

# Solar Photovoltaic Power with Control Strategies and Applications: A Review

Vikas Sharma<sup>1</sup>, Gagandeep Khajuria<sup>2</sup>

<sup>1</sup>Department of Electrical Engineering, MBSCET, Jammu, India  
Email: vikas35127@gmail.com

<sup>2</sup>Department of Electrical Engineering, MBSCET, Jammu, India  
Email: gagan64064@gmail.com

**Abstract**—Growing concerns about environment issues, photovoltaic (PV) power is widely gaining importance all over the world. Use of this solar electric power is increasing day by day in many countries. This paper presents a review on applications of solar photovoltaic power for domestic purposes, irrigation purposes as well as for the grid purposes. Solar photovoltaic (PV) system works under variable solar irradiations and thus various control strategies to utilize this solar power in an efficient manner are also reviewed in this paper.

**Keywords**— Solar PV Array, Induction Motors (IM), MPPT, Grid, Efficiency.

## I. INTRODUCTION

Environment issue is a major problem in the present time. The major portion of problem arises from the use of nonrenewable resources especially coal, diesel etc. in order to cope for the energy demand. Furthermore the increase in the population and alarming use of these resources, the non-renewable energy resources which are available to us are going to get extinguish which is a major cause of concern. Due to extinguishing of these non-renewable resources, energy problems are going to be more and more serious. In order to overcome this problem, the use of renewable energy resources especially solar photovoltaic (PV) has become more and more popular. Solar energy is one of the most promising candidates available to us in plentiful amount and is going to be widely accepted by all. The annual photovoltaic (PV) power generation is currently around 37 TWh in 2010, it is estimated to be reached to 1247 TWh by 2030, 2907 TWh in 2040 and to 4572 TWh by 2050 [1] as shown below in bar graph form.

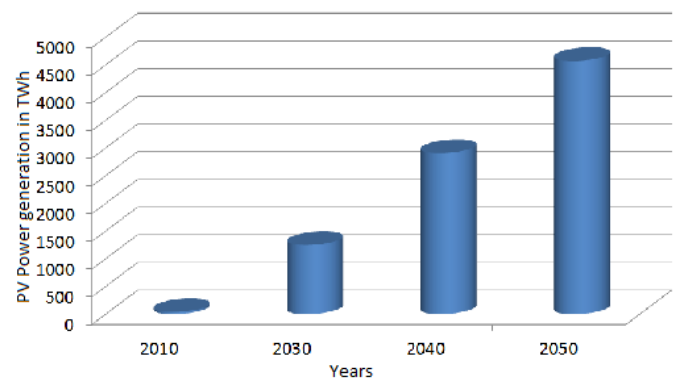


Fig.1 Showing PV power generation scenario in the world by International Energy Agency (IEA).

The cumulative installed PV capacity that was around 27 GW in 2010 had raised up to 30.4 GW in 2011 and 31.1 GW in 2012 and now it is expected to rise 872 GW by 2030 and 3155 GW by 2050, while this value was around 3.145 GW in 2003 as shown below in bar graph form [2].

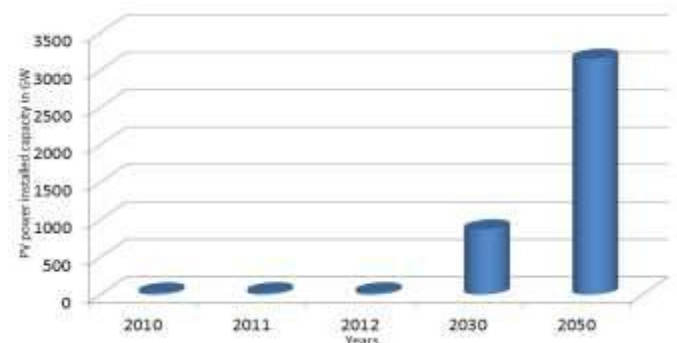


Fig.2 PV installed capacity scenario in the world by European PV Industry Association (EPIA).

The advantage of using the photovoltaic (PV) solar energy is that it is free and produces no greenhouse gases. Traditionally photovoltaic array were used for lighting, pumping and ventilation purposes because motors used for (pumping and ventilation) such purposes were the DC motors and the power generated was also DC, thus no conversion was required. Therefore major work was done

to improve the photovoltaic (PV) array output characteristics. But with the advancement in the AC induction motors (IM) the use of DC motor becomes less, because of IM reliability and maintenance free operation. Whereas the DC motors have brushes and commutator which requires proper maintenance after regular time period [3-4]. Due to numerous advantages of induction motors over DC motors these are widely used for different purposes in industrial, residential and agricultural such as water pumping, lifting, cooling, etc. Besides of these advantages of induction motor (IM), using the photovoltaic generated power for the pumping system led to the inefficient operation of the Induction motor, because the solar radiation and the temperature do not remains the same throughout the day and varies with the direction of the sun. Due to this, there occur the power imbalance between the power generated and the load and hence give rise to the inefficient operation of the machine. Many control strategies are employed by researchers to control the motor operation under changing solar irradiations.

Besides the applications of the PV array with motors, these are now also used in grid connected mode and are also integrated with other power generation sources so that power demand can be overcome and carbon emission can be reduced. In this paper the work done by different researchers is reviewed keeping in view the application of solar PV generation in:

(i). Isolated grid mode

(ii). Grid connected mode. Especially feeding DC/AC motor load. These are described below one by one.

## II. ISOLATED GRID MODE

Isolated grid mode application of PV array was used about 54 years ago since the first operational silicon cell was demonstrated [5]. In this mode PV arrays were not connected to the grid and supply power directly to the load. Isolated grid application of the PV array was used to supply power to residential/village loads, DC/AC motors load for pumping, cooling etc. Handling such load connected with isolated grid mode was very tough and requires proper knowledge of handling such load with variable solar irradiations. Thus many researches in this field have started to handle such problems. [6] Had proposed the efficient operation of the PV array connected with the residential load and hence found that efficient operation can be achieved. A.M. Sharaf et al. in [7] had also proposed a scheme to track the maximum photovoltaic solar energy and maximum energy utilization scheme to cope with the varying resistive load and the solar radiation under standalone mode. The various other applications of PV power and control techniques of different researchers in standalone mode are discussed below:

### 2.1. Solar PV Array Applications for DC Motors

First DC motor was invented by the British scientist William Sturgeon in 1832. With this invention many researchers started their work that how to improve characteristics, application etc of DC motors. Later on first practical DC motor was invented by Frank Julian Sprague in 1886 which work with constant speed under variable loads [8]. With the advancement in technologies these motors were used for different application such as cooling, pumping traction etc. Among these applications PV water pumping system was used by many countries since 1977 [9]. Earlier motors used for pumping were supplied with constant voltage source. But later on with the advancement of renewable resources such as solar photovoltaic (PV) these motors were also fed from variable voltage source. These variable voltage sources give rise to the inefficient operation of the DC motors. Thus in order to operate the DC motors efficiently many control techniques were introduced by the researchers. [10-11] observed that the efficiency of separately excited DC motor when fed from solar PV array was increased from 29% to 75% when armature winding control and field winding control were applied. With the advancement in research field of the photovoltaic (PV) power generation, [12-13] had observed that smooth operation of the DC motor can be achieved with the use of DC-DC converter, thus protecting the motor from higher currents and voltages. Later on, it was observed that output power of the DC motor can be increased by proper selecting the parameters of the DC motor's magnetization characteristics and hence it was formulated that improved matching between PV array and DC motor can be achieved without any interfacing unit between them [14-15].

### 2.2. Solar PV Array Application for A.C Induction Motors

In the earlier period DC motors were generally connected to the PV array for many applications because they use the DC power and need not any conversion i.e. from DC to AC. However use of DC motors has some disadvantages as it require regular maintenance. Also the DC motors were very costly [16]. On the other hand, use of induction motors has increased tremendously after its invention in 1885 [8]. Reason of its popularity can be because of its simplicity in design, cost effectiveness and robust construction. Furthermore these motors are more reliable than dc motors. Beyond these advantages, if induction motors are supplied from normal supply, they work with maximum efficiency but if the same motor is supplied from the PV array its operation becomes inefficient [17-18]. Thus in order to operate the motor efficiently with variable power source many techniques and methods were suggested by researchers.

The induction motor connected to variable power source PV system does not work at its maximum efficiency. This problem was overcome by [19] in which a control method was introduced. In this method, frequency of the inverter PWM control signal was adjusted according to the change in the solar irradiation and temperature. This method proved to be efficient because efficiency and operation of the induction motor was improved. Later on another method was introduced by [20] in which it was observed that the efficient operation of the induction motor can be achieved by the vector control method. In this method torque and the flux producing component of the motor was controlled. This work was carried out with the help of the digital chip signal processing. Furthermore with the advancement in solar technology, [21] had showed a new random inverter control technique for the motor drive application. This technique works on randomizing the inverter switching frequency without invoking any modification to the sampling and modulation. In this research work, experimental results derived from a microprocessor-based experimental drive system were presented to confirm the theoretical analysis. This technique shows that the calculations required for high switching frequency control, in comparison with the conventional space vector modulation technique can be reduced.

The various control strategies described above, help in achieving the efficient operation of the induction motor but also there are some control strategies which are cost effective and energy efficient in controlling induction motor. The method mostly used to achieve the efficient operation of induction motor generally use maximum power point tracking technique (MPPT) to track maximum power output of PV array [22-25]. In the conventional PV connected induction motor generally a DC-DC boost converter was used to boost up the voltage up to the desired limit. This technique however led to the cost inefficient operation. In order to overcome this problem [25] had proposed a technique in which DC-DC converter is eliminated from the circuit. In this control strategy output parameters of the PV array were used to trigger the inverter gates.

and IM was operated at maximum efficiency by optimizing the array terminal parameters by using genetic algorithm. In this technique it was proposed that for 100% isolation, dc link voltage obtain is about 360 volts and frequency obtained from equation is 58 Hz. Similarly for 80% isolation DC voltage is about 310 volts and corresponding frequency is about 54 Hz. From the above it was concluded that PV array feeding induction motor without boost converter led to the inefficient operation as proposed by M.A Elgendy et al. [27] although it reduces the number of switching circuit. For constant torque and speed control the efficient power utilization methods described

above were not utilizing the PV array output power efficiently. However some methods which were using these methods show some transient response. In order to overcome the problem of power matching between the load and the PV array [28] had introduced a speed controller method in which power change give rise to the change in speed of the induction motors. This control strategy was designed for constant head constant torque load. In this, as the load torque is constant then the load power will depend only on the speed of the induction motor. Thus the power mismatch between the load and the generated power give rise to the control strategy.

### III. SOLAR PV ARRAY GRID CONNECTED MODE

Solar panel used in the ancient time were of small rating and are used for small load. Furthermore these panels were very much costly which ultimately led to uneconomical operation. But now with the advancement in the field of solar technology these panels cost has declined with a high rate. And now in the present time photovoltaic power is widely used in almost all over the world. PV power generation has increased from few watts to many kilowatt rating. Due to this increase in power generation PV array are now connected to the grid in order to overcome the energy demand. In present time PV panels are available in higher rating and are of good quality which can operate for many years without any problem. Cost of the PV modules and the inverter used to connect with the grid has significantly decreased [29]. In this system power can flow in both forward as well as in reverse direction.

The main equipment of the PV array connected to the grid were: PV array, DC-DC boost converter with controller attached to it, DC-AC converter with a controller attached to it, filters to remove harmonics, transformer and the grid system [30]. In grid connected PV array, many problems related to the transfer of power occurs. In order to overcome such type of problem generally two converters were used. First converter was used to track the maximum power point (MPP) which was triggered by the maximum power point controller algorithm. This controller tracks the maximum power point of the PV array. Second converter is a DC-AC converter which was used to convert the DC power into AC power which was the form required by the grid. In grid connected system many algorithms were used to track the maximum power point of the array such as incremental conductance algorithm, P&O algorithm, Hill climbing, Fuzzy logic etc. each of these methods has its own advantages and disadvantages as described by [31-32]. Now presently research is going on to extract the maximum power from the PV. [33] Had presented a reconfiguration strategy. In this strategy efficient operation of the array was obtained by inserting a switching matrix

between the inverter and the PV generator. The main advantage of the electric array reconfiguration (EAR) technique was that it offer greater output as compared to the PV system having static configuration but this system also led to the disadvantage that it led to large complexity and cost[34]. On the other hand, it was also presented by many researchers that inverter triggering can be used to transfer the power in the most efficient way. Certain methods were being employed such as Adaptive current hysteresis band control scheme [35], vector control techniques, Line commutated inverter [36]etc. With the advancement in PV array, these were also integrated with the other generation sources such as Diesel power plant, Wind power plant in order to overcome the problem of load demand and to reduce the carbon emission into the atmosphere with suitable integration and to reduce the cost of the power[37],[38-39] had employed a variable speed control technique for wind turbine whereas MPPT was employed for the PV system and dynamic and control performance of wind/PV system was simulated. Later on with the advancement in the field of solar power, introduction of induction motor connected to the grid system was introduced. In this system, a single inverter was used which can draw the power either from the single phase ac supply coming from the grid or from the solar energy input coming from the panels. [40] Had proposed that bidirectional flow of power can be achieved by adding an inductor in one phase of the inverter, thus making a phase difference between two wave forms. Also in this research power flow and output voltage regulation had been presented and it was seen that theory and result match each other.

#### IV. CONCLUSION

Solar energy is in abundant form available to us and can be used in different applications with the most efficient ways. This source of energy can play great role in the upcoming time as power demand is going to increase with the increase in population and with the depletion of the non-renewable resources. This PV power can be used for domestic purposes as well as for the industrial purposes depending upon the requirement. As from the above it becomes clear that in future PV power generation can overcome our power demand. Special control strategies can help us in achieving our goals in power sectors especially with the PV power.

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