IMPROVED PERTURB & OBSERVE MPPT METHOD USING PI CONTROLLER FOR PV SYSTEM BASED ON REAL ENVIRONMENTAL AND CLIMATIC CONDITIONS

Ambe Harrison
Department of Electrical and Electronics Engineering,
College of Technology, University of Buea, Cameroon
ambeharrison2000@yahoo.com

Jean de Dieu Nguimfack Ndongmo
[2]Department of Electrical and Power Engineering,
Higher Technical Teacher Training College (HTTTC), University of Bamenda, Cameroon
nguimfack.jean@uniba.cm

Eustace Mbaka Nfah
Department of Electrical and Electronics Engineering,
National Higher Polytechnic Institute Bamenda, Cameroon
emnfah@yahoo.com

Olome Baudouin Ekute
Department of Electrical and Electronics Engineering,
Faculty of Engineering and Technology, University of Buea, Cameroon
olomeb@gmail.com

ABSTRACT
This paper covers the implementation of one of the most popular MPPT algorithm, Perturb & Observe Algorithm based on Proportional Integral (PI) Control for a typical PV system under real environmental and climatic condition. The environmental parameters were collected from an experimental setup made of Solar Meter and Temperature sensor to record Solar Irradiation and temperature respectively on a 50Watts Solar panel. The Experimental setup was mounted on the Campus of the University of Buea, Cameroon and data collected for one day in November which falls in the dry season at the site. The Real environmental parameters were injected into MATLAB/ Simulink were the system was investigated to show the enhancement of the tracking performance of the MPPT system coupled with PI controller.

Keywords: MPPT, Perturb &Observe, PI controller, Boost converter, PV system

INTRODUCTION
The effect of environmental changes couple with the high demand for energy stimulates urgent concern to embrace other alternative sources of energy. To fulfill the plea of energy, renewable energy becomes of utmost importance since it is the best alternative among other resources. In the context of renewable energy the solar energy through Photovoltaic system is one of the most reliable and mature sources of energy. The PV energy is green, and environmentally pleasant. The solar panel based on Photovoltaic principle converts solar energy to Electrical energy. The PV module is a nonlinear device whose output powers randomly changing environmental parameters, most importantly Solar Irradiation and Temperature [14, 15]. The main pitfall with the PV system is the problem of low efficiency of the modules [11]. Also, another major pitfall occurs as a result of non-perfect coupling of the Load and the PV generator [11]. Despite the nonlinear behaviour of the

PV module, there is a point in its operation where maximum power can be harvested. Therefore, it becomes important to extract maximum energy from the PV and transfer to the Load [12]. In order to avoid ambivalence in the term of tracking, it is important to distinguish between the panel tracking and MPPT. Panel tracking is based on mechanical control of the panel in the direction of the sun. This system depends on a set of sensors that track the daily movement of the sun and a motor that moves the panels so that they face the disk of the sun. The second system is MPPT; it is a tracking device that has nothing to do with moving panel, while it uses an electronic system to change an electrical operating point [4].

Researchers have been working to develop different techniques and algorithm to track maximum power from the solar panel. The most widely used are the Perturb & Observe (P&O) and Incremental Conductance (InC) MPPT algorithms [4, 14]. The conventional InC MPPT algorithm has less oscillations than its P&O Algorithm counterpart [1]. Houssamo et al., developed in [5] experimental comparison of P&O and InC MPPT algorithm, they found that the InC MPPT algorithm has better performance than the P&O. Kareem et al., simulated in [10], the InC MPPT algorithm using MATLAB under changing irradiation conditions, the result obtained in their simulation shows fast response with high accuracy of the algorithm, but the authors limited their investigation to Piecewise simulation. Jehun et al investigated in [8], the performance of different MPPT techniques under partially shaded condition their simulation result revealed high dependence of InC and P&O algorithm on climatic conditions. The authors proposed a new MPPT method supplied with reference voltage by the MPPT at sampling time to respond to sudden changes in insolation and load. Their new MPPT method converged quickly with small oscillations around the MPP during steady state than the other methods, but the authors did not extend their investigations to real environmental simulations.

In this paper, the Perturb and Observe MPPT algorithm is implemented in MATLAB/Simulink environment using Proportional Integral Control on YB-156M-50 solar panel characteristics under real environmental and climatic conditions. A Comparative study between the presence and the absence of the PI controller in the same context has been investigated.

PV SYSTEM MODELLING IN SIMULINK

PV Solar Panel

The Literature review shows the different modeling methods for PV cell, with the two majors as single diode model and the double diode model. The PV panel is composed of solar cells organized in series and parallel. In accordance to the work of [2, 7, 6], the authors implemented the diode models with real behaviors and modeled the parasitic losses. The equivalent circuit shown in FIGURE (1) is based on a current source to model the incident luminous flux, a single-diode, a parallel resistance due to leakage current and a series resistance [18].

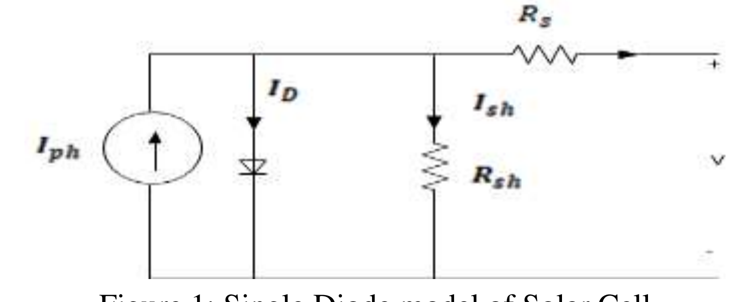

Figure 1: Single Diode model of Solar Cell

The current-voltage relation of the PV cell can be expressed as shown in EQUATION (1) [16].

$$I = I_{ph} - I_o\left[\exp^{\frac{qV_d}{KFTc}} - 1\right] - \frac{V_d}{R_{sh}} \quad (1)$$

$$I_{ph} = [\mu_{sc}(T_c - T_r) + I_{sc}] + G \quad (2)$$

$$I_o = I_{o\alpha}\left(\frac{T_c}{T_r}\right)^3 \exp^{\left[\frac{eV_g}{KF}\left(\frac{1}{T_r} - \frac{1}{T_c}\right)\right]} \quad (3)$$

$$V_d = \frac{V + IR_s}{R_{sh}} \quad (4)$$

Where V_d the diode voltage, I_{ph}-Photo current, I_o- Saturation current, q-Electric Charge ($1.6x10^{-19}$ C), K-Boltzmann's constant $1.38x10^{-23}$, F-cell idealizing factor, T_c-Absolute Temperture, T_r-cell's reference temperature, V_d-Diode Voltage, R_{sh}-Parallel Resistance, R_s-Series Resistance, $I_{o\alpha}$-Cell Saturation Current, G-Solar Irradiation in Kw/m^2. The above EQUATIONS (1), (2), (3) show the mathematical modeling of solar cell. From above equation, it is clear that the temperature and irradiation are the determinants of the solar output. Based on single diode model the solar module having reference number YB-156M-50 has been modeled in this paper. The parameters of the solar array have been given in Table 1 under STC.

Table 1: Parameters of the Solar array YB-156M-50 at STC

Maximum Power	P_{max}(W)	$50 \pm 3\%$
Current at MPP	I_{mp}(Ampere)	2.80.0
Voltage at MPP	V_{mp}(Voltage)	18.0
Short circuit Current	I_{scc}(Ampere)	3.15
Open circuit Voltage	V_{oc}(Voltage)	22.0
Number of cells in Series	N_s	41

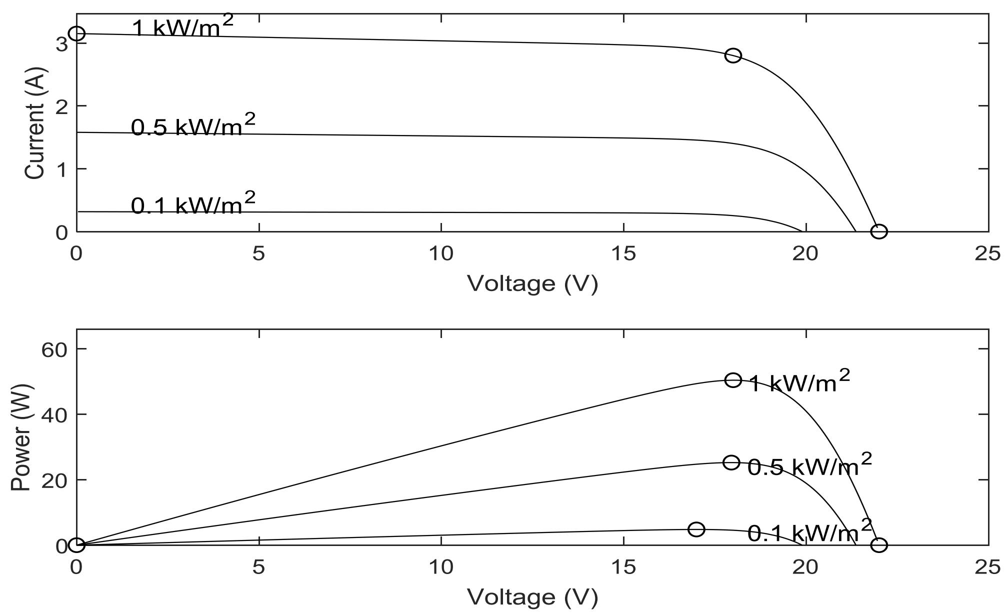

Figure 2: I-V and P-V curves of the Solar Cell at STC

The characteristics of the PV module can be observed by plotting its P-V and I-V as shown in FIGURE (2). The PV and I-V characteristics of the Solar cell, is clearly seen that there is high dependency of the PV Power with Irradiation and temperature. It can be noticed that the maximum power point (MPP) varies according to different irradiations levels. The curve also shows that despite the nonlinear behaviors of the solar array, there is still a point where maximum power is attained. The MPPT algorithm is responsible to follow this MPP point systematically.

Perturb and Observe MPPT Algorithm

Generally, the purpose of MPPT algorithm in PV system is to keep the PV panel voltage close to the MPP voltage. The Perturb & Observe algorithm senses the PV voltage and current and works by periodically perturbing the control variable (panel voltage) and comparing the instantaneous powers of the PV before and after the perturbation. If the change in output power increases, the panel voltage is increased in the same direction as in the previous cycle. If the change in power is negative, that means the system is operating from the optimal point and thus the perturbation has to be reduced in order to restore the operating point to the MPP. The flow chart in FIGURE (3), presents the P&O algorithm [5].

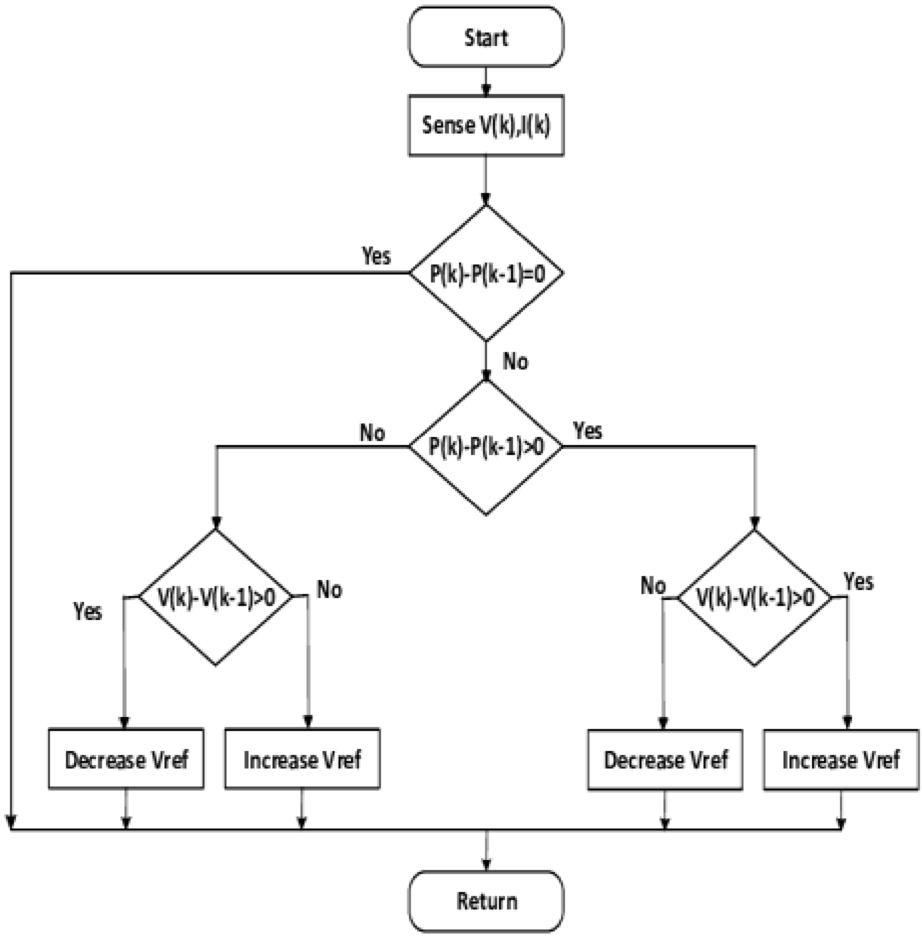

Figure 3: Perturb and Observe MPPT Algorithm

DC-DC Converter

In order to ensure duty cycle matching between the PV generator and the Load, a Power electronic DC-DC converter is improvised between the Load and the PV. In this study a Boost converter is employed due to its better efficiency in MPP based PV systems according to [17]. The Boost converter is used to efficiently increase the output voltage of the PV module. Therefore, it serves as an impedance adapter for the load connected to the PV system. The conversion is efficient if the Load power converges to input PV power in steady state [18]. The equivalent circuit shown in FIGURE (4) consists of one inductor (L), one capacitors (C), an active power switch Q (MOSFET), a diode D and the load R. The inductor of 11mH and Capacitor of 306µF are used respectively.

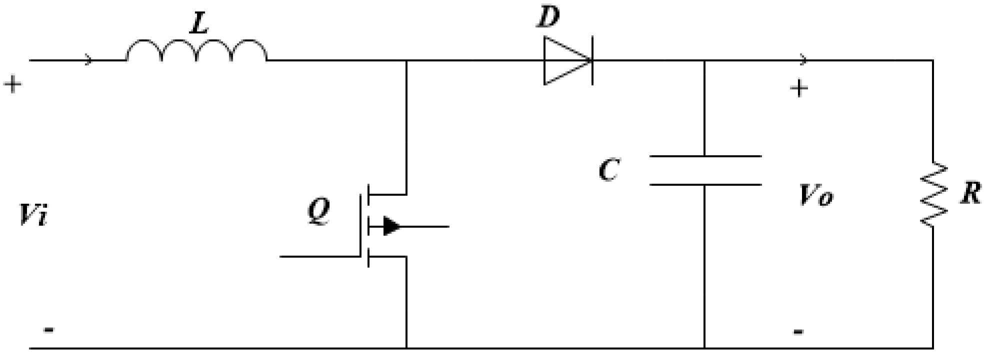

Figure 4: Equivalent Circuit of Boost Converter

Proportional –Integral Controller

The proportional integral controller produces an output signal $u(t)$ proportional to both the input signal, $v(t)$ and the integral of the input signal. The mathematical model of the PI controller is shown in EQUATION (5)

$$u(t) = K_p v(t) + K_i \int v(t)dt \qquad (5)$$

The control methodology of the PI+P&O controller is shown in figure 5.

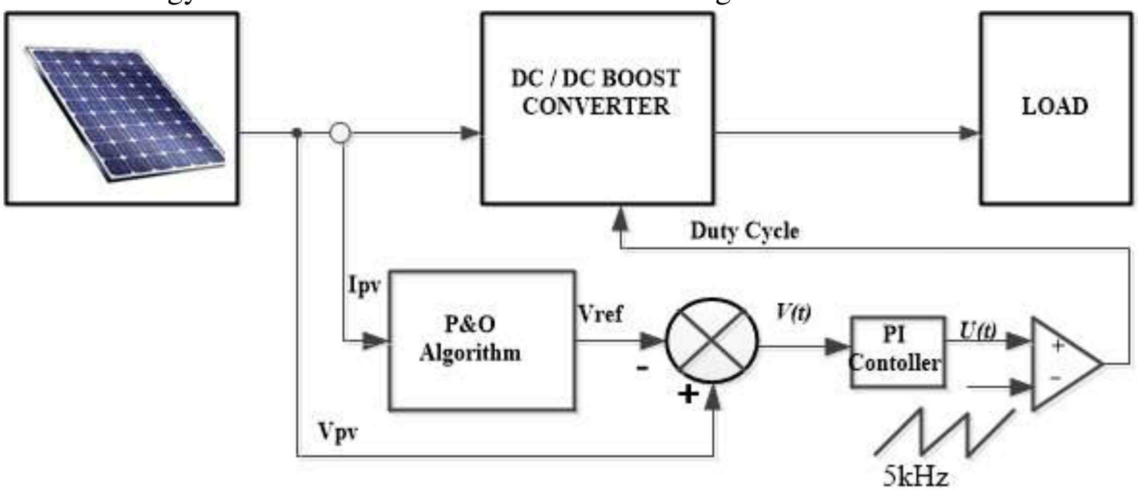

Figure 5: Block Diagram of the PI controlled Perturb & Observe Control for PV system

The MPPT algorithm receives input from the PV (PV current and PV voltage) and runs the P&O algorithm generating a reference voltage. The reference voltage is compared with the PV actual voltage and an error signal is generated. The error signal is manipulated by the PI controller, by properly selecting the PI controller, the desired response is obtained, and Table 2 shows the parameters of the PI controller. The control signal generated from the PI controller is then modulated with a frequency signal to generate the required PWM signal to control the Boost converter. Proportional Gain $K_p = 0.001$ and Integral Gain $K_i = 0.001$ are chosen and used after tuning their values.

EXPERIMENTAL SETUP AND DATA COLLECTION

An experimental setup was mounted in the campus of the University of Buea. This setup consisted of the following;

YB-156M-50 Solar Panel: This is the solar panel on which experimentation was carried out, its characteristics is found in Table 1 above

Solar Meter: The solar meter was employed in this setup to measure Solar Irradiance on the PV module. The Solar Meter used has model number PYR1307

Digital Thermometer: A digital thermometer based on the Waterproof LM35 temperature sensor was employed to measure temperature on the solar panel. The digital thermometer used has model number AP-IS11A001. This thermometer comes already embedded with an LCD display for easy reading of temperature as shown in FIGURE (6) of the Experimental setup

From the setup, data was measured at intervals of 15 minutes; this permitted collection of data from 9:30am-4:30pm.These two dataset were collected for 1 day specifically on 23/11/2021 which is a period of dry season in the site location, Buea Cameroon. The site is characterized by a Dry season running from November to February and rainy season running from March to October

Figure 6: Experimental Setup for Data Collection

Table 2: Presentation of Data collected

Time	Irradiance (W/m2)	Panel Temp (°C)	Time	Irradiance (W/m2)	Panel Temp (°C)
9:30	476	36.4	1:00	1171	53.6
9:45	470	40.1	1:15	1030	56.2
10:00	520	42.1	1:30	1048	53
10:15	570	40	1:45	720	50.5
10:30	755	40.1	2:00	940	50
10:45	740	42.6	2:15	920	50.2
11:00	830	48	2:30	460	39.6
11:15	915	46.9	2:45	620	38.3
11:30	909	48.1	3:00	525	37.8
11:45	897	45.9	3:15	340	37.3
12:00	985	45.5	3:30	538	37.3
12:15	1100	46.3	3:45	364	36.8
12:30	1140	50	4:00	335	34.4
12:45	1040	50.8	4:15	322	31.3
			4:30	225	29.2

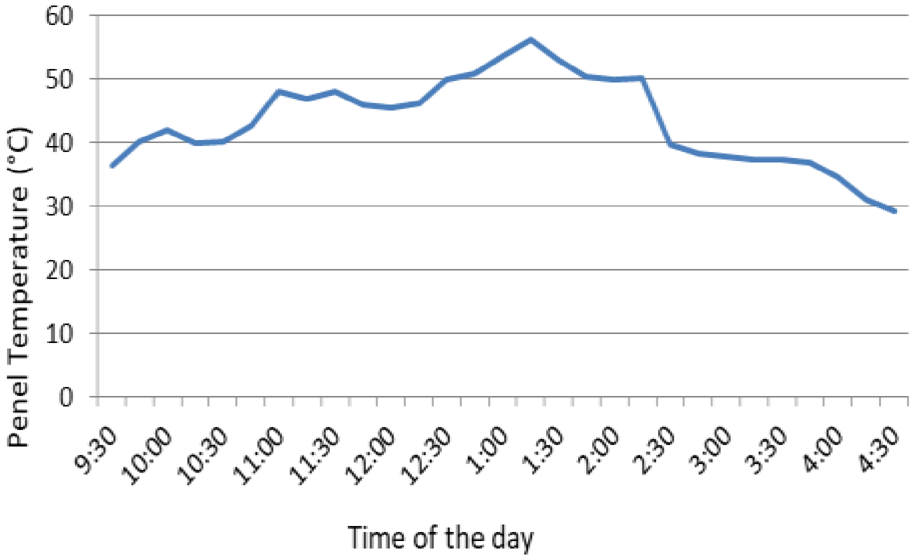

Figure 7: Panel Temperature (23/11/2021)

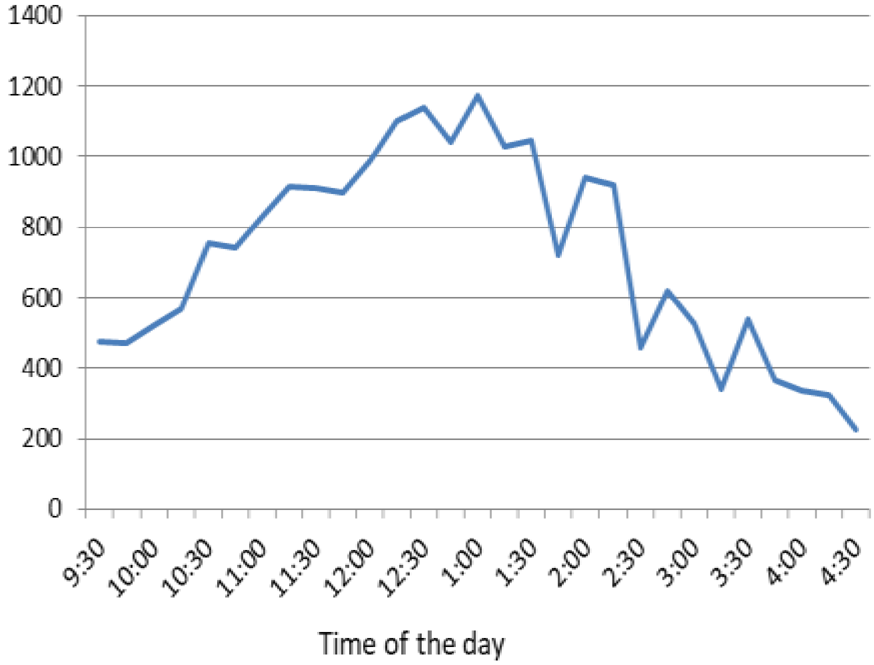

Figure 8: Solar Irradiance (23/11/2021) using [PYR1307 Solar Meter]

EXPERIMENTAL SIMULATION

Data collected from the site were injected into MATLAB and used to simulate the YB-156M-50 solar panel on a PI control P&O MPPT method. The data collected from 9:30 AM-4:30PM at sample time of 15 minutes, was scaled in Simulink using a 1 Dimensional Look up table and simulated for 1 second. FIGURE (7) and (8) shows the Plot of the Solar Irradiance and Panel Temperature respectively.

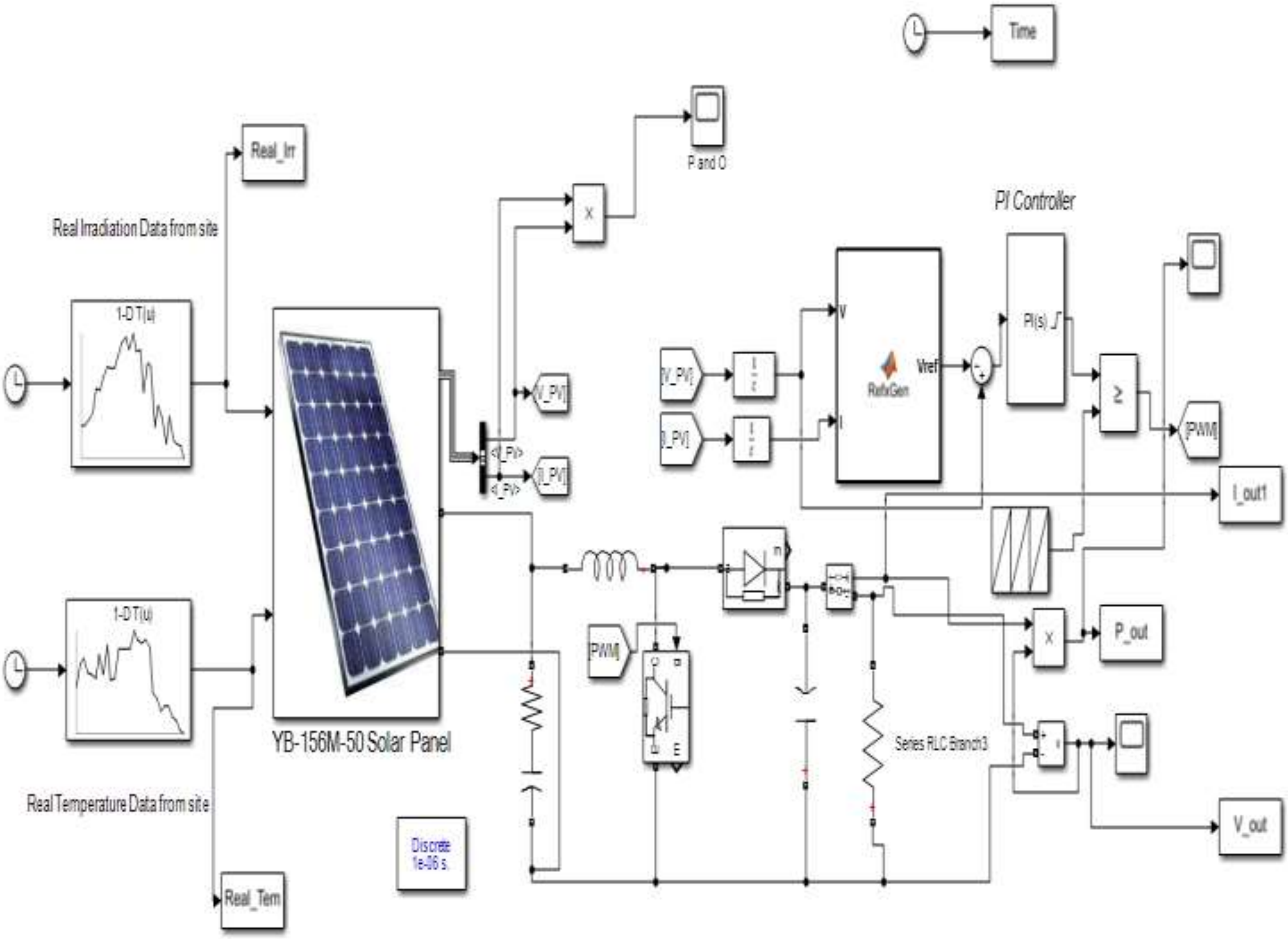

Figure 9: Simulink Model of PI controlled P&O based on real climatic conditions

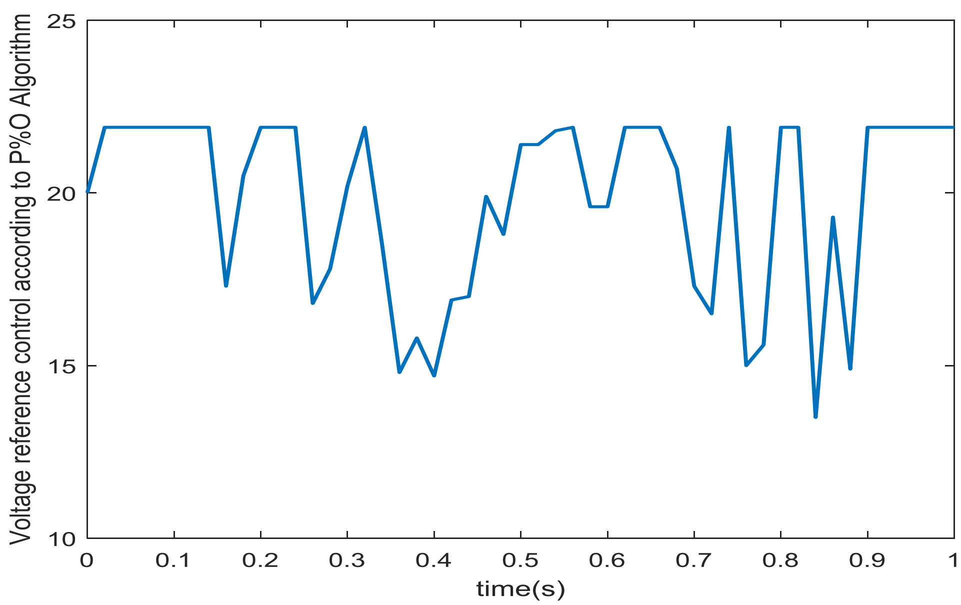

Figure 10: Voltage Control dynamics according to P&O Computation

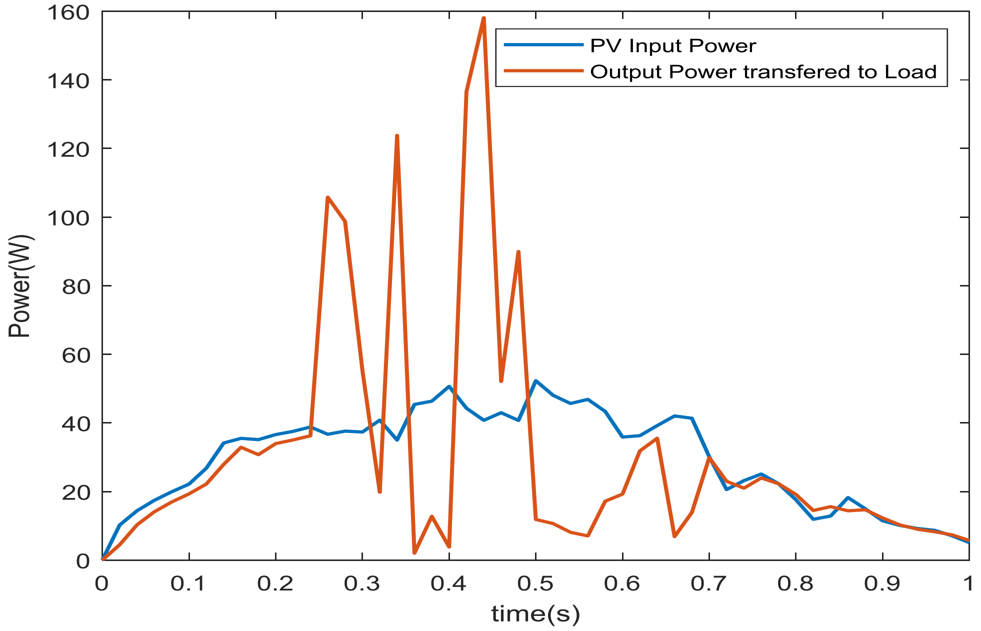

Figure 11: PV Input Power and Output Power transferred to Load according to P&O in absence of PI controller

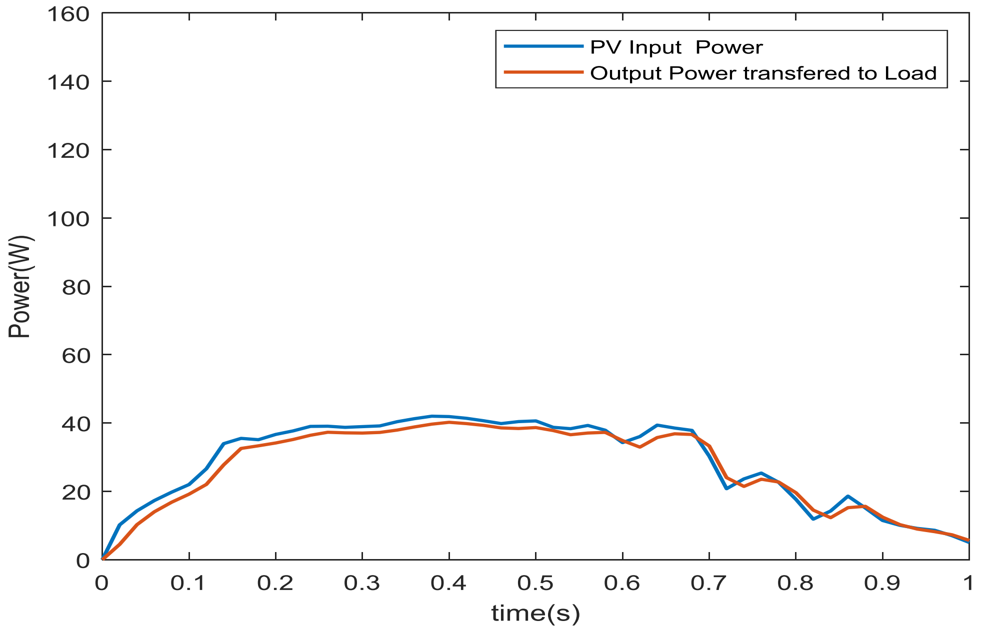

Figure 12: PV Input Power and Output Power transferred to Load according to P&O with PI controller

RESULTS AND DISCUSSIONS

The PV system and tracking performance is shown in FIGURE (9) and (10) respectively. FIGURE (9) represent the tracking performance in the absence of the Proportional Integral controller. It can be noticed in FIGURE (9) that the output Power transferred to the load does not follow the Input power, more so the output power contain spike jumps which in practice will have adverse consequences on the entire PV system. Therefore in the absence of the PI controller the Performance of the system is poor with adverse effects and relatively higher oscillations. In FIGURE (10), when a PI controller is introduce it is seen that the output power harvested or transfer to the load follows the available input power (input reference), more so the oscillation is reduced. The Perturb & Observe MPPT algorithm with Proportional Integral thus improves the performance of the PV system.

CONCLUSIONS AND FUTURE WORKS

The PV system has a low efficiency, which reduces when there is non-perfect coupling between the PV and the Load. Literature shows that the MPPT algorithm improves the efficiency of the PV system by optimizing energy harvesting at the input of the solar module. However, in order to characterize and have a better understanding of the MPPT behavior and performance, an almost real environment is required this is because in practice, environmental parameters follow a non-linear random pattern. Therefore, simulation of the PV system under piecewise changing irradiation does not give a better characterization of the MPPT system. In this paper, one of the most popular MPPT method, Perturb and Observe is implemented in MATLAB/Simulink under real environmental conditions which was set by dataset (Solar Irradiance and Temperature) collected from site (experimental setup) on a Solar panel (YB-156M-50 model). This paper further demonstrated that the introduction of the Proportional Integral Controller, improves the tracking performance of the MPPT system. The Pi controller should therefore be employed in MPPT based system for improved performance systems

For future works, more data should be collected on a daily profile to have a better characterization of the dynamic behaviour of this improved P&O method. More so, the data in this paper was collected during the dry season characterize by good weather conditions. The authors recommend that in order to better characterize the performance of the improved Perturb and Observed method, data should be collected in different climatic conditions especially, characterised by extreme conditions

Other MPPT algorithms should be implemented with PI controller which should also be efficiently tuned to provide a better response for the overall system control under real environmental conditions. Furthermore, modern nonlinear controllers should be used to replace the classical PI controller for better performance of the controller during abrupt variations of temperature or irradiation.

REFERENCES

1) Aicha, D. & Rezaoui, Mohamed & Teta, Ali. (2018). Comparative Study of Perturb-and- Observe and Incremental Conductance MPPT Methods for PV System. Second International Conference on Electrical Engineering “ICEEB’18.Biskra, Algeria
2) Chan, S. D., & Phang, C. J. (1987). Analytical methods for the extraction of solar-cell single-and double-diode model parameters from IV Characteristics. IEEE Transactions on Electron Devices, 286-293.
3) Chang, D., Philips, J., & Phang, J. (1986). A comparative study of extraction methods for solar cell modell parameters. Solid-State Electronics, 29, 329-337.
4) Elbaset, A., Hussein, A., Brisha, E., & Mostafa, R. M. (2014). Implementation of a PIC based Photovoltaic Maximum Power Point Tracking control system. ijetae) International of Emerging, 4(5), 392-401.
5) Houssamo, I., Locment, F., & Sechilaru, M. (2010). Maximum Power Tracking for Photovoltaic power system: Development and experimental comparison of two algorithms. Busan, Korea. New York, NY, USA ,(pp. 2381-2387).
6) Ishague, K., Salam, Z., & Taheri, H. (2011). A comprehensive MATLAB Simulink PV system simulator with partial shading capability based on two diode model,. Solar Energy , 85, 2217-2227
7) Ishaque, K., Salam, Z., & Taberi, H. (2011). Simple, fast and accurate two diode model for photovoltaic modules. Solar Energy Materials and Solar cells, 95, pp. 586-594.
8) Jehun, H., Baek, J., Kang, H., Lee, H., & Park, M. (2015). "Matlab-Based Modeling and Simulations to Study the Performance of Different MPPT Techniques Used for Photovoltaic Systems under Partially Shaded Conditions. International Journal of Photoenergy, 10 pages

9) Kish, G. J., Lee, J. J., & Lehn, P. W. (2012). delling and control of photovoltaic panels utilising the incremental conductance method for maximum power point tracking. IET Renewable Power Generation, 6(4), 259-266
10) Kareem, P. (2019). Simulation of the Incremental Conductance Algorithms for Maximum Power Tracking of Photovoltaic System based on MATLAB. Journal of Engineering Sciences,34-43
11) Li, D., & Chou, P. (2004). Maximizing efficiecny of solar-powered systems by load Matching Proceedings of the 2004 International Symposuim on Lowered Power Electronics and design, (pp. 162-167).
12) Manel, H., & Hfaiedh, M. (2016). Comparison of different MPPT algorithms with a proposed ne using power electronics estimator for grid connected PV systems. International Journal of Photoenergy
13) Nnadi, D. (2012). Environmental/Climatic Effect on Stand-Alone Solar Energy Supply Performace for Sustanable Energy. Nigerian Journal of Technology,31(1), 79-88
14) Sera, D., Kerekes, T., & Teodorescu, R. (2006). Improved MPPT algorithms for rapidly changing Environmental Conditions. 12th International Power Electronics and Motion Control Conference, (pp. 1614-1619). Portoroz, Slovenia.
15) Sharma, P., & Agarwal, V. (2014). Extract maximum power point tracking of grid-connected partaially shaded PV source using current compensation concept. IEEE Trans Power Electron, 4684-4692
16) Villalya, M. G., & Gazoli, J. R. (2009). Comprehensive approach to modeling and simulation of photovoltaic array. Power Electronics, IEEE Transactions, 24, 1198-1208
17) Vlasner, I., & Appelbaum, J. (1996). Advantage of boost vs. buck topology for maximum power point tracker in photovoltaic system. Proceedings of 19th Convention of Electrical Electronics Engineers in Isreal, (pp.355-356). Jerusalem: IEEE
18) Jean de Dieu Nguimfack-Ndongmo, Godpromesse Kenné, René Kuate-Fochie, Arnaud F. Tchouani Njomo, Eustace Mbaka Nfah, Adaptive neuro-synergetic control technique for SEPIC converter in PV systems, International Journal of Dynamics and Control, doi.org/10.1007/s40435-021-00808-1, 2021