Improving Power Quality of a grid connected PV System through the choice of MPPT algorithm for optimizing power requirement in industrial development

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ABSTRACT

Renewable Energy has been commercially popular since it can potentially reduce the harmful emissions from burning of fossil fuels which most traditional power generations rely on. The renewable energy sources such as photovoltaic (PV) system and wind energy system are among the preferred renewable energy technology in many countries. Photovoltaic systems in particular have greater potential for geographical locations that receive abundance sunlight throughout the year. Moreover, the PV systems can be made as a small scale power plant and installed near to the load centers, thus, being able to avoid transmission congestion and line losses. However, the efficiency of the solar PV conversion is quite low typically less than 20%. Therefore, the efficiency of the PV system is really an important concern. One of the method of improving the efficiency is through the use of maximum power point tracking (MPPT). In this respect, therefore, this paper aims to compare the two most popular MPPT algorithms to determine which of them will be the better option for a grid-connection PV power system.

Keywords: *—photovoltaic, renewable energy, maximum power tracking, mppt algorithm, solar irradiance.*

I. INTRODUCTION

The concerns of using fossil fuels and their harmful gas emissions have pushed the green initiative worldwide towards more development and implementation of renewable energy resources such as the wind, geothermal, biomass and solar energies. Renewable energy is a good substitute for the nuclear power and fossil fuels, and was generally called alternative energy in the 1970s and 1980s [1][2] Renewable energy resources have also become more popular as nations around the world are moving from large central power plants towards distributed generations due to environmental and economic reasons. There have been many proposals to place highly efficient small scale power plants based on renewable energy sources near the load centres to simultaneously avoid the transmission congestion and line losses [1].

However, photovoltaic power generation is expensive compared to other sources of power generation because of the equipment needed for its installation. Therefore, the efficiency of PV plants should be carefully enhanced in order for the generated power to increase, which will compensate for the power generating cost and make the PV power generation to be cost effective.

Three factors upon which the PV plant efficiency depends are: to improve the algorithm for the maximum power point tracking (MPPT) control which is the most easiest and less expensive technique; to improve PV panel efficiency; and to improve the inverter efficiency [3][4]. Additionally, the design of a suitable solar-energy systems for a particular location requires the knowledge of the available solar radiation at that location and also the load to be connected. The electrical load connected at the output of a PV module will be largely dictated by its operating point in addition to the varying irradiance and temperature. The grid-connected power might supply many different kinds of loads ranging from simple residential loads to more complex industrial loads. These loads could be adjustable dc, sinusoidal ac or high frequency ac. For example, the role of power electronics in energy conservation has brought recent development that help users to benefit from reduced energy consumption. But as a consequence, these type of loads contribute to the distortion and lead to poor power quality [1].

This paper aims to review the basic MPPT algorithms after which two (2) selected algorithms namely, perturb and observe (P&O) and incremental conductance (Inc-Cond) will be evaluated and analysed to compare their performance on a grid-connected PV solar power system. Thorough investigation is envisaged on the tracking ability for maximum power under changing irradiance, temperature and load conditions. And also to analyse how their capability is related to the power quality of the generated supply connected to the grid system. It describes the methods and then compares them based on their tracking ability for maximum power following variations in irradiance and temperature conditions. The simulation test and measurement will be carried out in MATLAB Simulink environment.

II. MPPT ALGORITHMS

There are a lot of published literatures on the comparison of MPPT algorithms considering the fact that there are so many of them ranging from normal to the improved ones. Though each has its own uniqueness, but they all have one objective that is to force the solar PV system to operate at maximum power point (MPP) so as to extract the maximum power possible from the PV module. In [6], the authors compared Fuzzy Logic Control (FLC) with two hill climbing algorithms, namely the P&O and Incremental Conductance. The objective was to test the performance of FLC as compared to the two hill climbing algorithms. An improved version of the hill climbing algorithms were later used and finally it was concluded that the P&O performed better. The study in [6] used a simplified version of the PV system model and a controlled current source was used to replace the power converter to carry out the dynamic MPPT efficiency test. This was done to meet up with the European Standard EN 50530. A good attempt was made but the problem with this work is that it lacks a detailed model of the converters which may potentially give inaccurate results.

Another publication is the work of [7] which compared three improved algorithms: "three-point P&O", "fixed-step Inc-Cond", and "variable-step Inc-

Cond". They were compared based on implementation simplicity, ability to follow variations in irradiance condition and their sensitivity to noise. The photovoltaic system used was integrated with several other generation and storage elements. The authors arrived at a conclusion that the "three-point P&O" is the simplest to implement. However, the system used in [7] had bigger variations of the DC-link voltage that the solar converter would not be able to control and this could affect the performance of the MPPT.

Reference [8] also compares the performance of P&O and Inc-Cond algorithms for maximum power point tracking under dynamic weather conditions. The result of their experiment as mentioned by the authors show that both P&O and Inc-Cond methods in their fixed step perturbation structure did not yield better efficiency. The Inc-Cond method had slightly better average performance and 98.5% efficiency compared with 98.3% efficiency obtained in P&O.

Other literatures on MPPT algorithms are "A comprehensive comparison of different MPPT techniques for photovoltaic systems" [9], "Comparison of modified incremental conductance and fuzzy logic MPPT algorithm using modified CUK converter" [10] and "Energy performance and cost comparison of MPPT techniques for photovoltaic and other applications" [11]. In [12], comparative evaluations were conducted on direct, indirect and computational MPPT methods for photovoltaic systems. Another set of researchers are those that tried to improve the existing MPPT algorithms for better efficiency such as the work of [13] who implemented an advanced Fuzzy MPPT Controller for a Stand-alone PV System, [14] that implemented an adaptive Inc-Cond MPPT Algorithm for Photovoltaic Systems, and [15] who used modified P&O method for improving the efficiency of the system.

A hybrid of the basic MPPT algorithms was also reported to achieve high efficiency, for instance, the work of [5] who made a hybrid of P&O and FLC algorithm to develop an adaptive perturb and observe-fuzzy control in maximum power point tracking for photovoltaic boost dc–dc converter.

Both P&O and In-Cond algorithms are formulated based on the same principle that involves moving the PV operating point in the direction of increasing power [31] and [32] this is the reason why they are termed "hill-climbing" algorithms. These techniques are easy to implement and have good performance especially at constant irradiation. This makes them the most popular MPPT methods [32]. Another advantage of these methods, in addition to their simplicity, is the low computational power required. But they have their shortcomings as well, they oscillates around the MPP at steady state and sometimes they can track the MPP in a wrong direction when the atmospheric conditions changes rapidly [15], [32] and [33].

III. SIMULATION MODEL

MATLAB® Simulink Function blocks are used to implement the MPPT algorithms. Fig. 1 shows the simulation model used in this research work. The solar PV system has the following specifications and descriptions: 100 kW PV array at 1000 W/m2, signal builder as inputs to the temperature and irradiance, dc-dc boost converter, MPPT controller, 273V - 500V dc-link voltage, three-phase inverter 415V/11kV, 100kVA three-phase step up transformer, 10-kvar filter and utility grid.

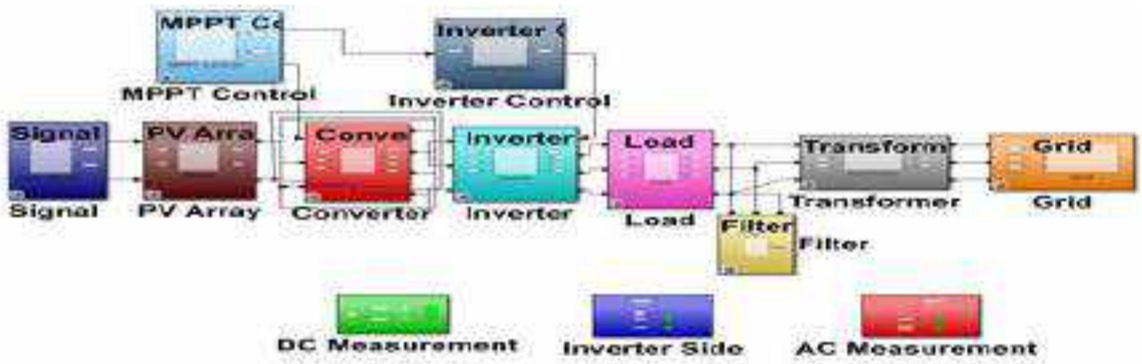


Fig. 1. Simulation model of the solar PV power system

P&O algorithm works based on a perturbation in the duty cycle for the power switch of the dc-dc boost converter. The duty cycle is used to change the operating voltage and current of PV array, resulting in the change in the operating PV power. If there is an increment in the power, the perturbation should be kept in the same direction. The perturbation is continuously retained and the reference duty cycle is further increased by a fixed step/amount (ϕ). If the power decreases, then the next perturbation should be in the opposite direction. In this P&O method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be. Once the vicinity of MPP is reached, the algorithm will be going back and forth around the MPP. Consequently, it will never stay exactly at MPP; rather, it oscillates around that point indefinitely [8]. Fig. 2(a) depicts the flow chart of P&O algorithm implemented in this simulation model.

On the other hand, the incremental conductance (Inc-Cond) algorithm is based on the fact that the slope of the power curve vs. voltage (current) of the PV module is zero at MPP. The PV power is positive (negative) on the left of it and negative (positive) on the right, as can be seen in Fig. 3. By comparing the increment of the power vs. the increment of the voltage (current) between two consecutives samples, the change in the MPP voltage can be determined, it works by comparing the ratio of derivative of conductance with the instantaneous conductance [34]. This idea is derived from the fact that at MPP, the derivative of power with respect to voltage (dP/dV) is zero, as given by

$$dP/dV=(d(VI))/dV=I+V\,dI/dV=0 \qquad (1)$$

Rearranging equation (1) gives

$$-I/V = dI/dV \cong \Delta I/\Delta V \qquad (2)$$

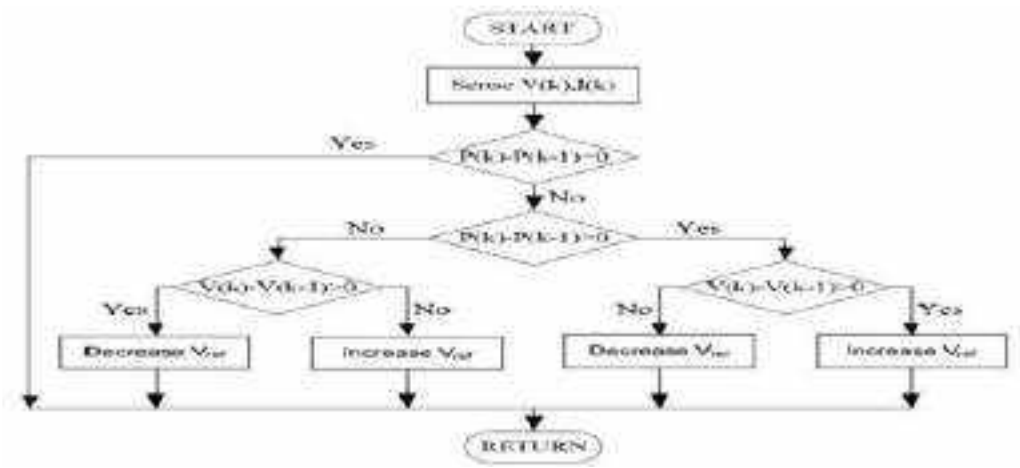
where ΔI and ΔV are the increments of PV current and voltage, respectively. The basic rules for Inc-Cond algorithm are:

$$dI/dV = -I/V \quad \text{at MPP} \qquad (3)$$

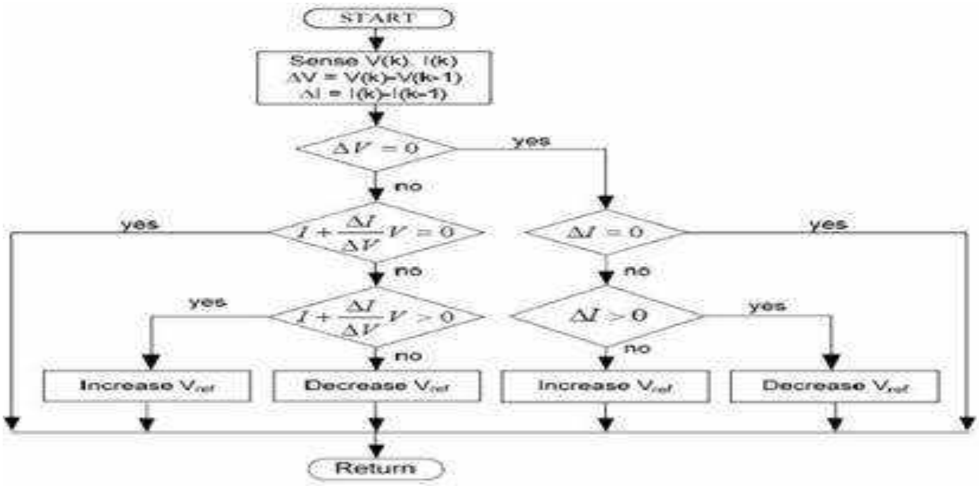
$$dI/dV => -I/V \quad \text{at the left of MPP} \qquad (4)$$

$$dI/dV =< -I/V \quad \text{at the right of MPP} \qquad (5)$$

Fig. 2(b) shows the flow chart of Inc-Cond algorithm used in this simulation model.



(a) P&O algorithm



(b) Inc-Cond algorithm

Fig. 2. Flow charts for P&O and Inc-Cond agorithms

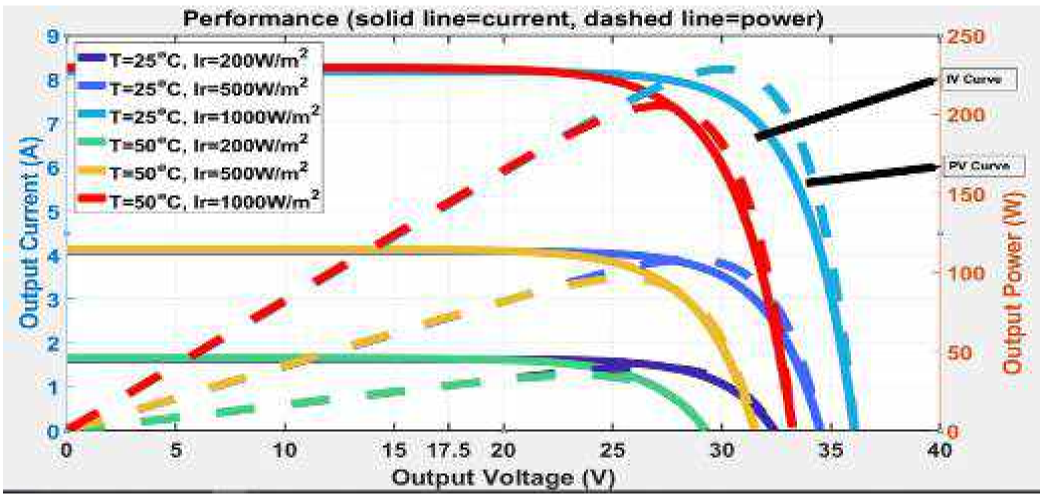
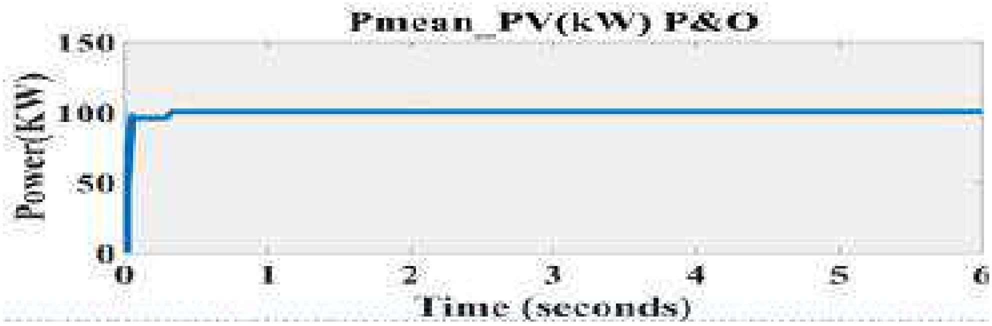


Fig. 3. Typical P-V and I-V characteristics of PV module

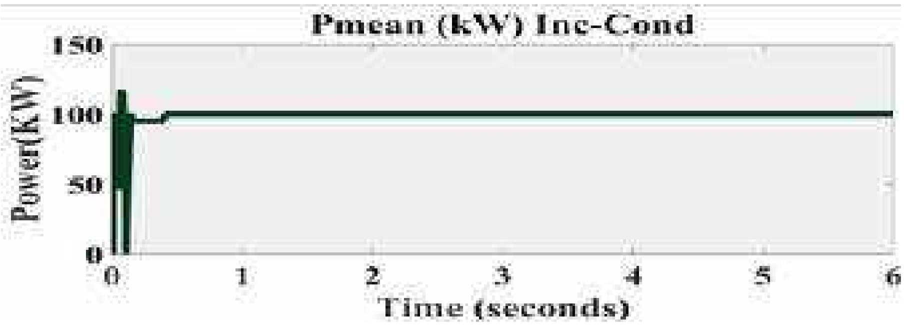
IV. Results and Discussion

A. Standard Test Condition

The first simulation was conducted using the standard test condition (STC) of 25 ºC temperature and 1000 W/m^2 irradiance. This is to evaluate the performance accuracy of the built PV model at STC, and the results are shown in Fig. 4 for both P&O and Inc-Cond methods respectively. As can be seen, both control techniques, roughly within 0.5sec, are able to track maximum power i.e. 100kW from the PV array to the ac grid. Both algorithms can track accurately the MPP when the irradiance is constant with very little oscillation around the MPP. Their performances are quite good with very high efficiency of more than 99% in all cases.



(a) P&O algorithm

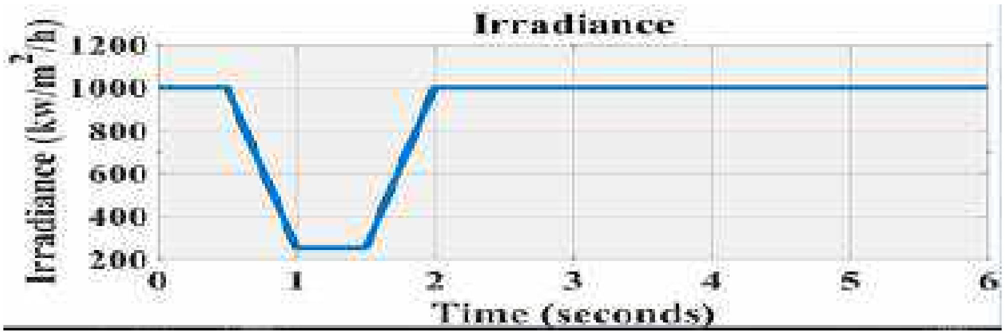


(b) Inc-Cond algorithm

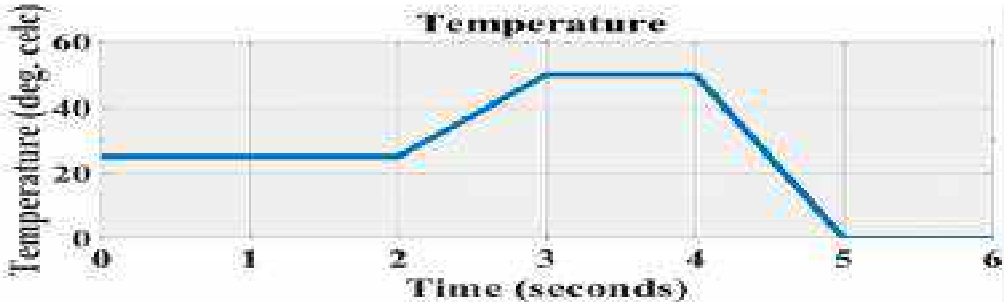
Fig. 4. Output power from solar PV power system at STC

B. Dynamic Test Condition

The dynamic simulation was carried out to further evaluate the MPPT algorithms and their performance under varying irradiance and temperature conditions as shown in Fig. 5. In this case, the simulation started with STC (25 ºC, 1000 W/m^2) from 0sec to 0.3sec. A constant duty cycle of D= 0.5 was used for the boost converter. The MPPT was activated at 0.3sec. In order to extract maximum power, the MPPT regulator starts to regulate PV voltage by varying duty cycle. In order to follow the European standard EN 50350 insolation sequence, the simulation was carried out in stages following the irradiance and temperature changes with time. The PV array operated at standard test conditions (25 ºC, 1000 W/m^2) up to 0.5 sec. From 0.5sec to 1.0sec, sun irradiance was made to drop down from 1000 W/m^2 to 250 W/m^2. And the MPPT performance was noted. Irradiance of 250 W/m^2 was maintained up to 1.5sec. From 1.5sec to 6.0sec, sun irradiance was raised back to 1000 W/m^2, and then temperature was varied between 50 ºC. and 0 ºC. This was done in order to investigate the effect of temperature.



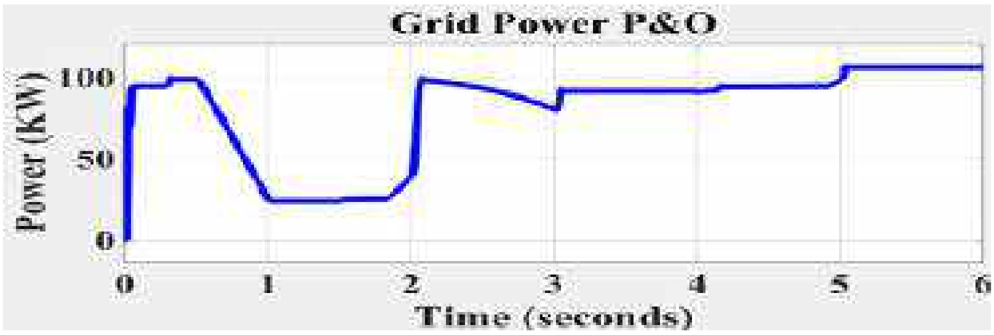
(a) sun irradiance



(b) temperature

Fig. 5. Variation of sun irradiance and temperature of the PV array used in the dynamic test

As can be seen from Fig. 6, both P&O and Inc-Cond algorithms are capable of tracking the MPP with good accuracy even under changing irradiance and temperature. Their performances are quite good with very high efficiency of more than 98% in all cases. The algorithms are quite similar in their tracking ability. It is also noted that, P&O algorithm is able to track the MPP for all settings, but the Inc-Cond technique is more responsive to dynamic changes with good tracking and negligible oscillation.



(a) P&O

(b) Inc-Cond

Fig. 6. Performance of the solar PV power system under dynamic test

C. Efficiency

Dynamic efficiency of MPPT (η_{MPPT}) is calculated as the ratio of power extracted by the system and available power as given by

$$\eta_{MPPT} = \frac{\int_0^{T_M} V_{PV}(t) \times I_{PV}(t)dt}{\int_0^{T_M} P_{MPPT}(t)dt} \quad (6)$$

where $V_{PV}(t)$ and $I_{PV}(t)$ are the instantaneous voltage and current at the output of the PV array. $P_{MPPT}(t)$ is the available maximum power of the PV array with respect to the instantaneous P_{MPP}. T_M is the time duration. To conduct this test, a signal builder was used to achieve the ramp profile of the EN 50530 standard as found in [35], though meant for inverters but could also be applicable to boost converter. This is done to test the dynamic

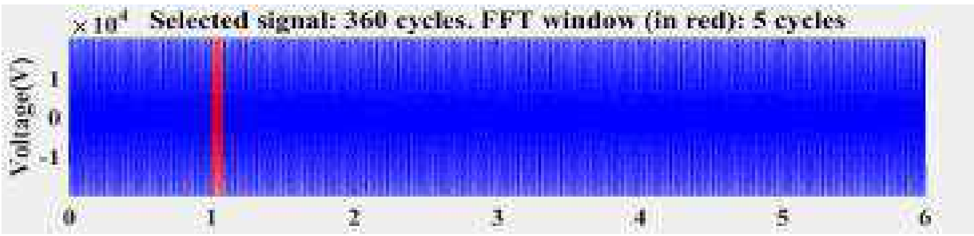
MPPT efficiency under rapid changes of weather conditions. Table I gives the summary of MPPT efficiency for both algorithms respectively.

Table I. Dynamic MPPT effficiency

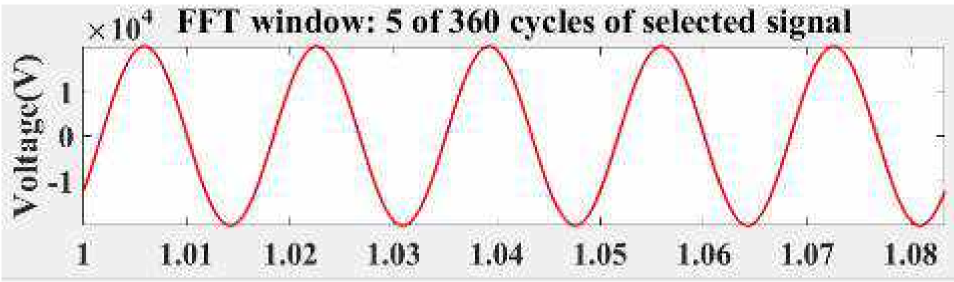
Efficiency (%)		Dynamic	Steady state	Step changes	THD
MPPT	Inc-Cond	99	99.61%	99.49%	0.07%
	P&O	98.8	99.62%	99.47%	0.20%

D. Power Quality and THD

The quality of the output power with regards to total harmonics distortion (THD) and the overall efficiency is compared, and the results are presented in this section. The efficiencies are tabulated before as given in Table I. The ac output voltages connected to the ac grid are maintained at the rated value of 14kV line-line. Fig. 7 shows the output ac voltages which are almost sinusoidal waveform, owing to effective ac filter used right after the three-phase inverter. THD on the ac voltage is measured as shown in Fig. 8 for both algorithms respectively. The THD is very low indeed, about 0.07% for the Inc-Cond method and 0.20% for P&O method.

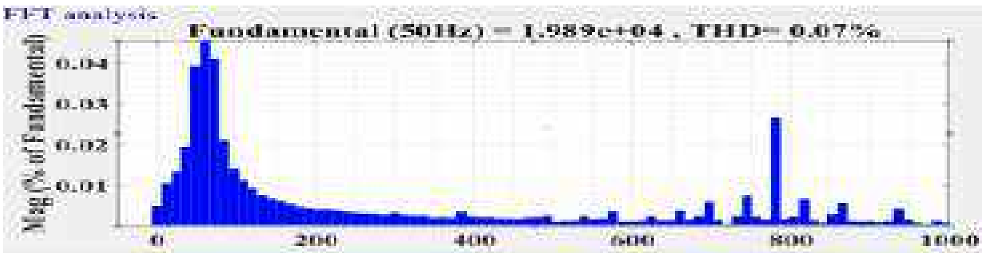


(a) ac voltages after the step-up transformer under dynamic test

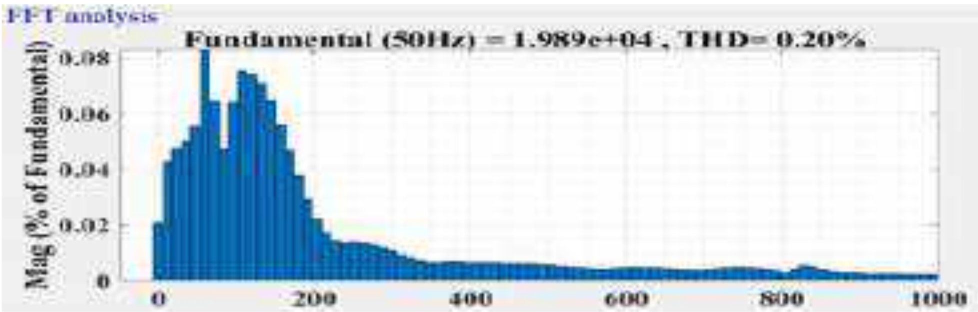


(b) waveform of the ac voltage

Fig. 7. Output ac voltages



(a) Inc-Cond



(b) P&O

Fig. 8. FFT analysis on the output ac voltages to estimate THD

V. CONCLUSION

The performance of two popular algorithms i.e. P&O and Inc-Cond have been investigated and compared in the solar PV power system connected to the ac grid. From the results obtained, it is found that Inc-Cond algorithm control is slightly better than P&O, however, the difference is quite small. Inc-Cond control gives slightly higher overall efficiency, even though the dynamic MPPT efficiency of the Inc-Cond and that of the P&O algorithm are very close. Nonetheless, the Inc-Cond is slightly more complicated to design than P&O algorithm.

VI. RECOMMENDATION

The findings of this work has created a research gap for future work. The scope of the thesis was limited to simulation work and no practical implementation was conducted to further validate the acquired results. More over the scope of the work also assumes all PV panels receive the same amount of irradiance and temperature at all times. So to this end, the following recommendations are made:

a) A practical lab experiment should be conducted to further testify the research findings of this work.

b) A partial shading condition should be considered in the future work to include all possible situations.

VII. REFERENCES

[1] N. Mohan, "First Course on Power Electronics." p. 298, 2009.

[2] E. B. Babatunde, "Public Lecture Series Solar Energy, a Friendly Renewable Energy Option for Nigeria." vol. 1, no. 15, 2007.

[3] O. S. Ohunakin, M. S. Adaramola, O. M. Oyewola, and R. O. Fagbenle, "Generation of a typical meteorological year for north–east, Nigeria," Appl. Energy, vol. 112, pp. 152–159 Dec. 2013.

[4] G. J. Dalton, D. A. Lockington, and T. E. Baldock, "Feasibility analysis of renewable energy supply options for a grid-connected large hotel," Renewewable Energy, vol. 34, no. 4, pp. 955–964, Apr. 2009.

[5] Zainuri, MAAM Radzi, MAM Soh, NA Rahim Development of adaptive perturb and observe-fuzzy control maximum power point tracking for photovoltaic boost dc–dc converter. IET 2013

[6] M. Calavia, J. M. Perié, J. F. Sanz, and J. Sallán, "Comparison of MPPT Strategies for Solar Modules," Renewable Energy Power Qual. J., vol. 1, no. 08, pp. 1440–1445, Apr. 2010.

[7] David Sanz Morales "Maximum Power Point Tracking Algorithms for Photovoltaic Applications" Thesis submitted for examination for the degree of Master of Science in Technology, Aalto University.

[8] K. Ishaque, Z. Salam, and G. Lauss, "The performance of perturb and observe and incremental conductance maximum power point tracking method under dynamic weather conditions," Appl. Energy, vol. 119, pp. 228–236, 2014.

[9] H. Rezk, A. E.-S. energy, 2015, "A comprehensive comparison of different MPPT techniques for photovoltaic systems," Elsevier.

[10] A. Farayola, A. Hasan, A. A.-2017 8th International, 2017, "Comparison of modified

incremental conductance and fuzzy logic MPPT algorithm using modified CUK converter," ieeexplore.ieee.org.

[11] O. Ezinwanne, F. Zhongwen, L. Z.-E. Procedia, 2017, "Energy performance and cost comparison of MPPT techniques for photovoltaics and other applications," Elsevier.

[12] E. Kabalci, "Maximum power point tracking (MPPT) algorithms for photovoltaic systems," Lect. Notes Energy, vol. 37, pp. 205–234, 2017.

[13] B. Bendib, F. Krim, H. Belmili, M. F. Almi, and S. Boulouma, "Advanced Fuzzy MPPT Controller for a Stand-alone PV System," Energy Procedia, vol. 50, pp. 383–392, Jan. 2014.

[14] C. Li, Y. Chen, D. Zhou, J. Liu, and J. Zeng, "A high-performance adaptive incremental conductance MPPT algorithm for photovoltaic systems," Energies, vol. 9, no. 4, 2016.

[15] D. G. Gupta, S. K., A. Ahlawat, "comparison between inverter control techniques in grid connected solar photovoltaic systems", 2019

[16] X. Meng, M. Leng, H. Zhang, and T. Xu, "MPPT control strategy based on CVT and variable step hysteresis comparison method," Proc. 29th Chinese Control Decis. Conf. CCDC 2017, pp. 3252–3257, 2017.

[17] Esram, T.; Chapman, P.L. Comparison of photovoltaic array maximum power point tracking techniques. IEEE Trans. Energy Convers. 2007, 22, 439–449. [CrossRef]

[18] Kollimalla, S.K.; Mishra, M.K. A novel adaptive P&O MPPT algorithm considering sudden changes in the irradiance. IEEE Trans. Energy Convers. 2014, 29, 602–610.

[19] Ruddin, S.; Karatepe, E.; Hiyama, T. Artificial neural network-polar coordinated fuzzy controller based maximum power point tracking control under partially shaded conditions. IET Renew. Power Gener. 2009, 3,239–253

[20] Abdelsalam, A.K.; Massoud, A.M.; Ahmed, S.; Enjeti, P.N. High-performance adaptive perturb and observe MPPT technique for photovoltaic-based microgrids. IEEE Trans. Power Electron. **2011**, 26, 1010–1021.

[21] Piegari, L.; Rizzo, R.; Spina, I.; Tricoli, P. Optimized adaptive perturb and observe maximum power point tracking control for photovoltaic generation. Energies 2015, 8, 3418–3436.

[22] Petrone, G.; Spagnuolo, G.; Teodorescu, R.; Veerachary, M.; Vitelli, M. Reliability issues in Cheng, P.C.; Peng, B.R.; Liu, Y.H.; Cheng, Y.S.; Huang, J.W. Optimization of a fuzzy-logic-control-based

[23] Photovoltaic power processing systems. IEEE Trans. Ind. Electron. 2008, 55, 2569–2580.

[24] Mei, Q.; Shan, M.; Liu, L.; Guerrero, J.M. A novel improved variable step-size incremental-resistance MPPT method for PV systems. IEEE Trans. Ind. Electron. 2011, 58, 2427–2434.

[25] Chen, Y.; Lai, Z.; Liang, R. A novel auto-scaling variable step-size MPPT method for a PV system. Sol. Energy 2014, 102, 247–256.

[26] Faraji, R.; Rouholamini, A.; Naji, H.R.; Fadaeinedjad, R.; Chavoshian, M.R. FPGA-based real time incremental conductance maximum power point tracking ccontroller for photovoltaic systems. IET Power Electron. 2014,7, 1294–1304.

[27] Tey, K.S.; Mekhilef, S. Modified incremental conductance MPPT algorithm to mitigate inaccurate responses under fast-changing solar irradiation level. Sol. Energy 2014, 101, 333–342.

[28] Elgendy, M.A.; Zahawi, B.; Atkinson, D.J. Assessment of the incremental conductance maximum power point tracking algorithm. IEEE Trans. Sustain. Energy 2013, 4, 108–117.

[29] Mamarelis, E.; Petrone, G.; Spagnuolo, G. Design of a sliding-mode-controlled SEPIC for PV MPPT applications. IEEE Trans. Ind. Electron. 2014, 61, 3387–3398.

[30] T. Esram, P.L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," IEEE Transactions on Energy Conversion, vol. 22, no. 2, pp. 439-449, June 2007.

[31] Tat Luat Nguyen, Kay-Soon Low, "A Global Maximum Power Point Tracking Scheme Employing DIRECT Search Algorithm for Photovoltaic Systems," IEEE Transactions on Industrial Electronics, vol. 57, no. 10, pp. 3456-3467, Oct. 2010.