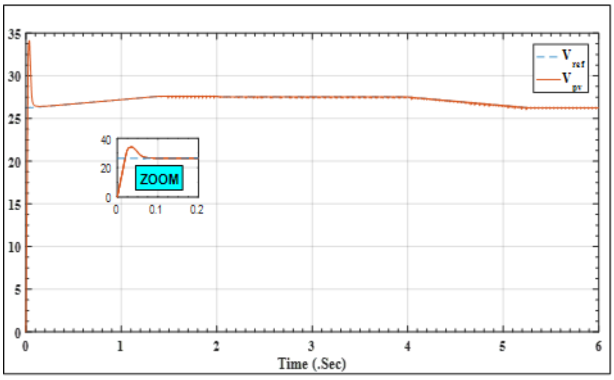


Fig.7. Reference and PV voltages describing the voltage tracking behavior

According to Fig.7, it can be seen that the proposed voltage *PID* controller is able to track the reference voltage that is previously imposed by the modified *INC* algorithm. The dynamics in question is characterized in transient-state by a fast rise time and a very acceptable settling time. It also characterized in steady-state by a reduced tracking error. These good dynamic characterizations certainly allow providing the maximum PV power which is shown in Fig.8 as follows

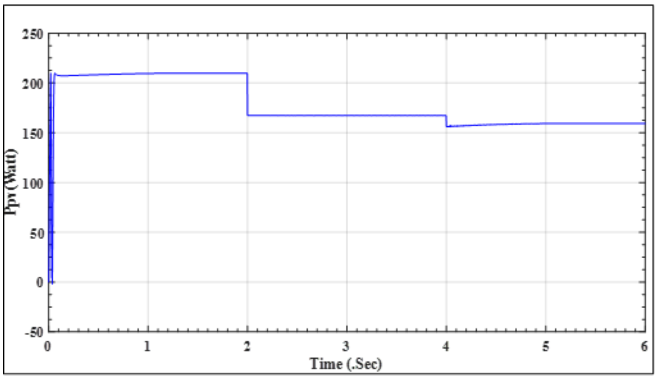


Fig.8. Power output response used to feed the varying climatic conditions

From Figs. 6 and 8, it is clear that the change in *PV* power response depends heavily on the change in solar irradiance, so they have the same pattern. However, the effect of absolute temperature on the *PV* power response is slightly more important compared to the effect of solar irradiance. Finally, Obtaining a smooth maximum power response confirms that the ripple problem in the neighbourhood of the *MPP* is completely avoided, leading to achieve the main target of the proposed control strategy. This last point is achieved by providing the duty cycle control as well as its variation, which are given together in Fig.9 as below

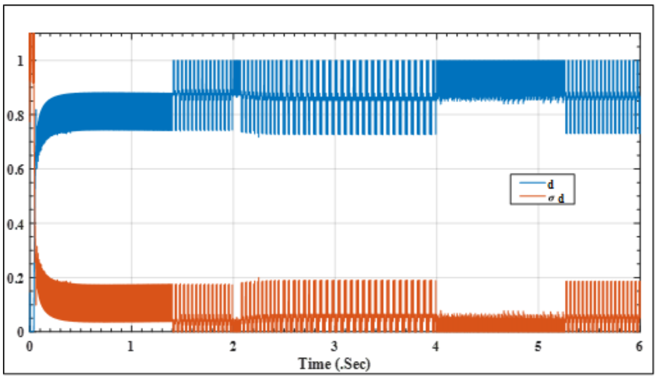


Fig.9. Duty cycle control and the corresponding variation

From Fig. 9, the resulting optimal duty cycle control always varies in the range $0 < D < 1$. This confirms the feasibility of the proposed control strategy, as this fluctuation range allows increasing the PV voltage of the *KC200GT* panel from $V_{PV} = 26.3\,V$ to $V_{out} = 316.34\,W$ at *STC*.

6. Conclusions and Recommendations

The improved *INC-MPPT* control strategy wasapplied to monitor the solar system based on the *KC200GT* panel. The corresponding *MPP* tracking was achieved by performing two separate steps. First, the INC algorithm has previously modified to generate the optimal reference voltage where the existing solar irradiance and absolute temperature are examined. Afterward, the actual solar behavior was modeled by the linear small-signal model, by which the desired voltage *PID* was synthesized. The simulation results given by the resulting new control strategy have confirmed its efficiency in terms of the tracking dynamic of the reference voltage, the form of the power output and closed loop robustness against the sudden change in atmospheric conditions.

References

[1] Mohanty, Parimita, et al. "MATLAB based modeling to study the performance of different MPPT techniques used for solar PV system under various operating conditions." Renewable and Sustainable Energy Reviews 38 (2014): 581-593.

[2] Hegazy Rezk, Ali M. Eltamaly, “A comprehensive comparison of different MPPT techniques for photovoltaic systems” , Solar Energy, vol 112, 1 – 11. doi:10.1016/j.egypro.2014.11.010.

[3] N. Femia, G. Petrone, G. Spagnuolo, M. Vitelli, “Optimizing Duty cycle Perturbation of P&O MPPT Technique”, Proceedings of PESC. Aachen (Germanv). June20-25.2004.

[4] Yiğit, E., Özkaya, U., Öztürk, Ş., Singh, D., and Gritli, H. (2021). Automatic detection of power quality disturbance using convolutional neural network structure with gated recurrent unit. Mobile Information Systems, 2021, 1-11.

[5] Mei Q, Shan M, Liu L, Guerrero JM, “A novel improved variable step- size a novel improved variable step-size method for PV systems”, IEEE Trans IndElectron 2011;58:2427–34.

[6] Abdelsalam AK, Massoud AM, Ahmed S, Enjeti P, “High-performance adaptive perturb and observe MPPT technique for photovoltaic-based micro grids”, IEEE Trans Power Electron 2011;26:1010–21.

[7] Kollimalla, S. K., & Mishra, M. K. (2014). A novel adaptive P&O MPPT algorithm considering sudden changes in the irradiance. IEEE Transactions on Energy conversion, 29(3), 602-610.

[8] Harrag, A., & Messalti, S. (2015). Variable step size modified P&O MPPT algorithm using GA-based hybrid offline/online PID controller. Renewable and Sustainable Energy Reviews, 49, 1247-1260.

[9] Althobaiti, A., M. Armstrong, and M. A. Elgendy. "Space vector modulation current control of a three-phase PV grid-connected inverter." 2016 Saudi Arabia Smart Grid (SASG). IEEE, 2016.

[10] Lasheen, M., Rahman, A. K. A., Abdel-Salam, M., & Ookawara, S. (2017). Adaptive reference voltage-based MPPT technique for PV applications. IET Renewable Power Generation, 11(5), 715-722.

[11]Bechouat, M., Younsi, A., Sedraoui, M., Soufi, Y., Yousfi, L., Tabet, I., &Touafek, K. (2017). Parameters identification of a photovoltaic module in a thermal system using meta-heuristic optimization methods. International Journal of Energy and Environmental Engineering, 8(4), 331-341.

[12] Bechouat, M., Sedraoui, M., Feraga, C. E., Aidoud, M., & Kahla, S. (2019). Modeling and Fuzzy MPPT Controller Design for Photovoltaic Module Equipped with a Closed-Loop Cooling System. Journal of Electronic Materials, 1-10.

[13]M. G.Villalva, T. G.De Siqueira&E.Ruppert, (2010). Voltage regulation of photovoltaic arrays: small-signal analysis and control design. IET Power Electronics, 3(6), 869-880.