CHAPTER 2

LITERATURE SURVEY

Global warming and energy policies have become a hot topic on the international agenda in the last years. Developed countries are trying to reduce their greenhouse gas emissions. For example, the European union has committed to reduce their greenhouse gas to at least 20% below 1990 levels and to produce no less than 20% of its energy consumption from renewable sources by 2020 [1]. In this context, photovoltaic (PV) power generation has an important role to play due to the fact that it is a green source. The only emissions associated with PV power generation are those from the production of its components. After their installation they generate electricity from the solar irradiation without emitting greenhouse gases. In their life time, PV panels produce more energy than that for their manufacturing [119]. Also, they can be installed in places with no other use, such as roofs and deserts. They can produce electricity for remote locations, where there is no electricity network. The latter type of installations is known as off-grid facilities and sometimes they are the most economical alternative to provide electricity in isolated areas. However, most of the PV power generation comes from grid-connected installations, where the power is fed in the electricity network. In fact, it is a growing business in developed countries such as Germany which is world leader in PV power generation followed by Spain, Japan, USA and Italy [134]. On the other hand, due to the equipment required, PV power generation is more expensive than other resources. Governments are promoting it with subsidies or feed-in tariffs, expecting the development of the technology so that in the near future it will become competitive [134, 130]. Increasing the efficiency in PV plants so as to increase the power generated is a key aspect, as it will increase
the incomes, reducing the cost of the power generated, cost approaching the cost of the power produced from other sources.

Solar cells are the basic components of photovoltaic panels. Most are made from silicon even though other materials are also used. Solar cells take advantage of the photoelectric effect: the ability of some semiconductors to convert electromagnetic radiation directly into electrical current. The charged particles generated by the incident radiation are separated conveniently to create an electrical current by an appropriate design of the structure of the solar cell [130].

The use of efficient photovoltaic solar cells has emerged as an important solution in energy conservation and demand side management. Owing to their initial high costs, they have not been an attractive alternative for users who are able to buy cheaper electrical energy from the utility grid. However, they have been extensively used in pumping and air conditioning in remote and isolated areas where utility power is not available or too expensive to transport. Although solar cell prices have decreased considerably during the last years due to new developments in the film technology and the manufacturing process [130], PV arrays are still considered rather expensive compared with the utility fossil fuel generated electricity prices.

After building such an expensive renewable energy system, the PV array has to be operated at its highest conversion efficiency by continuously utilizing the maximum available output of the array. The electrical system powered by solar cells requires special design considerations because of the varying nature of the solar power generated resulting from unpredictable changes in weather conditions which affect the solar radiation level as well as the cell operating temperature.

The efficiency of a PV plant is affected mainly by three factors: the efficiency of the PV panel (in commercial PV panels it is between 8-15\% [134]), the efficiency of
the inverter (95-98 % [132]) and the efficiency of the maximum power point tracking algorithm (which is over 98% [128]). Improving the efficiency of the PV panel and that of the inverter is not easy as it depends on the technology available. It may require better components, which can increase drastically the cost of the installation [129]. Instead, improving the tracking of the maximum power point with new control algorithms is easier, not expensive and can be done even in plants which are already in use by updating their control algorithms, which would lead to an immediate increase in PV power generation and consequently a reduction in its price.

MPPT algorithms are necessary because PV arrays have a non linear voltage-current characteristic with a unique point where the power produced is maximum [53]. This point depends on the temperature of the panels and on the irradiance conditions. Both conditions change during the day and are also different depending on the season of the year. Furthermore, irradiation can change rapidly due to changing atmospheric conditions such as clouds. It is very important to track the MPP accurately under all possible conditions so that the maximum available power is always obtained. In the past years numerous MPPT algorithms have been published [97]. They differ in many aspects such as complexity, sensors required, cost or efficiency. However, it is pointless to use a more expensive or more complicated method if with a simpler and less expensive method, similar results can be obtained.

In practice, the voltage dependency on the irradiation is often neglected. As the effect on both the current and voltage is positive, i.e. both increase when the irradiation rises, the effect on the power is also positive. More the irradiation, the more power is generated. PV panel manufacturers provide in their data sheets the temperature coefficients, which are the parameters that specify how the open circuit voltage, the short circuit current and the maximum power vary when the temperature
changes. As the effect of the temperature on the current is really small, it is usually
neglected [26].

One of the first descriptions of a MPPT system had been published when
A.F.Boehrinfer and J.Hausmann described a self adaptive DC converter for spacecraft
power supply. It was the beginning of the huge development of the domain [8]. A
bread board verification has been done with energy transfer in the 50W range using
hill climbing algorithm clubbed with bidirectional current mode power cell.

Salameh and Dagher [7] have proposed a switching system that changes the cell
array topology and connections or the configurations of the cells to get the required
voltage during different periods of a day.

Maheshappa et al [19] stated that if there is no battery present in the system, in
order to tie the bus voltage at a nearly constant level, a simple control can be applied.

Mohammad A. S. Masoum, Hooman Dehbonei, and Ewald F. Fuchs [37] felt that
the boost converter is shown to have a slight advantage over the buck converter
particularly at low light levels.

Weichen et al [98] used PV system with storage batteries, as a MPPT device to
enhance battery charging. The enhancement must be greater than the internal loss of
the device itself. MPPT device under different climatic conditions of Beijing and
Gaungzhan in china was considered.

Kenj Kobayashi [84] found that a PV array alone had relatively low output power
density and had greatly drooping I-V characteristics. Therefore MPPT was used. This
control concept was done by simulation study using PSM and Labview software.

Jensak Eakburanawat [80] studied a TE battery that uses waste heat and described
a battery charger which was powered by TE power modules.
V. Salas et al [89] reviewed the MPPT methods in terms of Quasi seeking methods which include wave filtering method, backup table method etc and true seeking methods including sampling methods, differentiation method etc.

Weidong Xiao [58] discussed a modified hill climbing MPPT technique for PV system installed as a test bench using TMS320LF2407 controller for automatic testing mechanism.

A solar cell is a semiconductor device that absorbs sunlight and converts it into electrical energy. Today's most common cell is a mass manufactured single p-n junction Silicon cell with efficiency up to about 17% [12]. Since 1973, the word energy has been continuously in the news. There has been shortage of oil in many parts of the world and the price of this commodity has increased steeply. It is clear that the fossil fuel era of non-renewable resources is gradually coming to an end. Oil and natural gas will be depleted first, followed eventually by coal. In India the energy problem is very serious. In spite of discoveries of oil and gas off the west coast, the import of crude oil continues to increase and the price paid for it dominates all other expenditure. This amount forms a major part of India’s import bill. The need for developing energy alternatives is thus evident and considerable research and development work is already in progress in this direction. One of the promising options is to make more extensive use of renewable sources of energy derived from the sun. Solar energy can be used both directly and indirectly. It can be used directly in a variety of thermal applications like heating water or air, drying, distillation and cooking. A second way in which solar energy can be used indirectly is through the photovoltaic effect in which it is converted to electrical energy [33]. Use of photovoltaic technology to generate electricity is increasing world-wide. Over the past two decades PV has become well established in remote area power supply, where it
can be the most cost-effective choice. PV is also becoming more common in grid connected applications, motivated by concerns about the contribution of fossil fuel use to the enhanced greenhouse effect and other environmental issues. In designing any power generation system that incorporates photovoltaic, there is a basic requirement to accurately estimate the output from the proposed PV array under operating conditions. Good system design is essential to provide reliable systems. An appropriately sized PV array enables consumers, especially of remote area systems, to receive a reliable energy supply at a reasonable cost. It is known that different PV technologies have different seasonal patterns of behavior. These differences are due to the variation in spectral response, the different temperature coefficients of voltage and current and in the case of amorphous silicon modules, the extra effect of photo degradation and thermal annealing. However, PV modules are rated at standard test conditions of 1000 W/m² and a module temperature of 25°C and these conditions do not represent what is typically experienced under outdoor operation. Good system design assists in promoting the renewable energy industry. The increased use of PV, in turn, assists in attaining environmental goals [12].

In recent years, there has been an increasing interest in electrical power generation from renewable energy sources such as PV, wind power systems [82, 47]. The benefits of power generation from these sources are widely accepted. They are essentially inexhaustible and environmentally friendly. Among the different renewable energy sources possible to obtain electricity, solar energy had been one of the most active research areas, both for grid connected and stand-alone applications [77, 100, 99, 90, 87, 81, 112]. The installed PV power had been increasing and a more significant increase is expected, owing to the potential advances in the PV conversion technology and the reduction in cost per watt that a large scale production will bring
about [71]. The exponential rate of growth in the cumulative PV capacity is mainly
due to grid connected applications. According to the reports from the International
Energy Agency on Photovoltaic Power Systems, 90% of PV cumulative capacity
belongs to grid connected systems [95].

Byunggyu Yu, Gwonjong Yu, Youngroc Kim [136] presented the design and
experimental results of improved dynamic MPPT performance using P&O MPPT
method which was evaluated by European Standard EN 50530. Performance of P&O
method was evaluated using 250 KW PV inverter. It was shown that P&O method
shows high dynamic MPPT efficiency under EN 50530.

G.M.S. Azevedo [105] presented a study of two maximum power point tracking
methods for grid connected photovoltaic systems. The best operating conditions of the
perturbation and observation and the incremental conductance were investigated to
identify the performances of photovoltaic systems.

N.Femia et al [52, 54] discussed the customization of duty cycle perturbations to
the dynamic behaviour of the boost converter to realize P&O MPPT. They had shown
that the P&O parameters must be customized to the dynamic behaviour of the specific
converter adopted. A theoretical analysis allowing the optimal choice of such
parameter was carried out and was experimentally verified.

Xuejun liu et al [60] discussed IP&O method and the control scheme was
implemented in a DSP on a Siemens SM110 module.

Youngseok Jung [74] proposed IP&O method and implemented the method on
the high precision PV array simulator and 3KW grid connected PV inverter. It was
found that IP&O increases the total power output by 0.5% at an unsettled weather
condition.
A. Tariq, J. Asghar [62] constructed a simple and cheap MPPT. The algorithm was based on the fact that the MPP voltage is a fixed percentage of the open circuit voltage of the PV panel. An unloaded pilot PV panel with characteristics similar to those of the main PV panel and installed under similar conditions was used to measure the open circuit voltage.

Hussein K.H. [11] developed an MPT algorithm based on the fact that the maximum power operating point of a PV generator can be tracked by comparing the incremental and instantaneous conductances of the PV array.

T.Kawamura et al [17] described characteristics evaluation of the power conditioner which has the function of MPPT, by mountain climbing method through computer simulations.

Martina Calais [20] described an algorithm which required the analysis of the phase relationship between the DC voltage and DC power ripple to determine the maximum power point.

Eftichios Koutroulis [27] developed a MPPT method that used the output power to control the DC-DC converter directly.

Logue D.L., Krein P.T. [29] demonstrated how an analytical point of view on ripple correlation control was formulated by recasting the method in a dynamic programming framework. The method took the advantage of small signal ac information contained within the ripple signals to generate localized gradient information. This information was used by the control loop to move the operating point to optimal condition.

Xiafenq Sun, Weiyang Wu, Xin Li, Oinglin Zhao [42] introduced a photovoltaic energy system controlled by a dc-dc converter and a single phase bi-directional PWM converter to realize the inversion. A current controlling method of tracking the
maximum power point and forcing the system to operate close to this point was used. An artificial neural network was used in the MPPT system and its robustness and insensitivity the intermittent weather conditions was enhanced. UC 3854 was used as an inversion current controller.

Eugene V.Solodovnik, Shengyi Liu and Roger A.Dougal [46] presented a state based approach to the design of a MPP tracking system. The controller was able to track the time varying MPP reference point and to reject static load disturbances.

G.J.Yu et al [48] investigated thoroughly the effectiveness of three different control algorithms via simulation and proposed the method of experimentation on a 3KW power generation system.

S. Jain, V. Agarwal [57] presented a new fast tracking algorithm for tracking maximum power point in photovoltaic systems. An initial approximation of maximum power point was quickly achieved using a variable step size. Subsequently, the exact maximum power point was targeted using a conventional method. The strength of the algorithm came from the fact that instead of tracking power, which does not have one to one relationship with duty cycle, it tracked an intermediate variable which had a monotonically increasing one to one relationship. The algorithm was verified on a photovoltaic system modeled in Matlab Simulink software.

Weidong Xiao, William G Dunford [59] developed an experimental evaluation method to test the performance of tracking using photovoltaic modules and low cost artificial lights.

D. Shmilovitz [63] proposed that photovoltaic maximum power point tracking can be accomplished by monitoring the readings of the load parameters instead of the photovoltaic panel output parameters.
Gow J.A., Manning C.D. [65] proposed a maximum power point tracking algorithm for single stage converters connecting photovoltaic panels to a single-phase grid. The algorithm was based on the processing of current and voltage low frequency oscillations introduced in the PV panels by the single-phase utility grid. The algorithm was developed to allow an array of PV modules connected to the grid by a single-stage converter, yielding higher efficiency. The proposed numerical algorithm had been numerically simulated and experimentally verified by means of a converter prototype connected to a single-phase grid.

Shimolvitz D presented [72] a new approach for tracking the maximum power point of photovoltaic arrays. The maximum power point tracker output voltage and current were used for control purposes, rather than for its input voltage and current. Using this approach, only one output of the two output variables needed to be sensed. Theoretically it was shown that MPPT control that used a single output control parameter applied to nearly all practical load types regardless of the load nature.

V. Salas et al [73] proposed an algorithm for seeking the maximum power point of a PV array for any temperature and irradiation level using the measurement of the photovoltaic current. The algorithm was simulated and experimented on a 100W, 24V, PV converter prototype model.

Casadei D., Grandi G., Rossi C. [76] presented a maximum power point tracking algorithm for single stage converters connecting photovoltaic panels to a single-phase grid. The algorithm was based on the application of the ripple correlation control. The proposed technique allowed the generation of sinusoidal grid currents with unity power factor. This structure yielded higher efficiency compared with standard solutions based on double stage converter configurations. The proposed algorithm had
been numerically simulated and experimentally verified by means of a converter prototype connected to a single phase grid.

Tarik Duru [78] developed a method to force a photovoltaic generator to operate at its maximum power point under variable load and insolation conditions. An experimental study was made with a 100MHz Pentium PC with a Bytronic IO interface card for data acquisition.

Joung Hu Park et al [83] presented the voltage and current information of two modules shared and utilized for the detection of the maximum power point without measuring power.

Neil S. D’Souza [66, 86] presented an alternative approach based on non switching zones. Implementations of P&O algorithms based on peak current control and on instantaneous sampled values had shown to provide very fast transients and small oscillations around the maximum power point. However, the operation with fixed variation of the reference current resulted in a trade-off between speed of response and maximum power yield in the steady state.

V. Salas et al [88] presented a new algorithm using the current as the only one parameter of measurement. The algorithm was tested on 50W, 12V PV converter prototype without batteries.

Sachin Jain and Vivek Agarwal [96] presented a new MPPT algorithm based on current control for a single stage grid connected photovoltaic system.

Bazzi A.M., Karaki S.H. [102] introduced a new two stage maximum power point tracking technique for multiple photovoltaic arrays operating under different levels of irradiance and temperature. This technique aimed to locate the global maximum power point on the P-I curve of the interconnected arrays thus bypassing any local
maximum that might trap single stage algorithms. A system of two PV arrays, a battery load with the proposed technique were simulated in Simulink.

Jung-Min Kwon, Bong-Hwan Kwon, Kwang-Hee Nam [106] proposed a three phase photovoltaic system with three level boosting maximum power point tracking control using power hysteresis, giving direct duty control for the three level boost converter. The three level boost converter reduced the recovery losses of the diodes. A weighted error PI controller was suggested to control the dc link voltage faster. Experimental results were obtained on a 10KW prototype.

Ortiz Rivera E.I. [109] presented an alternative maximum power point tracking algorithm for a photovoltaic module to produce the maximum power using the optimal duty ratio, for different types of dc-dc converters and load matching. The proposed algorithm had the advantages of maximizing the efficiency of the power utilization, integration to other MPPT algorithms without affecting the performance, was excellent for real time applications, was a robust analytical method. The existence and uniqueness of optimal internal impedance, to transfer the maximum power from a photovoltaic module using load matching was proved.

Often, the PV arrays get shadowed, completely or partially, by the passing clouds, neighboring buildings and towers, trees, and utility and telephone poles. The situation is of particular interest in case of large PV installations such as those used in distributed power generation schemes. Under partially shaded conditions, the PV characteristics get more complex with multiple peaks. Yet, it is very important to understand and predict them in order to extract the maximum possible power. Patel H., Agarwal V. [110] presented a MATLAB based modeling and simulation scheme suitable for studying the I-V and P-V characteristics of a PV array under a nonuniform insolation under partial shading. The proposed models conveniently
interface with the models of power electronic converters. It was observed that for a
given number of PV modules, the array configuration significantly affects the
maximum available power under partially shaded conditions. The model was
experimentally validated and the usefulness was highlighted with the help of several
illustrations.

Riming Shao, Liuchen Chang [111] introduced a new maximum power point
tracking method with the golden section search algorithm for photovoltaic systems.
The PV simulation model was developed in Matlab-Simulink. The proposed method
had the advantage of fast convergence, noise-resistance and robustness.

T. Kerekes et al [115] presented a novel concept for MPPT that was used in the
case of voltage controlled grid connected PV inverters. The concept was based on the
information that at MPP, the power oscillations were very small.

Carannante G. [118] investigated the effects of non uniform solar irradiance
distribution on a PV source. An MPPT algorithm that was able to optimize the source
instantaneous operating power under non uniform irradiance was proposed. The
ability of the algorithm and its increased performance were evaluated by means of
experimental tests performed on a real PV power system.

Kalantari A., Rahamati A., Abrishamifar A. [121] focused on alternatives for
implementing variable size perturbations in peak current controlled perturbation and
observation maximum power point trackers. Implementations of P&O algorithms
based on peak current control and on instantaneous sampled values had shown to
provide very fast transients and small oscillations around the maximum power point.
Operation with fixed variation of the reference current resulted in a tradeoff between
speed of response and maximum power yield in the steady state. Variable variation of
the reference current was done with fuzzy logic. They discussed a fuzzy logic based
P&O MPPT with peak current control with variable variation of the reference current for improved transient and steady state performance.

Mastromauro R.A. [122] presented a single phase PV system that provided grid voltage support and compensation of harmonic distortion at the point of common coupling. The power provided by the PV panels is controlled by a maximum power point algorithm based on the incremental conductance method modified to control the phase of the PV inverter voltage.

Mummadi V. [108] proposed a variable incremental duty ratio algorithm to improve the tracking performance. In this algorithm, duty ratio was high at starting and followed a geometric progression in the subsequent iterations. Proposed concept was verified experimentally.

Jantharamin N., Zhang L. [126] proposed a mathematical model based approach for maximum power point of photovoltaic array which was suitable for small stand-alone photovoltaic systems. The array voltage corresponding to the maximum power point was directly calculated from measurements of irradiance and temperature. The scheme was simple in implementation, low in computation cost and caused no disturbance to the normal system operation.

Tat Luat Nguyen [133] presented a maximum power point tracking approach for a photovoltaic system using the dividing rectangles algorithm. The proposed scheme performance was validated through experimental studies and was found to be robust. This scheme was particularly for partially shaded systems.

Yuncong Jiang, Oahoug [138] focused on developing an MPPT controller suitable for multiple PV panel maximum power points tracking. The output current of the power converter following the solar array was sensed and used as the control variable
in P&O algorithm. The controlled operation was tested and verified experimentally using a proof-of-concept laboratory prototype.

Beck Y et al [103] presented a novel design of photovoltaic grid connected inverter. The design included an H-bridge topology that is switched by the ac grid and hence no special synchronization scheme was required. The inverter was realized so as to attain current source characteristics for simple connectivity to the grid. The system was combined with a maximum power point tracker with only output current control.

Noppadal Khaehintung et al [55] developed an MPPT using fuzzy logic controller. The proposed controller was integrated with a boost converter for realization of a high performance solar powered battery charger.

Kottas T.L., Boutalis Y.S., Karlis A.D. [85] presented a maximum power point tracker using fuzzy set theory to improve energy conversion efficiency. The simulation studies were carried out and the method gave a good maximum power operation of PV array under changing insolation and temperature conditions.

Altas and Sharaf [93] presented a study of standalone photovoltaic energy utilization system feeding hybrid mix of electric loads and is controlled by on-line fuzzy logic based tracking controller under excursion in solar insolation.

A.D. Karlis, T.L. Kottas, Y.S. Boutalis [91] presented a novel MPPT method based on fuzzy cognitive networks which gave a good maximum power operation of any PV array under changing insolation and temperature.

Guphui Zeng, Oizhong Liu [120] presented an intelligent fuzzy method for maximum power point tracking of photovoltaic systems. This method saved memory space and accelerated operation process. The method was validated by experiments using PV arrays, boost converter and single phase grid connected inverter. The
method was simple, fast responding and gave increased output power extracted from PV arrays.

Syafaruddin, Engin Karatepe, Takashi Hiyama [123] presented a novel polar coordinated fuzzy controller based real time maximum power point control for different types of photovoltaic modules. The simulation technique of PV generation system had been realized using Matlab/Simulink. In order to validate the performance, the proposed system had been implemented in dSPACE software and digital signal processor card on personal computer. The proposed system included artificial neural network and fuzzy logic controller scheme using polar information. ANN was utilized to determine the optimum operating voltage for monocrystalline silicon, thin film cadmium telluride and triple junction amorphous silicon solar cells.

G. Balasubramanian, S. Singaravelu [140] presented a fuzzy logic controller for maximum power point tracking in photovoltaic system. A MATLAB based modelling and simulation scheme along with MPPT and fuzzy logic controller was proposed which was suitable for studying the I-V and P-V characteristics of a PV array under a non-uniform irradiation and different temperatures.

Zhang L., Yunfei Bai, Al-Amoudi A. [43] presented a novel genetic algorithm trained radial basis function neural network based model to carry out the maximum power point tracking for grid connected photovoltaic power generation systems. The hidden layer of the neural network was self organized by the GA based RBF algorithm. The trained MPP model was then employed to predict the maximum power points of a PV array using measured environmental data.

Petchiatuporn P. et al [68] presented the development of a maximum power point tracking algorithm using an artificial neural network for a solar power system. The tracking algorithm integrated with a solar powered battery charging system had been
implemented on a PIC16F876 RISC microcontroller without external sensor unit requirement.

Samangkool K., Premrudeepreechacharn S. [69] proposed a method of maximum power point tracking using neural networks for grid connected photovoltaic systems composed of a boost converter and a single phase inverter connected to a utility grid. Back propagation neural network was used as pattern classifier. The single phase inverter used hysteresis current control which provided current with sinusoidal waveform. The system was able to deliver energy with low harmonics and high power factor.

Zhang L., Yunfei Bai [75] presented an RBFN based approach to model the I-V characteristics and maximum power variations of PV panels. The advantage of this model was that it did not require a priori knowledge of the PV panels and the models derived were sufficiently accurate for real time MPPT applications. The method was verified using data collected from two real PV panels.

Bo Cao, Liuchen Chang, Li H [104] implemented a radial basis function neural network as a system on a programmable chip to carry out maximum power point tracking for photovoltaic control systems. The tracking algorithm changed the duty cycle of the IGBTs to make the PV converter to work at the maximum power. This made the MPPT unit of the PV system an independent and highly integrated product including peripheral design and a control algorithm.

L. Zhang, Y.F. Bai et al [107] presented a new method to achieve maximum power point tracking for practical grid connected PV panels. The method employed the radial basis function neural network to predict the PV plant’s maximum power points corresponding to different weather conditions. The method had been verified by modeling the MPP points for practical PV panels located at Southampton and Leeds.
Kuei-Hsiang Chao, Ching-Ju Li [127] proposed a novel maximum power point tracking technique to fully utilize photovoltaic array output power that depends on solar insolation and ambient temperature. The proposed intelligent algorithm can automatically adjust the step size to track the PV array maximum power point. Simulations are performed to improve the dynamic and steady state performance of the PV systems.

Zhao Yong, Li Hong, Liu Ligun [139] used sliding mode control to track maximum power point of PV system for better tracking characteristic. The neural network was used to improve the sliding mode control in order to increase the electrical energy quality and reduced output vibrations. The results have shown the reliability of the suggested method and the output characteristic of the PV system was significantly improved.

Akira Hirai et al [9] dealt with the problem concerning the sensing of the weld pool phenomena in the robotic welding. The method proposed was based on the back propagation method used to train feed forward neural networks.

A. Mellit et al [117] presented an overview of the Artificial Intelligence techniques for sizing stand alone photovoltaic systems, grid connected PV systems, PV-wind hybrid systems. The advantage of using an AI based sizing of PV systems was that it provides good optimization, especially in isolated areas where the weather data are not always available.

Timothy D. Unruh and Ward T. Jewell [5] discussed the various steps involved in designing the photovoltaic cell. It mainly concentrates on collection of data from the Sun which was done using data acquisition system.

J.A Gow and C.D. Manning [24] discussed the effects of supplying a boost DC-DC converter from power sources such as PV-array.
Gawtam et al [39] presented an algorithm to simulate the performance of photovoltaic arrays which used a linear programming technique. The algorithm had been written as a program in C++.

Yeong-Chau Kuo [45] proposed a single-phase, three-wire photovoltaic energy conversion system with single stage structure using a novel MPPT algorithm. The proposed system employed a three leg inverter to control the MPPT process, the line current and the neutral line current. The proposed system was acting as a solar generator on sunny days and functioned as an active power filter on rainy days. Computer simulations and the experimental results demonstrated the superior performance of the proposed technique.

Mohamad A.S. Masoum et al [51] developed a simple, fast and reliable technique for charging batteries by solar arrays. The operating point of a battery was carefully forced near the maximum power point of solar cells under all environmental conditions. The charger operating point was continuously adjusted by changing the charging current.

S. Armstrong, W.G. Hurley [70] investigated the effectiveness of maximum power point tracking and proposed a quantitative measure of efficiency. Using vector methodology to track the direction and path of the Sun throughout the day, the optimal solar tracking angle and angle of incidence of the Sun’s rays were derived.

I.H. Altas, A.M. Sharaf [94] developed a photovoltaic array simulation model to be used in Matlab-Simulink GUI environment. The model was tested using a directly coupled dc load as well as ac load via an inverter. Test and validation studies were simulated.

Sergio Busquets et al [113] considered the connection of the photovoltaic arrays to a multi level diode clamped converter. A control and pulse width modulation scheme,
capable of independently controlling the operating voltage of each array was proposed. The performance of the proposed system configuration and control strategy were tested with three photovoltaic arrays connected to a four level three phase diode clamped converter.

Villalva M.G. [124, 125] proposed a method of modeling and simulation of photovoltaic arrays. The objective was to find the parameters of the nonlinear I-V equation by adjusting the curve at three points: open circuit, maximum power, and short circuit. Given these three points, which were provided by all commercial array data sheets, the method found the best I-V equation for the single-diode photovoltaic model including the effect of the series and parallel resistances and warranties that the maximum power of the model matched with the maximum power of the real array. With the parameters of the adjusted I-V equation, one could build a PV circuit model with any circuit simulator using basic math blocks. The modeling method and the proposed circuit model were useful for power electronics designers who needed a simple, fast, accurate, and easy-to-use modeling method for using in simulations of PV systems.

Shahparasti M. [131] proposed a photovoltaic system based on quasi Z source inverter which was connected to a single phase grid. Quasi Z source inverter was a one stage power conditioner that employed a capacitor inductor network for connecting inverter to photovoltaic module and was a topology derived from Z-source inverter. The objective of tracking maximum power point was accomplished by means of controlling duty cycle. The amount of power delivered to grid was regulated through the use of controller of QZSI capacitor voltage.

Converting the abundant flow of solar power to the Earth into affordable electricity is an enormous challenge, limited only by human ingenuity. PV conversion has
emerged as a rapidly expanding technology capable of reaching GW scale electric power generation with the highest power density among the renewable sources. Flat PV panels deployed in rooftop installations are oriented using simple rules of thumb to optimize solar energy collection, while in large scale solar energy generation plants, sunlight collection is optimized using bulky and expensive Sun trackers. However solar energy collection largely occurs on flat structures in contrast with the strategies adapted in nature. Marco Bernardi et al [142] studied the problem of how to best arrange solar panels in three dimensions to make macroscopically three dimensional PV devices capable of optimizing the energy generated in a given base area. They formulated, solved computationally and studied experimentally the problem of collecting solar energy in three dimensions. They demonstrated that absorbers and reflectors can be combined in the absence of Sun tracking to build three dimensional PV structures that generated measured energy densities higher by a factor of 2-20 than stationary flat PV panels.

Minan Gu et al [144] presented the complete design of a photovoltaic noise barrier installation that was used either to supply local electric loads or for sale using the premium subsidy awarded by the China Government. Possible designs for the PVNB were investigated together with economic and environmental analysis. According to the site and environmental conditions, the form and the electrical connections for the PVNB were determined. Net Present Value and the Pay back period were chosen as the parameters to determine the profitability of a PVNB installation. At the same time, Energy Pay Back Time was used to evaluate the environmental benefits of PVNB systems.

Prabodh Bajpai, Vaishalee Dash [145] reviewed the research on the unit sizing, optimization, energy management and modeling of the hybrid renewable energy
system components. They also discussed developments in research on modeling of hybrid energy resources, backup energy systems, power conditioning units and techniques for energy flow management. They made an attempt to present a comprehensive review of the research in this area in the past one decade.

Giraud F., Salameh Z.M. [28] reported the performance of a 4 KW grid connected residential wind photovoltaic system with battery storage located in MA, USA. The performance study was based on two year operation. Around noontime, this system satisfied its load and provided additional energy to the storage or to the grid. System reliability, power quality, loss of supply and effectiveness of the randomness of the wind and the solar radiation on system design were discussed.

Mummadi Veerachary [38] developed a MPPT scheme for the IDB converter fed PV system using fuzzy controller. A 5x5 rule base table was used for fuzzy controller.

Nopporn Patcharaprakiti [40, 67] proposed a method of maximum power point tracking using adaptive fuzzy logic control for grid connected photovoltaic systems composed of a boost converter and a single phase inverter connected to a utility grid. The maximum power point tracking control was based on adaptive fuzzy logic to control the switch of boost converter. The single phase inverter used predictive current control which provided current with sinusoidal waveform and hence the system was able to provide the energy with low harmonics and high power factor.

F.D.Kanellos, A.I.Tsouchnikas and N.D.Hatzigiorgiou [64] presented the models of two dispersed generation units namely wind turbine and PV system.

A.Yasin, G.Napoli, M.Ferraro, V.Antonucci [135] presented time domain performance analysis results of a standalone hybrid system based on commercial wind generator, photovoltaic generator and battery energy storage system. The hybrid system was designed and modelled using Matlab/Simulink/SimPowSys environment,
a control strategy was proposed to control the voltage DC bus and the energy flow between the different energy sources. The wind and photovoltaic generators were controlled locally to obtain the maximum power extraction, while battery energy storage system was controlled using specific control strategy depending on the voltage of the DC bus and energy flow. To test the performance of the system three different cases were analyzed. The frequency deviation, stability of DC bus voltage and voltage total harmonic distribution are taken as system performance indices. The simulation results ensured the effectiveness of the proposed hybrid system control strategy in following up the variations in load demand and weather data, providing the ground for practical realization.

Keya Huang, Wenshi Li, Xiaoyang Huang [137] focussed on the maximum power point tracking algorithm based on fuzzy control. Control rules were adopted using artificial neural network with measured data.

Takeshi Uematsu et al [41] proposed a double bridge inverter in which the first stage bridge circuit can operate at either of voltage boost and voltage buck modes which can regulate the output voltage for a wide range of input voltage.

Isao Sakata et al [79] described two new national R&D programs for photovoltaics which had been created with reference to PV roadmap towards 2030-PV 2030, taking account of the fact that the PV market in Japan is rapidly expanding.

Matthew Lave, Jan Kleissi, Ery Arias-Castro [143] computed clear sky indices for one site and for the average of six cities separated by less than 3 km to estimate the smoothing of aggregated power output due to geographic dispersion in a distribution feeder, using six San Diego solar resource stations.

Silicon had been almost the only material used for manufacturing of solar cells. Although other materials and techniques had been developed, silicon is used in more
than 80% of production [13]. Silicon is so popular because it is one of the most abundant materials in the earth’s crust in the form of silicon dioxide and it is not toxic. Monocrystalline and polycrystalline silicon solar cells are the two major types of silicon solar cells. Amorphous silicon is less used because of its lower efficiency. Other new solar cells are made of Copper Indium Gallium Selenide(CIGS) and Cadmium Telluride(CdTe). Though much research and development effort is being made, there is no commercial substitute for the above types of solar cells.

Monocrystalline silicon solar cells are the most efficient ones. They are made from wafers of single crystals obtained from pure molten silicon. These single crystal wafers have uniform and predictable properties as the structure of the crystal is highly ordered. The manufacturing process occurs at high temperatures and is expensive. The efficiency of these cells is around 15-18% [25]. The surface needed to get 1 KW is sq-m.

Polycrystalline silicon cells are also made from wafers of pure molten silicon. However the crystal structure is random. As the silicon cools, it crystallizes simultaneously in many different points producing an irregular structure i.e. crystals of random sizes, shapes and orientation. Since these structures are not as ideal as in the monocrystalline cells, the efficiency is lower, around 11-15% [25]. However the manufacturing process is less expensive. The surface needed to obtain 1 KW is about 8 sq-m.

Amorphous silicon is the non-crystalline form of the silicon and can be deposited as thin films onto different substrates. Though the manufacturing process is simpler, easier and cheaper, the drawback is their lower efficiency around 6-8% [35]. The advantages of thin film technologies are the ease of manufacturing at low temperatures using inexpensive substrates, continuous production methods, avoiding
the need for mounting individual wafers and the potential for light weight and flexible solar cells.

Over recent years, one more type of silicon had been developed, microcrystalline silicon [36]. The light absorption of microcrystalline silicon is poor compared to amorphous silicon.

There are other materials that can be used for manufacturing of solar cells, apart from silicon. The efficiency of these compounds is around 10-13% [30], the disadvantage being the toxicity of some of the compounds and the shortage of some of the elements used. Gallium Arsenide(GaAs) had been used for space applications. Triple junction GaAs solar cells have already passed 40% efficiency in the laboratory using light concentrators [22]. The disadvantage of this technology is that the concentration systems are expensive. Another technology is dye-sensitized cells [22] which are made from artificial organic materials. The efficiency of these cells is above that of the amorphous silicon and with in the thin film ones. It is still a non-commercial technology.

For large scale application of photovoltaics it is imperative to reduce the manufacturing cost of PV modules by a factor of 2-3, when compared to present prices determined by traditional, wafer-based crystalline silicon PV technology, a module technology that dominates the world market. In order to turn PV into a competitive energy source in future, such a further substantial cost reduction will be the deciding factor. However, the concept of wafer was always accompanied by a significant loss in efficiency. The efficiency drops down to less than a half, when compared to efficiencies of close to 25%, as achieved with mono crystalline silicon wafers [22, 34]. This situation motivated researchers to intensify the study to various thin film solar module concepts. In these thin film concepts, the semiconductor was
deposited on low cost large area substrates. The cells did not have to be self supporting. So, large area substrates were used and the substrates formed a part of the encapsulation. Thin film solar cells based on compound semiconductors such as CdTe attracted much attention due to the remarkable work of many groups [15, 16, 44, 21]. Amorphous silicon technology achieved an industrial level [21, 32] and contributed to a reduction of the module price. Amorphous silicon had always been associated with low efficiencies and with further efficiency losses during operation due to Staebler-Wronski effect. The low deposition temperature and the application possibility of the monolithic series connection technique for module manufacturing [31, 56] were considered to be significant advantages for amorphous silicon technology as they are key features that are needed to obtain low manufacturing costs.

J. Meier, U. Kroll, E. Vallat-Sauvain, J. Spitznagel, U. Graf, A. Shah [49] studied that very high frequency glow discharge technique leads to a considerable enhancement in the deposition rate of amorphous and microcrystalline silicon layers and also the concept of micromorph tandem solar cell concept. They studied that both the VHF-GD deposition technique and the micromorph tandem solar cell concept are essential for thin film PV modules, as they bear the potential for combining high efficiency devices with low cost manufacturing processes.

J. Meier et al [141] observed that the up scaling of R&D processes lead to modules having initial powers of 139.1 W for amorphous silicon and 163 W for micromorph tandem. Oerlikon Solar introduced a new improved production concept, Thin Fab TM, which brought production costs down to remarkable value.

Gow J.A., Manning C.D [23] proposed a generic modular photovoltaic power conversion system, which was small, light and constructed from readily available components, aimed at single-phase applications which can supply passive AC and
DC loads with a regulated voltage or by way of a maximum power tracking system with the maximum power available from the array.

Koutroulis E., Kalaitzakis K. [50] presented a battery charging system for standalone photovoltaic applications. Using the proposed method, a better exploitation of the available PV energy compared to a commercial battery charger based on the on/off principle was achieved and simultaneously a 100% battery state of charge was reached in shorter time. Advantages of the proposed method are better exploitation of the available PV energy by means of a maximum power point tracking technique employed in the control algorithm, increased battery lifetime due to higher level state of charge operation, and the charging control process does not depend on accurate battery current measurements, reducing the effect of the current sensor sensitivity on the battery final state of charge. Also, since it is based on the battery current regulation principle, it was effectively used with large battery strings.

A.M. Sharaf, A.R.N.M. Reaz Ul Haque [61] developed a novel error driven online search and tracking controller for maximum PV solar energy utilization for a low cost village energy scheme. It proposed a maximum photovoltaic energy tracking and efficient energy utilization control scheme to cope with changing resistive loads and motor torque variations.

Andreas K. Athienitis [92] described the design of a two-storey single family detached solar home located in Montreal. The major features of the house were direct gain passive solar design that emphasizes utilization of distributed thermal mass in the south facing part of the ground floor, a BIPV/T system, a two stage ground source heat pump, an auxiliary floor heating system integrated in the floor mass of the direct gain zone and a two zone air distribution system controlled by a multi zone programmable thermostat.
Building integrated photovoltaic-thermal systems that pre-heat ambient air are used in combination with ventilated concrete slabs for thermal storage purposes. This is one of many ways to maximize solar energy utilization. Yuxiang Chen et al [101] described the design and simulation of a solar house with an innovative BIPV/T system and ventilated concrete slab. The BIPV/T system could harvest a considerable amount of useful heat, however, some of this energy typically needed to be stored for later use with an appropriate thermal storage design.

Sridhar S. [114] dealt with the design and implementation of a photovoltaic-electro mechanic chain, composed of a PV generator, a boost converter and an induction motor controlled by space vector pulse width modulation. The PV generator was operated at its maximum power by implementing voltage based maximum power point control algorithm. The proposed system was implemented using PIC18F4550 microcontroller.

X.Q. Zhai et al [116] designed and installed a solar powered adsorption in the green building of Shanghai research institute of building science. Compared with the ambient temperature, it was deduced that solar radiant intensity had a more distinct influence on the performance of solar powered air-conditioning system.

The major advantage of photovoltaic system [2, 3, 10, 14, 18, 6] is that it requires only naturally abundant sunlight as fuel. It is environmental friendly as there are no gaseous emissions, pollutants. It can be easily transported, assembled and installed in remote areas as per the availability of sunlight. The system is robust, reliable, weather proof and has long life. It produces DC electricity which can be easily stored in a battery. Maintenance cost of system is low. Despite these advantages, photovoltaic systems have also certain limitations like high initial cost, non availability of repair
and maintenance facilities readily. PV systems are not always the best source for meeting large requirements of power.

2.1 THE PROPOSED WORK

A basic hardware model is developed to illustrate the concept of maximum power point tracking in solar cells using a cost effective microcontroller, ATMega8L which can provide the required number of ADC channels for tracking purpose. Different methods of maximum power point tracking are proposed to be brought on to the same platform. All the concepts are implemented on 60W simulation model. Hardware implementation was done on KL Solar 60W module. The advantages and disadvantages of various methods are also discussed with respect to 60W module.

2.2 CONCLUSIONS

It can be concluded that lot of research work is going on, on extracting power from the solar cells in many directions, one direction being the capturing of maximum power point of the solar cell under given environmental conditions. The present work implements different methods for tracking maximum power of a 60 W module.