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Improving the Accuracy and Response Time of P&O in Detecting the Maximum Power Point for a Photovoltaic System Environment

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Abstract— In this research article the implementation of developing a new adaptive P&O fuzzy controller approach will be introduced to seek the maximum power point MPP through a new improvement over the maximum power point tracking algorithm for photovoltaic system to provide a fast time response in tracking the maximum power point, and to eliminate the oscillations around it through a new design in adapting fuzzy logic controller FLC that would work in adjusting automatically the step size through varying the duty ratio to move appropriately the operating point towards the maximum power point at the minimal required steps and function under any dynamic environmental weather conditions. The design will embrace a high-efficiency DC-DC boost converter with a modified P&O algorithm. The functional converter will withdraw a maximum power from the PV panel for a given solar irradiance and temperature by adjusting the duty cycle of the converter. The modeling and the simulation of this research was implemented using MATLAB/Simulink.

Keywords—***PV, MPPT, DC-DC converter, P&O, Fuzzy logic controller FLC.***

I. INTRODUCTION

The need for electricity is increasing worldwide and acquiring it is almost vital. This led to a growing reliance on it, however it has been noted that an increase in limitations in supplying this source and the undergoing high prices of classical sources (increase in our electricity bills, generation, and distribution as well as the continuous maintenance of an electrical plants, and other factors), the need for photovoltaic (PV) energy is a promising alternative source for the conventional scheme option as it is available , and accessible openly, environmentally friendly as it is a green produced energy with no pollution with a minimal impact factor on the operational costs. As per the preceding, the concentration on the photovoltaic modules can be extended towards the standalone and grid connected PV stations [1].

Photovoltaic stations and modules have a curve that displays an ultimate operating point recognized as the maximum power point (MPP) which varies as a change in two elementary factors changing which are namely, the irradiance and temperature conditions [2]. Due to the environmental and weather changes, the optimum values for the maximum power point will continue changing over a specific periods of time. Due to these dynamic changes in weather conditions, tracking the MPP at a particular operating point requires to design and develop a controller to cope with the mentioned changes [3]. Fuzzy logic controller is a prevalent among the other controllers since it is easy to be implemented and depends on the knowledge base of the system [4].

II. THE PV ELECTRIC EQUIVALENT CIRCUIT

The equivalent mathematical model of photovoltaic would correspond to a single diode that entails a photocurrent source (I_{ph}), a nonlinear diode (D), a set of resistances, series resistance (R_s) and a parallel resistance (R_{sh}) that compensate for internal losses, as displayed in Fig. 1.

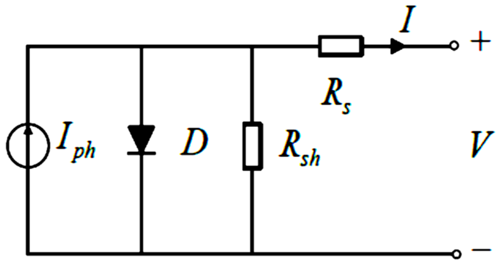

Fig.1. The equivalent circuit of the PV module.

Since the series resistance R_s is very small and the shunt resistance R_{sh} is very large then these parameters are neglected as calculating the other unknown parameters of the electrical equivalent system and to simplify the overall calculations of the PV model. To derive the mathematical equations of the unknown parameters of a PV system an analysis of how to obtain them will be explained in the below section [5, 6]. The mathematical relationship between the current and voltage through a single diode equivalent circuit can be prescribed as:

$$I = I_{pv} - I_0(eA(V + IR_s) - 1) - \frac{V + IR_s}{R_{sh}} \quad (1)$$

The photocurrent is functioning in reference to the solar irradiances and the panel temperature which can be described as
[4];

$$Iph = \frac{[Ish + Ki(T - 298)]x\lambda}{1000} \qquad (2)$$

The reverse saturation current of a PV module can be calculated from the below equation;

$$Irs = \frac{Ish}{\exp\left(\frac{qVoc}{NsKAT}\right) - 1} \qquad (3)$$

The PV module saturation current I_0 is;

$$Io = Irs\left[\frac{T}{Tr}\right]\exp[\left(\frac{qEg}{AK}\right)\left(\frac{1}{Tr} - \frac{1}{T}\right) \qquad (4)$$

Where; I_o = Saturation current, Eg= Band gap, and T_r = Reference temperature (25°C) in Kelvin.

Based on the above equations we can deduce that the output current of PV module is;

$$Ipv = NpIph - NpIo[\exp\left\{\frac{q(Vpv + IpvRs)}{NsAKT}\right\} - 1 \; (5)$$

As a general perspective of the Photovoltaic module we modeled it through the use of the Matlab /Simulink as shown below in Fig. 2.

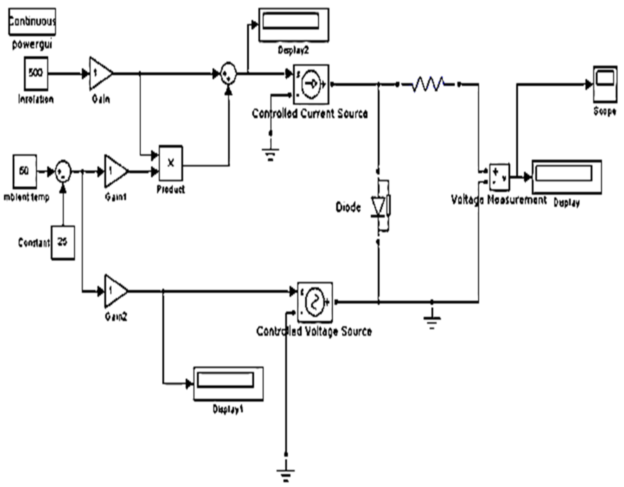

Fig.2. PV Simulink module.

III. THE BOOST CONVERTER

The ideal photovoltaic system operating point relies on the curve of the load with a slope which is represented by I = $\left(\frac{1}{R}\right)$. V along the P-V curve., where if the load varies then the output power will also varies based on the R load value and hence PV power fluctuation will be noticed, so to solve this issue (unwanted fluctuation of PV power) a DC-DC converter shall be integrated between PV module and load so as to maximize the power transfer from PV system to load. This can be noticed in Fig. 3. Fig. 4 demonstrates a boost topology of a DC-DC converter configuration.

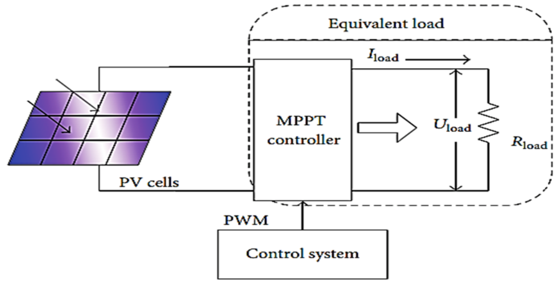

Fig. 3. A PV power structure model.

The DC-DC boost converter topology in its detailed structure is shown in Fig. 5 where it consists of two separate conduction modes, which are the continuous mode for effective conversion of power and discontinuous mode which mainly serves as a low power operation and acting in a standby operation mode.

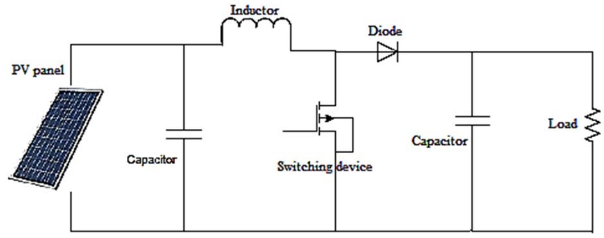

Fig. 4. Boost converter structural circuit

The mathematical model is expressed as follows:

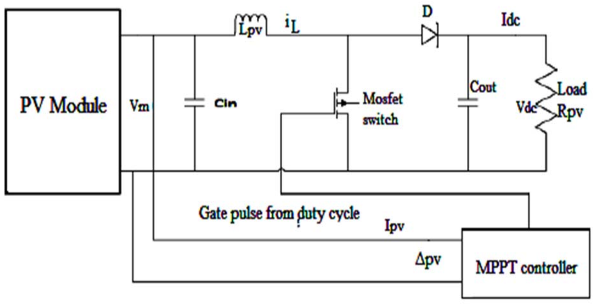

Fig. 5. Topology of a power boost converter

$$\begin{pmatrix} Vm \\ idc \end{pmatrix} = m\begin{pmatrix} Vdc \\ iL \end{pmatrix} \qquad (6)$$

The calculation of the duty cycle D is calculated as follows:

$$D = \frac{ton}{T} = ton\,.fs \qquad (7)$$

Where;
fs= MOSFET switching frequency
T= time per each cycle
Ton= The ON time within a cycle

Two operation modes are available for a DC-DC boost converter. In the first mode, switching circuit is turned ON and as a result the current from photovoltaic system flows in the inductor (L_{PV}) and the MOSFET. In the second mode, the switching circuit represented by the MOSFET is turned OFF and the current in this case will flow in the; inductor (L_{PV}), diode (D), as well as capacitor (C_{out}) and eventually the Rload as shown in Fig. 5 [7].

IV. INTELLIGENT P&O FUZZY CONTROL

In this research article we will implement an adaptive fuzzy P&O. This control would utilize the already existing inputs of P&O algorithm in the sense of differential power (P) and voltage (V). In this proposed control we will adapt a novel change in this algorithm where comparing along with switching methods will be eliminated by using a new approach of fuzzy logic. This is shown in Fig. 6.

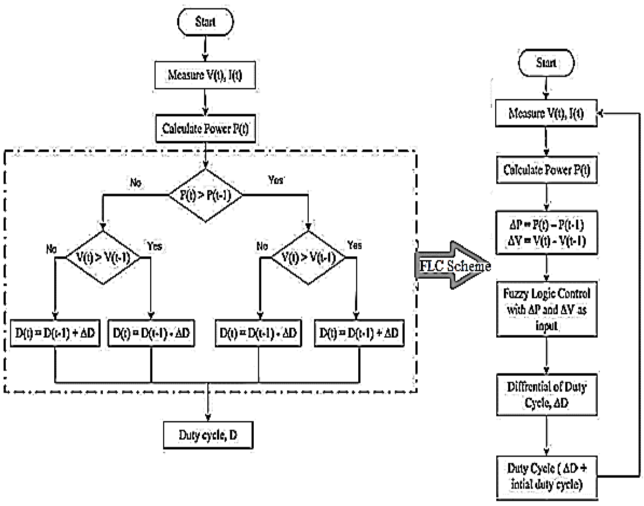

Fig. 6. New approach of fuzzy MPPT flowcharts

The fuzzy logic controller has four portions: fuzzification process, knowledge base, engine interface, and a defuzification process. In implementing a maximum power point tracking algorithm (MPPT) fuzzy logic control (FLC) would be composed of two inputs: The error dented as "E" and the change in error "CE" during an interval of time k. This is illustrated in (6) and (7). Note that the output of FLC is going to be represented by the duty cycle D [8, 9].The error would represent the current operating point on the P-V curve of a photovoltaic model whereas the change of error would represent the placement or movement of the operating point so as to move that point towards the maximum power point MPP when the change of power to the change of voltage is equal to zero [10,11].

$$e(k) = \frac{\Delta \mathrm{p}(\mathrm{k})}{\Delta \mathrm{v}(\mathrm{k})} = \frac{P(k) - P(k-1)}{v(k) - v(k-1)} \tag{8}$$

$$ce(k) = e(k) - e(k-1) \tag{9}$$

The FLC controller (duty cycle D) output is;

$$D(k) = D(k-1) + \Delta D(k) \tag{10}$$

Based on the above equations, as we work on the calculation of E and CE then; their inputs are going to be converted into linguistic variables and then the duty ration output D is generated by searching up in a rule-base table.

Fig. 7 illustrates a general structure of fuzzy interface system, whereas Fig. 8 demonstrates the block diagram of classical fuzzy MPPT algorithm.

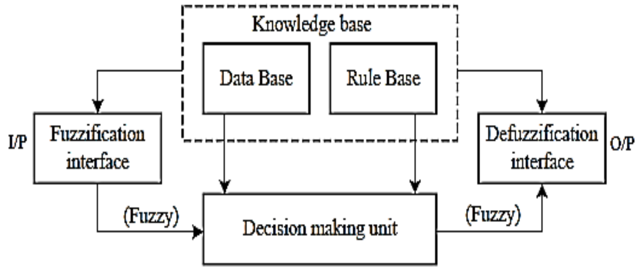

Fig. 7. Fuzzy interface system.

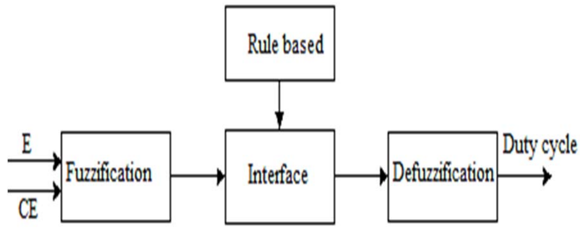

Fig. 8. Block diagram of classical fuzzy MPPT algorithm.

Fig. 9 shows the block diagram of the fuzzy logic controller FLC.

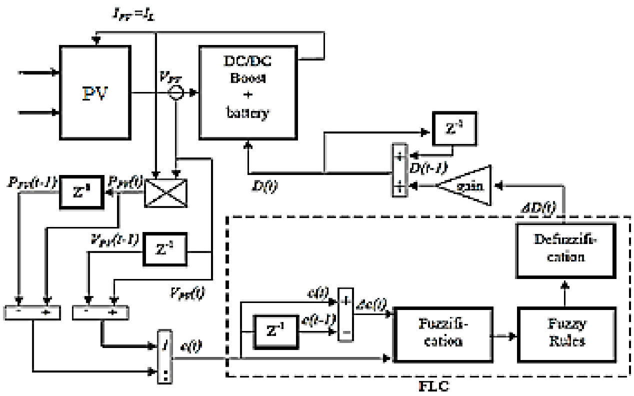

Fig. 9. Fuzzy logic controller diagram

V. PHOTOVOLTAIC PV SOLAR PANEL CHARATERISTICS

In this research we used the SunForce-Dc12-80 polycrystalline solar panel. SunForce-Dc12-80 was selected because it can deliver a reliable efficiency where this type of panels could reach a high energy output per Watt with 14% according to previous studies on this type of solar panels [12].

TABLE I. TECHNICAL SPECIFICATIONS OF SUNFORCE-DC12-80

Open - Circuit Voltage (V_{oc})	21.3V
Optimum Operating Voltage (V_{mp})	17.1V
Short - Circuit Current (I_{sc})	5.16A
Maximum Power Current (I_{mp})	4.68A
Maximum Power at STC (P_{max})	80W
No. of Cells	36

To build the PV model the above parameters in table I are used to investigate its nonlinear I-V and P-V output characteristics. The characteristic curves for the (I-V) current/voltage and (P-V) power/voltage under various combination of irradiances levels where we can plot these curves under the standard test conditions STC at25°C temperature and 1000 W/m2 of irradiance.

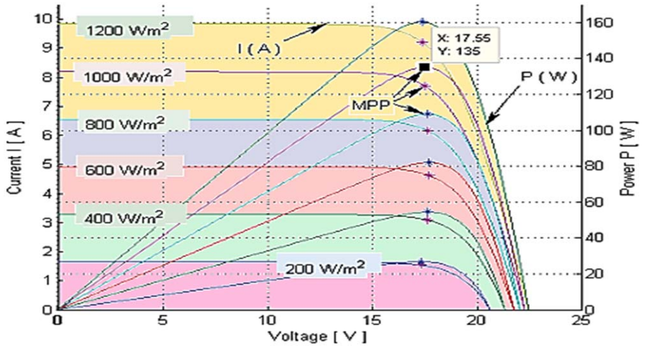

Fig. 10. I–V and P–V characteristics curves.

VI. ADAPTIVE P&O USING FUZZY CONTROLLER

Fuzzy logic controller relies on the rule base which is considered as an essential element in collecting all the data which fuzzy inference engine will construct through a logical conclusion which depends on the collected data [13]. In table II the control rules are shown with respect to the two inputs and one output, the error E, change of error CE, and the output duty cycle D respectively.

TABLE II. RULE BASE

E / CE	NB	NS	ZE	PS	PB
NB	NS	NS	NB	ZS	ZE
NS	NB	NB	NS	ZE	NS
ZE	NS	NB	ZE	PB	PS
PS	NS	ZE	NS	NS	NS
PB	PB	PS	ZE	PB	NS

The adaptive P&O fuzzy controller would use five proposed variables for a total of twenty five rules base (table II). These MFs are shown in Figs. 11, 12, and 13 where their membership functions MFs for the input ΔP, ΔV input and output ΔD (difference in duty ratio). As the parameters of ΔV and ΔP are calculated, they are fed into the FLC as a linguistic variables and the output parameter ΔD is calculated based on examining the rule base table as shown in Table II, which is composed of 25 rules.

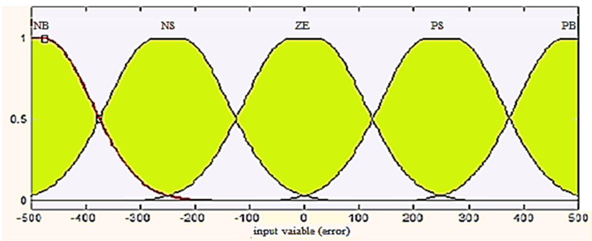

Fig. 11. Membership function of error.

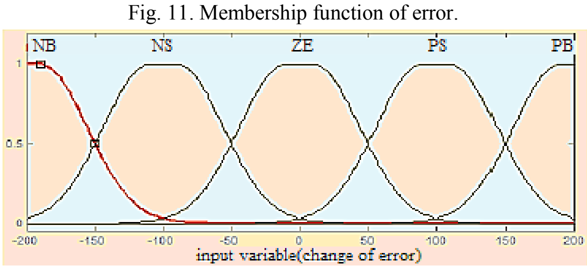

Fig. 12. Membership function of change in error.

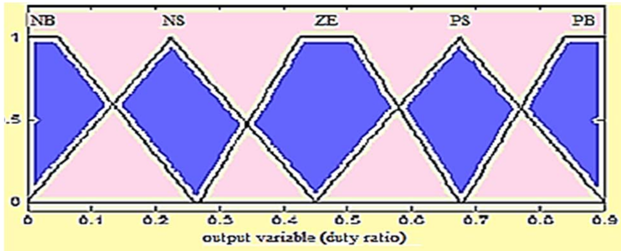

Fig. 13. Membership function of duty ratio.

VII. SIMULATION AND MODELLING OF THE PV SYSTEM

A comparative investigation of the performance was established by evaluating the P and O MPPT and adaptive P and O fuzzy MPPT. The calculated maximum power at irradiance 1000w/m^2 was around 80 watts, at 800W/m^2 was around 60 watts and at irradiance level of 600 W/m^2 around 45 watts. Figs. 14, 15, 16, and 17 show the obtained simulated results of the PV Vmax and Pmax at 1000W/m^2 and 600W/m^2 solar irradiances. From Figs. 14 and 15, can demonstrate to track the Vmax. However, it was noticed that the adaptive P&O fuzzy MPPT was faster (around a 50% faster) in tracking the Vmax as compared with the conventional P&O MPPT at both irradiances (1000W/m^2 and 600W/m^2 which would lead to achieve getting an increase in the energy from the PV system and thus providing a more reliable overall performance.

During the verification of the P&O and the newly adaptive fuzzy P&O where irradiances G (600W/m2 and 1000W/m2) were applied, it was once again noticed that the performance of adaptive P&O fuzzy logic MPPT is better than the P&O MPPT. We need to stress an emphasis that the P&O and the adaptive P&O fuzzy controllers were tested under different levels of irradiances as mentioned earlier. As per denoting to Figs. 18 and 19 the initial applied irradiance was set to 800W/m^2 and later to the STC condition of irradiance 1000W/m^2. The P&O and the adaptive P&O fuzzy MPPTs were able to attain the maximum power (Pmax=60W at G=800). However, as we compared the performance of each individual one we observed that the adaptive P&O fuzzy controller was able to track the maximum power point MPP faster and this was evident at time 18s as compared to 20s in the conventional P&O (figs. 18, 19) and obviously the oscillations around the maximum power point in the adaptive P&O fuzzy controller was eliminated to a minimal state however as this was compared to the P&O MPPT we observed a large oscillations around MPP and fluctuations which proves the weaknesses of the algorithm that tries to reach the MPP however never being able to point effectively towards it but keep oscillating around it due to the continuous perturbation that takes place in this method.

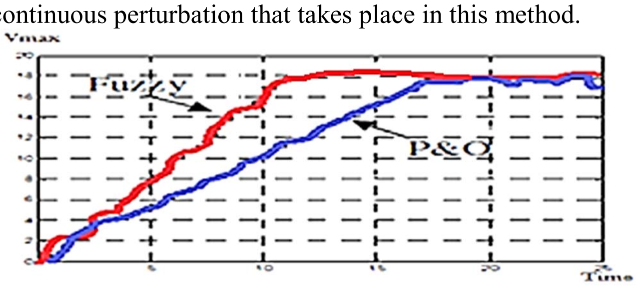

Fig. 14. Vmax at1000W/m^2.

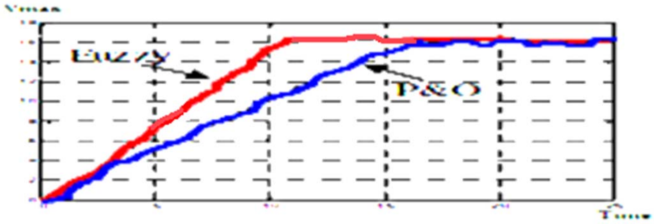

Fig. 15 Vmax at 800 W/m^2

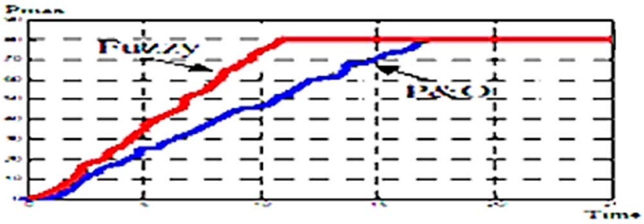

Fig. 16. Maximum power at 1000W/m^2

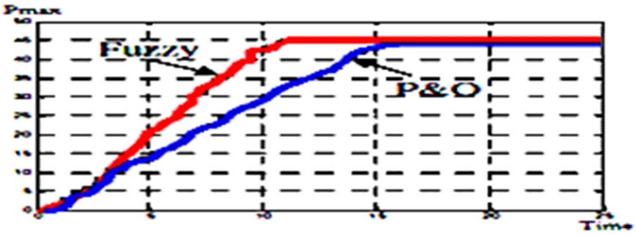

Fig. 17. Maximum power at 600W/^{m2}

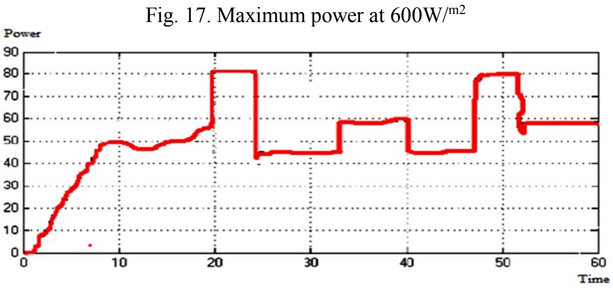

Fig. 18. P&O MPPT algorithm tracking MPP at various irradiances

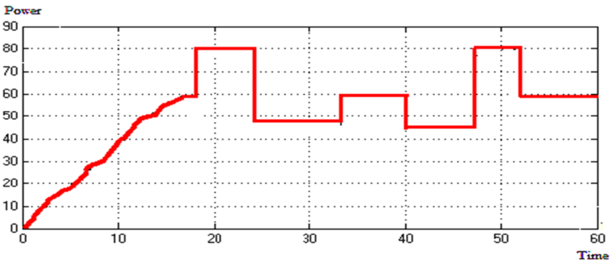

Fig. 19. Fuzzy MPPT tracking MPP at different irradiance levels.

VIII. Conclusion

An analytical modeling study of the PV photovoltaic equivalent electric circuit was introduced to calculate the five unknown parameters of the system. The calculation of the PV model curves (P-V and I-V) was constructed through the utilization of Mathlab/Simulink to determine the initial values required to run and verify the performance of the model at different irradiances levels. The fuzzy logic controller was constructed by adapting five membership functions and the conducted simulations revealed that the adaptive P&O fuzzy controller was faster in tracking the maximum power point and was able to minimize the perturbation steps which led to eliminations in the oscillation around the MPP.

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