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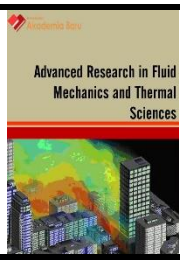

Maximum Power Point Tracking in PV Device: Material, Efficiency and Models to Supply Non-Linear DC Power Supply

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ABSTRACT

The depletion of fossil fuel and coal has set a worrying trend in recent times. In addition, emissions have reached worrying heights leading to phenomenon of global warming. Thus, the need for development in the technology for renewable energy has been at the center stage of scientific development. Current developments point towards solar energy as the most promising and reliable potential to replace fossil fuel and coal in the long-term. This study analyzes solar photovoltaic technology based on cell material, efficiency levels as well as models of array. In addition, the ability of PV cells to supply DC is also evaluated.

1. Introduction

Due to the growth of population and technology causes the demand of electricity increasing rapidly. The current source of electricity (fossil fuel, coal) will only last few years from now on. Besides, this fossil fuels and coals are expensive and also increase the CO_2 emission that causes the global warming. The renewable energy sources such as solar, tidal, wind, hydro and biomass become popular these days due to their ability to generate electricity. Among all the renewable energy sources, solar is the most promising energy and has the wide range of utilization. It is environmental friendly, clean, reliable and inexhaustible. The solar energy has been utilized in many applications such as to power satellite in space program, power generation, solar battery charging and powering solar vehicle etc. [1]. The solar power energy is strongly depending on the radiation and temperature. The incident of solar irradiation that converted into electrical energy is about 30-40% while the maximum efficiency of solar panel is only 15-20% [2].

In order to capture the sunlight, solar photovoltaic (PV) is used. PV is a device that captures the energy of sunlight and converts it into electricity. It is made of several thin layers of silicon. When the

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sunlight radiation strikes solar panel, one of the electron of silicon gets excited to the higher level of energy and move around freely, then the current produced. PV system will not generate electricity in the night, but stored collected energy in battery. The solar PV system can operate as a stand-alone or connected to grid. In addition, the combination between solar PV with other equipment such as battery, diesel generator or other renewable resources to form hybrid is also possible. The battery and diesel generator acts as backup supply during unavailability of sources. Based on previous research, when the system included solar PV, battery and diesel generator, the output of the system was always satisfied even at night and the cost reduced [3]. The solar PV must be kept clean from any dust particles, deposits left by birds or fallen leaves to obtain the best result. Based on [4], the output power losses and the efficiency is reduced because of the different environmental factors (dust, color, shading and temperature). There are three parameters of solar PV that affected by the temperature fluctuations which is maximum output power P_{max}, short circuit current I_{sc}, and open circuit voltage I_{oc} [5]. This solar PV can operate reliably for a long time with minimal maintenance.

Since the output from the PV cell is varied to the atmospheric conditions, the best way to get optimal output from the system is by implement maximum power point tracking (MPPT). MPPT is an electronic tracking system (DC – DC converter) where the input is in DC and change it into AC and convert back to different DC voltage and current that match to the battery. MPPT operates at high frequency (20-80 kHz). Maximum power transfer theorem is used in MPPT technique where it is stated as "maximum power transfer will occur if the source of impedance is equal to load impedance'. There are many MPPT techniques have been presented to adapt with every changes in solar PV system. Some of them are Perturbation & Observation (P&O), Incremental Conductance (INC), Fuzzy Logic Controller (FLC), Particle Swam Optimization (PSO), etc. Each of MPPT techniques has different algorithm, performance and circuit design. Among all the developed MPPT, INC algorithm and P&O algorithm are widely used to track the MPP in PV systems. Both methods have shown a stable performance during uniform and slow variation of solar radiation and temperatures.

2. PV Array Model and Characteristics

Solar photovoltaic cell is a semiconductor device that turns light energy into electrical energy directly. The working principle of solar photovoltaic cell is based on semiconductor of P-N junction (photon and hole). The flow of electricity is depending on the intensity of light (number of photons). Besides, the materials used for manufacturing the solar cells also affected the output. From the equivalent circuit shown in Figure 1, there are solar light current I_{ph}, dark current I_d, series resistor R_s, parallel resistor R_{sh} and load resistance R_L. A PV mathematical equation for practical as (1).

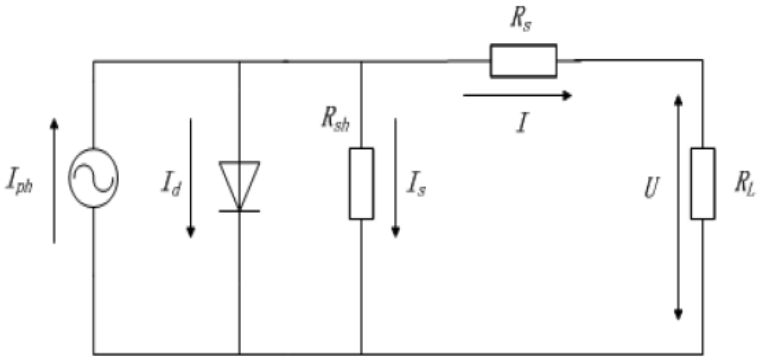

Fig. 1. The equivalent circuit of a solar cell

$$I = n_p I_{ph} - n_p I_{rs}[\exp\left(\frac{q}{kTA}\frac{V}{n_s}\right) - 1] \quad (1)$$

where I and V are the output current and voltage from PV array, n_s and n_p are the numbers of series strings and parallel strings in system, q is the charge of electron (q = $1.6\text{x}10^{-19}$C) while k is Boltzmann's constant (K=$1.38\text{x}10^{-23}$J/K), T for the temperature (T=t+273K) and A for P-N junction ideality factor. As illustrated in Figure 2, PV cell, PV module and PV array. The basic model of PV is PV cell. A number of PV cells connected together will form module. If the modules connected in series or parallel will form PV array. The voltage and current will increase in series or parallel connection respectively.

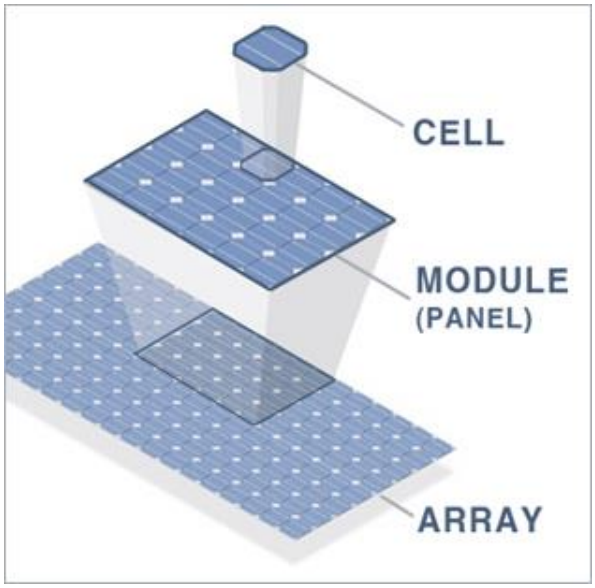

Fig. 2. The configuration of solar photovoltaic

Solar PV is the most convincing renewable energy sources but the cost of installation is very high, required about 20 years for payback and the conversion efficiency is too low. Therefore, some of the researchers presented other alternative to overcome those problems. Ibrahim *et al.,* proposed the dual-tariff PV system [6]. During day time, the load is supplied by the solar PV system and the battery is charged too. During the night time, the load is supplied by grid current. In this system, the number PV panels, battery, the capital cost and the payback period is reduced. The system also expected to reduce the electricity bill by 89%. An improved solar PV system is presented [7]. The solar PV system is modified by adding sun tracking device and reflectors. The mirrors are used as reflectors and installed around the solar PV panel to increase the sunlight's intensity. The system tested with and without both devices. The result shows the output from the system with those devices is higher and more reliable. Many sun tracking devices has been introduced to improve the efficiency of the system. Bin *et al.,* improved the efficiency by one-axis 3-position (1A-3P) tracking [8]. This tracking able to generate more power even on cloudy weather, easily mounted on the building walls and no such extra cost. Vinius *et al.,* implemented hybrid motor driver to reduce the power losses during tracking operation and eliminate the shoot-through effect [9]. The hybrid motor driver used simple circuit design. Sanjana *et al.,* states the efficient panel area depends on the angle between incident radiation and the normal of the panel plane which varies with the position of the sun and the panel mounting angle [10]. The mounting angles are different for each country. Besides, the addition of the traffic sensing in the system may diminish the energy consumption and system size. Kaifang *et al*., reported that, to track the solar, the program control and sensor control is combined and the working system is relying on the photodiode and algorithm of sun time [11]. The attitude of the solar panel

changes by controlling the solar altitude and azimuth motors. The system gives great performance which is low power consumption, high accuracy, able track the sunlight vertically and large electricity generated.

Since the solar PV panel is exposed to any dust or dirt, Mustafa *et al.,* proposed a self-cleaning control system for solar PV panel [12]. The process of the cleaning the solar panel by using water. This self-cleaning system get the power from the battery of the solar panel, therefore it didn't need external power and the cost of cleaning is reduced. In the renewable energy resources, energy storage is very essential and usually lead acid batteries is implemented in the system. Since the renewable resources such as solar not available throughout the time, the battery act as backup supply and store excess energy. The variabilities of solar PV will affect the battery performance. Alam and Saha reported to show the impact of variabilities of solar PV on battery operation using 'Rainflow counting' method [13]. The effect of this variabilities is high frequency micro-cycles appeared in battery system depth of discharge profiles. If the solar PV system come up with large battery size and small panel, the battery will never fully charge. Sizing of the PV panel and battery is one of the parameters that must be considered wisely. Khan *et al.,* reported that, increased the panel size will increase the output power even on low sunshine or bad weather [14]. Then, the battery size is reduced but the initial cost is increased as the panel size increased. According to Shaw *et al.,*, a solar PV system with battery storage system (BSS) is developed to control the process of charging and discharging of BSS based PV power load power demand [15]. MPPT algorithm is employed in this system to increase the operation and efficiency of the solar PV panel. In this system, battery will start charging when the power generated by PV is higher than the load demand and when the load demand is higher than power generated, battery starts to discharge to supply the load.

3. MPPT Method

Solar PV panel is a non-linear DC power supply. The output is varied due to weather condition. Hence, MPPT becomes indispensable in solar PV system to extract and track the MPP as quick as possible. There are many MPPT techniques had been proposed, some of the techniques had been improved in order to track the MPP correctly. Each MPPT has different technique, circuit design and advantages and disadvantages.

3.1 INC

In this technique, the incremental changes measured and calibrated by the controller to determine the effect of voltage changes. If the value of incremental conductance is equal to that instantaneous one, it means that the maximum power point is reached [16]. The output power is proportional to the voltage. This technique applied mathematical calculation to find MPP by comparing the incremental conductance (ΔI/ΔV) to the array conductance (I/V) [17-23]. The flowchart of INC algorithm is presented in Figure 3. The derivative equation of output power with the voltage in (2). According to Huang *et al.,*, at MPP, the dP/dV=0 [8]. The advantages of this MPPT technique are, it able to track the changes in irradiance rapidly with higher accuracy, does not oscillate at the MPP, and does not track in the wrong direction. It requires two sensors to track the MPP which current sensor and voltage sensor.

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} = I + V\frac{\Delta I}{\Delta V} \quad (2)$$

$$\frac{\Delta I}{\Delta V} = \frac{-I}{V} \quad \text{at MPP}$$

$\frac{\Delta I}{\Delta V} > \frac{-I}{V}$ at left of MPP

$\frac{\Delta I}{\Delta V} < \frac{-I}{V}$ at right of MPP

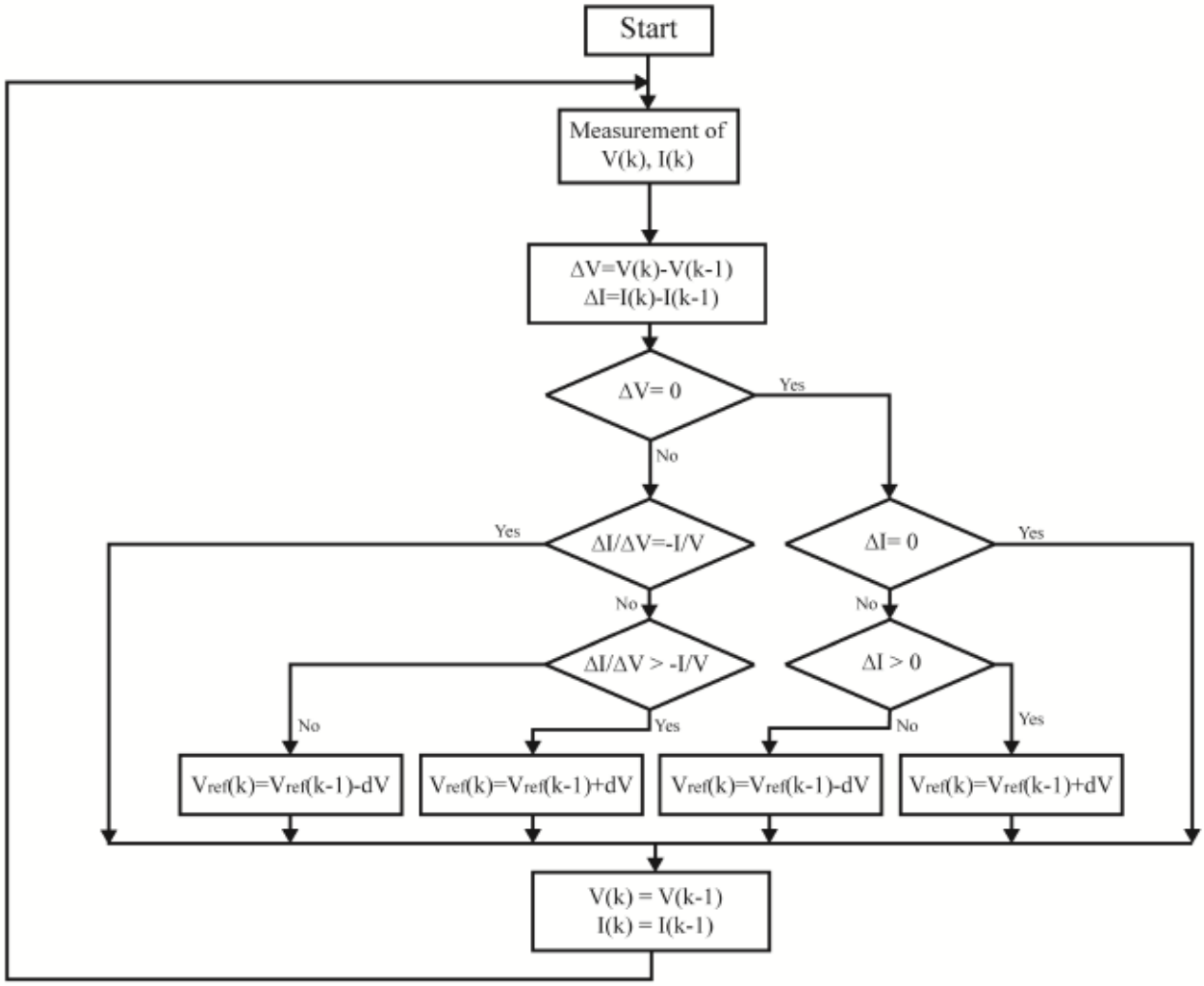

Fig. 3. Flowchart for INC algorithm

3.2 P&O

This P&O algorithm is widely used because of the simple implementation. It also known as Hill Climbing method. The operation of this algorithm is by periodically perturbing the voltage or current of PV array (incrementing or decrementing). The concept of P&O is, give the voltage firstly, then calculate the power at the end [24]. To make the system move along the direction of the voltage towards the MPP, set up the disturbance step and increased the output power (ΔP>0). If the ΔP<0, the perturbation moves in the opposite direction. The most important in this P&O algorithm is to select the appropriate step size in order to get the desired MPP. Larger the step change in the perturbation makes the response time faster to achieve the MPP but causes large oscillations near the MPP and vice versa [24-30]. Figure 4 shows the flowchart of P&O algorithm. Veerasamy *et al.,* reported, the advantage of P&O algorithm is less complexity in the implementation and the MPPT does dependent on the PV module characteristics [17]. The disadvantages of this method is the

system become unstable during the changes of the radiance level and there is oscillation occur near the MPP. This disadvantages affects the output power efficiency.

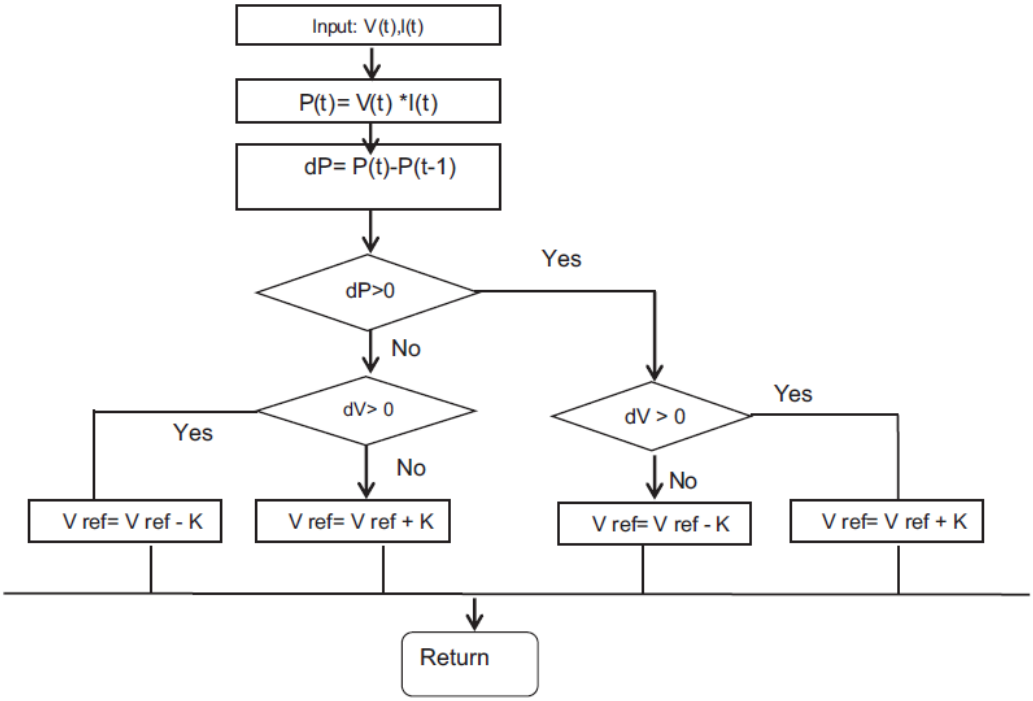

Fig. 4. Flowchart for P&O algorithm

3.3 FLC

In this recent years, artificial intelligence becomes popular. Some researchers already implemented artificial intelligence process to improve the MPPT techniques. The FLC system is able to give a very good performance, fast responses with no over-shoot, effective for both linear and non-linear system even under rapid atmospheric variations, and does not require the knowledge of the exact solar PV model [18,25]. Figure 5 shows the block diagram of FLC. There are two inputs and one output. The Mamdani Method and Defuzzification (centre of gravity method) is used to calculate the duty cycle of the FLC.

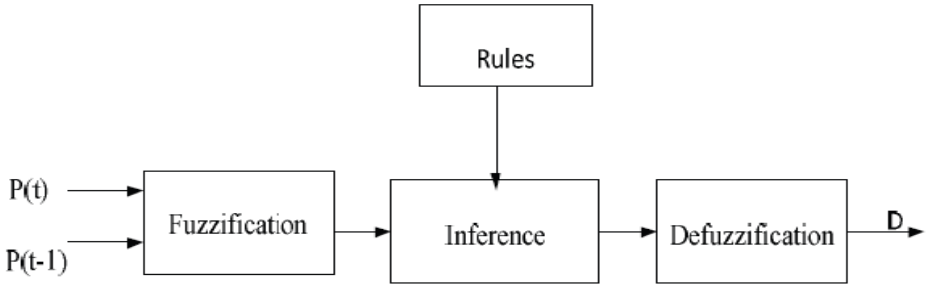

Fig. 5. Block diagram of FLC

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