Literature Review on Solar MPPT Systems

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Abstract

Use of electricity is increasing day by day. The electricity finds its application in all the domains. Converting solar energy into electrical energy is one of the best ways to reduce fossil fuel consumption. Owing to the cost and efficiency of the solar cells, it is not used in most of the electrical applications. But the introduction of Maximum Power Point Tracking (MPPT) algorithms has improved the efficiency of the solar cells. The various MPPT algorithms are discussed in the paper. The applications supported by these MPPT algorithms are also discussed.

Keywords: MPPT algorithms, solar energy, Review, classification, comparison.

1. Introduction

Electricity is one the most essential needs for humans in the present. Conversion of solar energy into electricity not only improves generation of electricity but also reduces pollution due to fossil fuels. The output power of solar panel depends on solar irradiance, temperature and the load impedance. As the load impedance is depends on application, a dc-dc converter is used for improving the performance of solar panel.

The solar irradiance and temperature are dynamic. Hence an online algorithm which dynamically computes the operating point of the solar panel is required. The efficient conversion of solar energy is possible with Maximum Power Point Tracking (MPPT) algorithm. There are various MPPT algorithms such as Perturb and Observe, Incremental Conductance etc. The various algorithms in MPPT and their topology is discussed in this paper. The comparison between these algorithms is also given in this paper.
2. Literature Review

The MPPT system can be classified based on the algorithms used; power converter in the system and application of the system (Standalone or grid interconnection).

2.1 Classification based on algorithms

Many methods to track Maximum Power Point (MPP) for PV arrays have been discussed by Trishan Esram et al [1]. It comprises of all the techniques implied in this field. It was shown that at least 19 distinct methods have been already introduced.

A high-frequency photovoltaic pulse charger (PV-PC) for lead-acid battery (LAB) guided by a power-increment-aided incremental-conductance maximum power point tracking (PIINCMPPT) was proposed by Hung-I Hsieh et al [2]. The PV-PC implemented by a boost current converter (BCC) is to eliminate sulphating crystallization on the electrode plates of the LAB and to prolong the battery life. The BCC associated with the PV module is modeled to maximize the energy charging to battery under maximum power transfer. A duty-control guided by the PI-INC MPPT is designed to drive the BCC operating at MPP against the random insulation. A design example of a PV-PC system for a four-in-series LAB battery (48 VDC) was examined. The charging behavior of the PVPC system in comparison with that of CC-CV charger was studied. Four scenarios of solar insulation changes to describe tracking behavior of PI-INC MPPT in PV-BC system were investigated, which is also compared with that of INC MPPT.

K.H. Hussein et al [3] have developed a new Maximum Power Tracking (MPT) algorithm to track Maximum Power Operating Point (MPOP) by comparing the incremental and instantaneous conductance of the PV array. The drawbacks of Perturb and Observe method were analyzed and it showed that the Incremental Conductance algorithm has successfully tracked the MPOP even when atmospheric conditions changes rapidly. The work was carried out by both simulation and graphs.

A new method for MPPT named CVT (Constant Voltage Tracking) is proposed by Zheng Shicheng et al with the analysis of characteristic curve and operation theory of PV array [4]. A lower power photovoltaic (PV) system with simple structure has been designed. This method has been verified by PV charging system and it showed that MPP of PV array can be tracked well by applying the charger controller.

An adjustable Self-Organizing Fuzzy Logic Controller (SOFLC) for a Solar-powered Traffic Light Equipment (SPTLE) with an integrated MPPT system on a low-cost microcontroller has been presented by Noppadol Khaehintung et al [5]. It comprises of boost converter for high performance SPTLE. Variation of duty ratio for DC-DC boost converter is implemented on PIC16F876A RISC-microcontroller.

A fuzzy based perturb and observe (P&O) MPPT in solar panel was presented by C. S. Chin et al [6]. The solar system is modeled and analyzed in MATLAB/SIMULINK. Simulation results showed that fuzzy based (P&O) MPPT has better performance and more power is produced from solar panel.

Panom Petchjatuporn et al introduced a maximum power point tracking algorithm using an artificial neural network for a solar power system [7]. By applying a three
layers neural network and some simple activation functions, the maximum power point of a solar array can be efficiently tracked. The tracking algorithm integrated with a solar powered battery charging system has been successfully implemented on a low-cost PIC16F876 RISC-microcontroller without external sensor unit requirement. The experimental results with a commercial solar array showed that the proposed algorithm outperforms the conventional controller in terms of tracking speed and mitigation of fluctuation output power in steady state operation. The overall system efficiency was well above 90%.

S. Yuvarajan et al proposed a fast and accurate maximum power point tracking (MPPT) algorithm for a photovoltaic (PV) panel that uses the open circuit voltage and the short circuit current of the PV panel [8]. The mathematical equations describing the nonlinear V-I characteristics of the PV panel were used in developing the algorithm. The MPPT algorithm is valid under different insulation, temperature, and level of degradation. The algorithm is verified using MATLAB and it is found that the results obtained using the algorithm were very close to the theoretical values over a wide range of temperature and illumination levels. The maximum deviation in the maximum power was less than 1.5% for the illumination levels and temperatures normally encountered by a commercial PV panel. The complete derivation of this MPPT algorithm was presented. It is seen that the algorithm is faster than other MPPT algorithms like perturbation and observation (P&O) and more accurate than approximate methods that use the linearity between voltage (current) at maximum power point and open-circuit voltage (short-circuit current).

Prof. Dr. IlhamiColak, et al. have modeled three separate solar farms that provide 15 kW power for each farm using Mat lab Simulink real-time analysis software [9]. Energy conversion was performed with maximum power point tracking (MPPT) algorithms in each converter using Perturb and Observe (P&O) structure. These were collected in DC bus bar with parallel connection of converters over inter-phase transformers (IPT). The voltage was applied to a full bridge inverter to generate 3-phase AC voltages at the output of inverter which was controlled with sinusoidal pulse width modulation (SPWM) scheme.

S. G. Tesfahunegn et al. designed a new solar/battery charge controller that combines both MPPT and over-voltage controls as single control function [10]. A small-signal model of lead acid battery was derived in detail to design the employed dual-loop control configuration. Case studies were then conducted, in SIMULINK/SIMPOWER, to evaluate the performance of the designed controller in terms of transient response and voltage overshoot. The designed controller was demonstrated to have good transient response with only small voltage overshoot.

Yuncong Jiang et.al. Present an analogue Maximum Power Point Tracking (MPPT) controller for a Photovoltaic (PV) solar system that utilizes the load current to achieve maximum output power from the solar panel [11]. Comparing to the existing MPPT controller circuitry which requires multiplication of the sensed PV panel voltage and current to yield panel power, the cost and size of the proposed circuit was
The tracking performance of the proposed MPPT controller was validated by simulation results.

Arash Shafie et al proposed a novel MPPT algorithm mainly for battery charging applications which were considered constant voltage type loads. This was achieved mainly with output current maximization [12]. This technique benefits from advantages such as very simple current controller and also circuit topology independency. This provides high efficiency for energy conversion with low cost for low power, low cost applications. A new hybrid PV model was introduced for simulation purposes. Finally, simulation results will be provided confirming the validity of the algorithm.

Solar photovoltaic (PV) systems have been an area of active research for the last few decades to improve the efficiency of solar PV module. The non-linear nature of IV curve of solar PV module demands some technique to track the maximum voltage and maximum current point on IV curve corresponding to Maximum Power Point (MPP). Thus, Maximum Power Point Tracking (MPPT) techniques were widely deployed for this purpose. Lot of MPPT techniques have been developed in recent past but still most commercial systems utilizes perturb & observe (P&O) MPPT technique because of its simple algorithm, low cost and ease of implementation [13]. However, this technique was slow in tracking MPP under rapidly changing irradiance conditions and it also oscillates around the MPP. Ali F Murtaza et al addresses this problematic behavior of P&O technique and hence presents a novel MPPT hybrid technique that was combination of two basic techniques i.e. P&O and Fractional Open Circuit Voltage (FOCV) technique in order to overcome the inherited deficiencies found in P&O technique. The proposed MPPT technique was much more robust in tracking the MPP even under the frequent changing irradiance conditions and was less oscillatory around the MPP as compared to P&O. The technique was verified using MATLAB/SIMULINK and simulation results show a clear improvement in achieving the MPP when subjected to change in irradiance.

The performance analysis of photovoltaic modules in non-ideal conditions and the topologies to minimize the degradation of performance caused by these conditions was introduced by Weidong Xiao et al [14]. It was found that the peak power point of a module was significantly decreased due to only the slightest shading of the module, and that this effect was propagated through other non-shaded modules connected in series with the shaded one. Based on this result, two topologies for parallel module connections have been outlined. In addition, dc/dc converter technologies, which were necessary to the design, were compared by way of their dynamic models, frequency characteristics, and component cost. Out of this comparison, were commendation has been made.

According to the output characteristics of photovoltaic (PV) array and battery charging characteristics, design of a PV charging system with maximum power point tracking (MPPT) was proposed by Jun Pan et al [15]. This paper proposes a MPPT strategy based on DC/DC converter output current, which adopts variable step of duty cycle to implement MPPT of PV array. This perturbation and observation (P&O)
method simplified the structure of the system, improved the speed and accuracy of tracking. In battery charging management, this paper adopts optimal charging strategy, charging controller combined MPPT charging and variable intermittent current charging increases the charge speed, raises the state of charge. Uses an efficient and reliable rule to determine the end of charging, avoids the overcharging of battery and extends the lifetime of battery.

In standalone dc system, dc-dc converter was used to interconnect solar photovoltaic (PV) and battery. To utilize solar PV to fullest, maximum power point tracking (MPPT) was incorporated in controller [16]. However, in case when the state of charge (SOC) of battery was high and system was partially loaded, excess power flows into the battery, thereby reducing the life of battery. Technique suggested in literature use output (battery) voltage controllers. However, it was shown in this paper that output voltage controlled dc-dc converter fed by solar PV may lead to instability. To address these limitations, a charge controller scheme was proposed by Sandeep Anand et al. This scheme ensures that the battery voltage remains below its gassing voltage. Salient features of the proposed scheme were optimal utilization of solar PV and battery capacities without effecting life of battery. The effectiveness of the scheme was verified through detailed simulation study. To confirm the viability of the scheme, experimental studies were carried out on a scaled-down laboratory prototype developed for the purpose.

A new maximum power point tracking algorithm for photovoltaic arrays was proposed by Mohamed Azab [17]. The algorithm detects the maximum power point of the PV. The computed maximum power was used as a reference value (set point) of the control system. ON/OFF power controller with hysteresis band was used to control the operation of a Buck chopper such that the PV module always operates at its maximum power computed from the MPPT algorithm.

The major difference between the proposed algorithm and other techniques was that the proposed algorithm was used to control directly the power drawn from the PV.

The proposed MPPT has several advantages: simplicity, high convergence speed, and independent on PV array characteristics. The algorithm was tested under various operating conditions. The obtained results have proven that the MPP was tracked even under sudden change of irradiation level.

Ashish Pandey et al describe about the limitations of Perturb & Observe (P&O) method because of continuously changing environmental conditions [18]. A variable-step-length algorithm was proposed and the drift was minimized by evaluating the entire trend in a power versus voltage curve.

Table 1 provides a comparison of different MPPT algorithms. The convergence speed and Implementation complexity are the two important aspects in choosing the MPPT algorithms. It is tabulated in table 1.
Table 1: Comparison between various MPPT algorithms.

<table>
<thead>
<tr>
<th>MPPT Technique</th>
<th>PV Array Dependent?</th>
<th>True MPPT?</th>
<th>Analog or Digital?</th>
<th>Periodic Testing?</th>
<th>Convergence Speed</th>
<th>Implementation Complexity</th>
<th>Scared Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sine-clamping P&amp;O</td>
<td>No</td>
<td>Yes</td>
<td>Both</td>
<td>No</td>
<td>Varies</td>
<td>Low</td>
<td>Voltage, Current</td>
</tr>
<tr>
<td>Lag-lead</td>
<td>No</td>
<td>Yes</td>
<td>Digital</td>
<td>No</td>
<td>Varies</td>
<td>Medium</td>
<td>Voltage, Current</td>
</tr>
<tr>
<td>Fractional Zc</td>
<td>Yes</td>
<td>No</td>
<td>Digital</td>
<td>Yes</td>
<td>Medium</td>
<td>Low</td>
<td>Voltage</td>
</tr>
<tr>
<td>Fractional Zs</td>
<td>Yes</td>
<td>No</td>
<td>Digital</td>
<td>Yes</td>
<td>Medium</td>
<td>Medium</td>
<td>Current</td>
</tr>
<tr>
<td>Fuzzy Logic-Control</td>
<td>Yes</td>
<td>Yes</td>
<td>Digital</td>
<td>Yes</td>
<td>Fast</td>
<td>High</td>
<td>Varies</td>
</tr>
<tr>
<td>Neural Network</td>
<td>Yes</td>
<td>Yes</td>
<td>Digital</td>
<td>Yes</td>
<td>Fast</td>
<td>High</td>
<td>Varies</td>
</tr>
<tr>
<td>OCC</td>
<td>No</td>
<td>Yes</td>
<td>Analog</td>
<td>No</td>
<td>Fast</td>
<td>Low</td>
<td>Voltage, Current</td>
</tr>
<tr>
<td>Current Sweep</td>
<td>Yes</td>
<td>Yes</td>
<td>Digital</td>
<td>Yes</td>
<td>Slow</td>
<td>High</td>
<td>Voltage, Current</td>
</tr>
<tr>
<td>DC Link Capacitor Droop Control</td>
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<td>No</td>
<td>Both</td>
<td>No</td>
<td>Medium</td>
<td>Low</td>
<td>Voltage</td>
</tr>
<tr>
<td>Lead/Feed Forward/Feedback Control</td>
<td>No</td>
<td>No</td>
<td>Analog</td>
<td>No</td>
<td>Fast</td>
<td>Medium</td>
<td>Voltage, Current</td>
</tr>
<tr>
<td>Array Reconfiguration</td>
<td>Yes</td>
<td>No</td>
<td>Digital</td>
<td>Yes</td>
<td>Slow</td>
<td>High</td>
<td>Voltage, Current</td>
</tr>
<tr>
<td>Linear Current Control</td>
<td>Yes</td>
<td>No</td>
<td>Digital</td>
<td>Yes</td>
<td>Fast</td>
<td>Medium</td>
<td>Voltage</td>
</tr>
<tr>
<td>Zvs &amp; Zcs Compensation</td>
<td>Yes</td>
<td>Yes</td>
<td>Digital</td>
<td>Yes</td>
<td>NA</td>
<td>Medium</td>
<td>Indoor, Temperature</td>
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<td>Stacked MPPT</td>
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<td>Both</td>
<td>Yes</td>
<td>Fast</td>
<td>High</td>
<td>Voltage, Current</td>
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<tr>
<td>OCC-MPPT</td>
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<td>Fast</td>
<td>Medium</td>
<td>Current</td>
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<tr>
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<tr>
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<td>No</td>
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<td>High</td>
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</tr>
<tr>
<td>Sliding Control</td>
<td>No</td>
<td>Yes</td>
<td>Digital</td>
<td>No</td>
<td>Fast</td>
<td>Medium</td>
<td>Voltage, Correct</td>
</tr>
</tbody>
</table>

2.2 Classification based on converter

Eftichios Koutroulis et al introduced a new MPPT system that uses Buck-type DC/DC converter which is controlled by a microcontroller [19]. In this method the output power of PV array is directly used to control the DC/DC converter. This method has high efficiency, lower cost and can be easily modified to handle more energy sources.

A new MPPT system has been developed by Eftichios Koutroulis et al [20], consisting of a Buck-type dc/dc converter, which was controlled by a microcontroller-based unit. The main difference between the method used in the proposed MPPT system and other techniques used in the past was that the PV array output power was used to directly control the dc/dc converter, thus reducing the complexity of the system. The resulting system has high-efficiency, lower-cost and can be easily modified to handle more energy sources (e.g., wind-generators). The experimental results show that the use of the proposed MPPT control increases the PV output power by as much as 15% compared to the case where the dc/dc converter duty cycle was set such that the PV array produces the maximum power at 1 kW/m² and 25°C.

A system with an alternative source of energy supply from photovoltaic energy system which operates in case of utility power failure has been discussed by C. Thulasiyammal [21]. The proposed PV system is composed of conventional novel single axis tracking system and PV system with DC-DC boost converter and PWM voltage source inverter. The PV panel voltage is taken as input parameter to maximize the output power.
PWM techniques to regulate the output power of boost converter at its maximum possible value and simultaneously control the charging process of battery was proposed by D.V.N. Ananth [22]. Analysis of boost converter was demonstrated using MATLAB/Simulink model.

ChamnanRatsame presented an intelligent control method for the maximum power point tracking (MPPT) of a photovoltaic powered water pump system for long tailed boat in Thailand by using DC-DC boost converter as switching charger. This system consisted of a solar array, a switching battery charger based on boost DC-DC converter, a battery and small water pump [23]. The solar array had a specification as 75 watts of output power, 14-18 volts of output DC voltage, and 3A of output DC current. The output power of solar array was the input power for boost DC-DC converters the switching charger. To control the boost converter, the pulse width modulation (PWM) was applied. The water pump was controlled by a microcontroller PIC 186627. When the water amount reaches the specified level, a sensor will send the signal to the microcontroller for controlling a relay to drive a motor in the water pump. To verify the proposed pump system, the prototype of water pump for small boat was built to experiment. From the results, to stabilize the output voltage of the boost DC-DC charger at 25.6 volts, the duty ratio was controlled at 35-50% with 100 kHz of switching frequency. The battery having rated voltage as 24 volts and rated current as 7 amps per hour was used in the system.

A novel cost effective, more accurate and efficient microcontroller based MPPT system for a solar voltaic system to ensure fast tracking of MPOP at all fast changing environmental conditions has been proposed by Siwakoti et al [24]. It uses PWM technique to regulate the power output of boost DC/DC converter at its maximum possible value and simultaneously controls the charging process of battery. Incremental Conductance algorithm is implemented here.

B.R.Sanjeeva Reddy et al proposed PWM techniques to regulate the output power of boost converter at its maximum possible value and simultaneously controls the charging process of battery [25]. Parameter extraction, model evaluation and analysis of boost converter was demonstrated using MATLAB/Simulink model.

A battery-integrated boost converter for module-based series connected photovoltaic (PV) system has been analysed by Yang Du et al [26]. Each PV module has its own battery and DC/DC converter. The converter achieves maximum power point tracking (MPPT) and battery charging. Application of proposed converter to module based series connected PV system can maintain string voltage and save an additional voltage amplification stage. Steady-state analysis of the converter to determine the power flow equations was presented. Three advantages comparing with the conventional series connected boost converter were reported. Simulation and experimental results of a laboratory prototype were presented.

For conventional paralleled PV sources, the current ripple at the load side increases when the ripples were added up from each converter, which also reduces the life time of the battery storage. This problem is addressed by Boyang Hu et al [27]. Even though the ripple was able to be reduced by increasing switching frequency, the extra
switching losses must be taken into account. In this paper, a switching technique was proposed based on paralleled multiple-input sources with boost converters. Since the current ripple of the battery charging current can be minimized without the restrictions of source voltages, currents and duty cycles, the Maximum Power Point Tracking (MPPT) algorithm was also able to be implemented with the proposed technique for integrating renewables into the smart grid. The proposed technique was validated through detailed numerical analysis, simulation and experiment results.

The modelling and control design of the PV charger system using Buck-Boost converter was presented by B. SreeManju et al [28]. The controller was designed to balance the power flow from PV module to the battery and the load such that PV power was utilized effectively and the battery was charged in three charging steps.

The latest development of inverters for photovoltaic AC-modules [29] is focused by SoerenBaekhoejKjaer et al. The past technology was based on Centralized Inverters, present on String Inverters and future on AC-Modules and AC-Cells.

Yun-Pam Lee et al focused on a DC to AC Inverter; power switching system; ability to generate the drive voltage and switching the power supply between the city electrical system and the solar power system [30]. The main aim is to construct a stabled, completed and low cost of solar energy conversion systems.

Novel photovoltaic converter system was proposed by J. H. R. Enslinan, implementing a new maximum power point tracking technique [31]. The three functions, battery regulation, inverting and maximum-power-point tracking, needed for photovoltaic systems with battery back-up, were integrated in a single cost effective converter. This converter charges the battery, operates close to the maximum power point of the photovoltaic array and forms a dc to ac inverter for a complex power load. The step down charger allows the combination of high-voltage PV arrays with low-voltage batteries. A full description of the circuit and practical measured results with efficiencies were presented.

2.3 Classification based on application
The control strategies in photovoltaic charge control including Maximum Power Point Trackers were presented by V. Salas et al [32]. It has been integrated on a Photovoltaic stand-alone system and has been simulated.

Roger Gules et al presented the analysis, design, and implementation of a parallel connected maximum power point tracking (MPPT) system for stand-alone photovoltaic power generation [33]. The parallel connection of the MPPT system reduces the negative influence of power converter losses in the overall efficiency because only a part of the generated power was processed by the MPPT system. Furthermore, all control algorithms used in the classical series-connected MPPT can be applied to the parallel system. A simple bidirectional dc–dc power converter was proposed for the MPPT implementation and presents the functions of battery charger and step-up converter. The operation characteristics of the proposed circuit were analysed with the implementation of a prototype in a practical application.
A single stage, three-phase three-level neutral point clamped inverter was designed by S. Ozdemir et al [34]. The proposed voltage source was operated in current controlled mode and a PI current controller was used for the production of switching pattern. Phase Locked Loop method was used to operate proposed inverter parallel with grid.

3. Application
L. Schuch, et al proposed an autonomous street lighting system based on solar energy as primary source, batteries as secondary source, and lighting emitting diodes (LEDs) as lighting source [35]. This system is being presented as an alternative for remote localities, like roads and crossroads. Besides, it presents high efficiency, because all power stages were implemented in DC current. The design of LEDs fixture, in order to replace a 70W high pressure sodium (HPS) lamp, was performed. This design takes into account the human eye response in isotopic conditions. LEDs driver and battery charger experimental results were presented. The battery charger presents three control modes: maximum power point tracker (MPPT) mode; constant current mode; and constant voltage mode. The control mode depends on the battery state (charged/discharged), and solar irradiance level. The battery charger input impedance was analysed in order to ensure that the MPPT was obtained for any solar irradiance and panel temperature.

Yi-Hwa Liu proposed a maximum-power-point tracking (MPPT) battery charger [36]. The maximum power point of PV power generation system depends on array temperature and solar insolation. Therefore, a digital controller was required to implement the MPPT algorithm. In this paper, the maximum power tracking algorithm was implemented based on a PIC16F877 microcontroller. In addition to the MPPT algorithm, a PV mathematical model was presented in this paper. Detailed description about the design and implementation of the proposed battery charger was also discussed. Simulation and experimental results demonstrate the effectiveness and validity of the proposed system.

4. Conclusion
The Pros and cons of the MPPT algorithms can be seen in table 1. It is noted that perturb and observe and incremental conductance is superior to all other MPPT algorithms. Though fuzzy and neural networks are developing in the present days, the efficiency remains high in perturb and observe and Incremental conductance methods. The converters such as buck, boost, buck-boost, cuk converters are being used in MPPT systems. PWM inverters are used for grid interconnection and standalone AC loads. The selection of converters is based on the load connected to the system. The ripples in dc voltage and current also influences the selection of converters. With the above mentioned converters and MPPT algorithms, solar panels can be configured to feed any kind of load. The vast development in improving efficiency of MPPT algorithms can encourage domestic generation of power using solar panels.
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