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Review of Maximum Power Point Tracking: History, Developments and Challenges

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ABSTRACT: In photovoltaic (PV) system applications, it is very important to design a system for operating of the solar cells (SCs) under best conditions and highest efficiency. Maximum power point (MPP) varies depending on the angle of sunlight on the surface of the panel and cell temperature. Hence, the operating point of the load is not always MPP of PV system. Therefore, in order to supply reliable energy to the load, PV systems are designed to include more than the required number of modules. In this study, the various aspects of these algorithms have been analyzed in detail. Classifications, definitions, and basic equations of the most widely used MPPT technologies are given. Moreover, a comparison was made in the conclusion.

Keywords : Photovoltaic (PV), Maximum power point tracking (MPPT).

I. INTRODUCTION

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that "physically moves" the modules to make them point more directly at the sun.

MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Additional power harvested from the modules is then made available as increased battery charge current. In the diagram below the curve is an example of the standard output expected from a solar cell, the Maximum Power Point is at the position marked on the diagram. The principle is that if the output from the cell can be regulated to the voltage and current levels needed to achieve a power output at this point, then the power generated by the solar cell will be used most efficiently. This is done using a Maximum Power Point Tracking solar regulator which will simulate the load required by the solar panel to achieve the maximum power from the cell. The regulator will work out at which point the cell will output the maximum power and derive from this the voltage and current outputs required for maximum power to be achieved.

It will then calculate the load that it must simulate based on these voltage and current levels, shown as equation no. (i).

$$R=V/I. \qquad \text{(i)}$$

The regulator, now receiving the maximum amount of power in, will then regulate the output according to what it is designed for. MPPT ensures to get the most power possible from your solar panels at any point in time, particularly during low light level conditions. During low light level situations it will compensate for the low light level and find the new point at which the solar cell delivers its maximum power output [1].

II. HISTORY OF SOLAR PHOTOVOLTAIC

The photovoltaic effect is discovered and first time the usage of sun to generate electricity is considered [3]. Famous French scientist Edmond Becquerel experimented to generate electricity with electrolytic cells when exposed to light. Becquerel generated voltage and current by placing silver chloride in an acidic solution.

The idea for a photovoltaic cell is born when London professor Adams and his student Richard Evans Day witness the photovoltaic effect when electrical current was produced by exposing selenium to light.

First working selenium cell invented by American inventor Charles Fritts. He coated selenium with a thin layer of gold. The efficiency of this first functioning solar cell was 1%., and the high material cost of cells restricted the wide scale adoption.

Theory of photo electricity developed by Albert Einstein. Einstein describes "light quanta" in which he described that light contained packets of energy .Quanta today are known as photons.

Einstein's theory helped understanding about how photons, when properly connected in a circuit, could generate electricity. He won the Nobel Prize in Physics in 1921 for "his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect."

Scientists at Bell Labs, USA develops first silicon PV cell, reaching at 6% efficiency with this. This is the first time enough of the sun's energy is converted to run electrical equipment. Mass production of solar cells begins, bringing solar practicality down from space shuttles and satellites for the general public. Dr. Elliot Berman, with funding from Exxon, designs a cheaper solar panel, and down the price from $100 per watt to $20 per watt. Berman found that using one crystal silicon rather than multiple crystals is cheaper, but at the loss of efficiency. Solar Energy Industries Association (SEIA) formed in USA, working to promote, develop and implement the use of solar energy. The U.S. Department of Energy launches the Solar Energy Research Institute, which later came to known as the National Renewable Energy Laboratory (NREL), for research and development projects.

ARCO Solar becomes the first panel manufacturer for generating 1 MW/ year production. After two years, the solar company installs the first megawatt-scale solar project in California. ARCO Solar releases the world's first commercial thin-film power module (made of amorphous silicon). University of South Florida hits 15.9% efficiency, using cadmium telluride thin-film. The first flexible thin-film product labeled as a solar shingle for BIPV use is invented by Subhendu Guha.

Total installed capacity (solar PV) worldwide crosses 1 GW. Country wise USA attains potential of 1GW (2008) and 25 GW (2015). World's largest PV manufacturing plant "First Solar" started in Perrysburg, Ohio having capacity of producing solar panels sufficient enough to generate 100 MW annually. It, however could reach up to 25 MW per year by 2005. Solar panels were deployed at International Space Station consisting largest solar power arrays in space so far.

UK-based British Petroleum (BP) and BP solar open the First full-service fueling / service station "BP Connect" with a solar - electric canopy over the pump in Indianapolis. This canopy was built with translucent PV modules produced by BP and helped the realization of concepts of solar carpets / canopies practically. The modules were built using thin films of Silicon deposited on glass.

USA based Powerlight Corporation installs USA's largest rooftop solar power system with installed capacity of 1.18 MW, on the roof of Santa Rita Jail, California. The plant almost catered to jail's approximately 30% daytime needs and resulted savings to tune of $400,000.

NABCEP (North American Board of Certified Energy Practitioners) founded in 2002 which is widely recognized national certification organization for professionals in the field of renewable energy. NABCEP offers credentials for skilled professionals, specialists and those new to working in the areas of photovoltaics, solar heating and small wind technologies. The first NABCEP Solar PV Installer certification exam (now called PV Installation Professional) was administered in 2003. The Solar Power Conference and Expo (later to be called Solar Power International) holds its inaugural event in San Francisco.

The Energy Policy Act of 2005 passed by United states made provision of 30% federal investment tax credit (ITC) for residential and commercial solar energy systems. The credit is extended in 2006, 2008 and 2015. Nanosolar starts selling the first commercialized CIGS thin-film modules at $0.99 cents / W which was much lesser than market price. World's first commercially successful Micro inverter system for the solar industry released by Enphase, California.

US Department of Energy's Solar Energy Technologies Office (SETO) launches Sun Shot Initiative in order to make solar energy affordable for all and sets a goal for solar energy to become market-competitive with traditional forms of electricity by 2020.

The International Solar Alliance (ISA) was unveiled by Prime Minister Narendra Modi and then French President Francois Hollande at the U.N. Climate Change Conference in Paris on November 30, 2015. The idea was to form a coalition of solar resource-rich countries mostly located between the Tropics of Cancer and Capricorn (as this is the region worldwide with a surplus of bright sunlight for most of the year) to collaborate on addressing the identified gaps in their energy requirements through a common approach. Towards this, the ISA has set a target of 1 TW of solar energy by 2030. The ISA is the first international body that will have a secretariat in India. India, with a target to produce 100 GW of solar energy by 2022, would account for a tenth of ISA's goal.

The U.S. residential solar market installs over 2 GW in one year for the first time. The total U.S. installed solar capacity exceeds 20 GW. Google launches Project Sunroof, which uses Google Earth imagery to analyze roofs and local weather patterns to create quick solar plans for homeowners.

In April 2016, the United States installs its one-millionth solar PV array. We're expected to reach 2 million by 2018. A new megawatt of solar PV came online every 36 minutes in 2016.

Energy Storage Summit, 26-27 Feb 2019, Victoria park plaza - London, UK. International Solar Alliance Meet at Delhi, March 2018 [2-3].

III. REVIEW OF MPPT ALGORITHMS

The three most common MPPT algorithms are:[4],[5]

A. Perturbation and observation (P&O)

This algorithm perturbs the operating voltage to ensure maximum power. While there are several advanced and more optimized variants of this algorithm. The most commonly used MPPT algorithm is P&O method. This algorithm uses simple feedback arrangement and little measured parameters. In this approach, the module voltage is periodically given a perturbation and the corresponding output power is compared with that at the previous. This algorithm uses simple feedback arrangement and little measured parameters. a basic P&O MPPT algorithm is shown as Fig. 1[6-7].

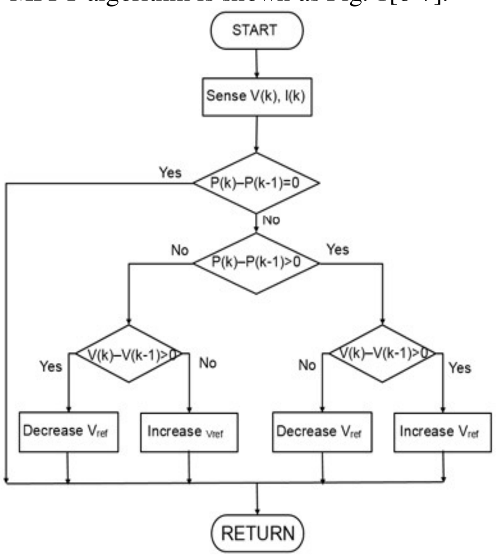

Fig. 1. A basic P&O MPPT algorithm

B. Incremental conductance

This algorithm, shown as Fig. 2, compares the incremental conductance to the instantaneous conductance in a PV system. Depending on the result, it increases or decreases the voltage until the maximum power point (MPP) is reached. Unlike with the P&O algorithm, the voltage remains constant once MPP is reached [8-9].

C. Fractional open - circuit voltage

This algorithm is based on the principle that the maximum power point voltage is always a constant fraction of the open circuit voltage. The open circuit voltage of the cells in the photovoltaic array is measured and used as in input to the controller.

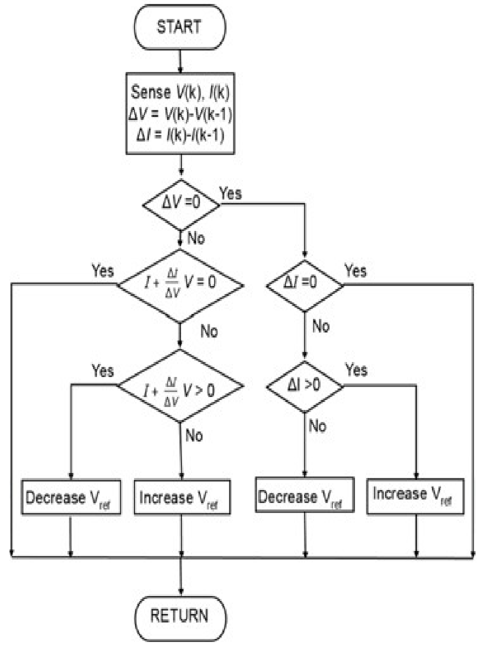

Fig. 2. Comparison the incremental conductance to the instantaneous conductance in a PV system.

MATLAB® and Simulink® can be used as platforms to implement these algorithms [10-11].

IV. IMPROVEMENT IN MPPT

The improvement in tracking performance of a SPV module using neural network (NN) controller under fast changing environmental condition. The tracking performance of NN controller is compared with conventional perturb and observe (P&O) MPPT controller. The slow tracking of P&O and wrong tracking during changing weather condition is eliminated using NN controller. The large drooping characteristic of P&O under fall of irradiation is also eliminated. The result is verified using MATLAB-Simulink software package under fast changing irradiation and temperature.

Under rapid fall of irradiation there is drooping characteristics seen in P&O method. Neural network (NN) MPPT is proposed to eliminate the above short comings of P&O method. NN have self-adapting capabilities which can handle nonlinearities, uncertainties and parameter variation with great accuracy. This paper proposes back propagation NN controller to track the maximum power point of the SPV system with rapid change of irradiation [12-13].

Table 1 presents MPPT techniques comparison on several parameters [9].

Table 1: MPPT techniques comparison on several parameters.

Comparison parameters	**MPPT Algorithms**					
	Perturb & observe	Modified P&O	Artificial intelligence	Constant voltage (current)	Parasitic capacity	Incremental conductance
Efficiency (%)	81.5–85	93–96	>95	88–89.9	99.8	73–85
PV Panel depending operation	No	No	Yes	Yes	No	No
Exactly MPP determination	Yes	Yes	Yes	No	Yes	Yes
Convergence speed	Varies	Fast	Fast	Medium	Fast	Varies
Analog or digital control	Both	Digital	Both	Analog	Analog	Digital
Periodic tuning requirement	No	No	No	Yes	No	No
Complexity	Low	Medium	High	Low	Low	Medium
Measured parameters	Voltage, current	Voltage, current	Varies	Voltage (current)	Voltage, current	Voltage, current

V. CONCLUSION

As discussed in paper that solar power is abundantly available and many improvements have taken place in technology to extract solar power and making it available for general use economically. Using MPPT method we can collect the maximum solar energy at the terminal end. Various MMPT techniques were discussed and compared on various parameters. Each technique is individually suited to meet specific conditions. However artificial intelligence method is gaining popularity and is most commonly used nowadays.

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