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Design and Development of MPPT based Converter for Efficient Solar Power Conversion

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ABSTRACT
The design of a Maximum Power Tracking (MPPT) controller for a solar photovoltaic system is proposed utilizing a buck-converter topology. Solar panel voltage and current are continuously monitored by a closed-loop microcontroller based control system, and the duty cycle of the buck converter will be continuously adjusted to extract the maximum power. MATLAB Simulation will be used for the initial validation of the proposed scheme and for the selection of circuit parameters. Actual controller will be implemented using AVR series microcontroller.

Keywords
Solar PV technology, MPPT, Efficiency of PV system.

1. INTRODUCTION
A Electrical Power is the basic need for economic development of any country. Conventional sources of energy like Coal, Natural Gas and Oil etc., contribute about 92% of total power generation in world. These source are limited & will be exhausted in near future, also they produce greenhouse gases leading to global warming and other environmental hazards. Non-conventional energy sources such as Solar, Wind, Sea, Geothermal, Biomass are eco-friendly. The solar PV module converts solar energy directly into usable electrical energy with no bi-products, which is not possible with fossil fuels. As the demand of power is increasing, new developments in the field of non-conventional energy are also being presented. As Sun is considered to be the only never ending source of energy known to mankind, solar energy seems to be the best solution for our future energy requirements.

Currently India is generating 2,06,456.04 MW of electricity out of which only 12.10 % i.e. 24,998.46MW is contributed by renewable energy sources. As India receives a large number of sunshine hours over the year, there is great scope of solar photovoltaic technology. The lower power conversion efficiency of PV systems is the major problem affecting the large scale implementation of solar PV systems.

This research work aims at the development of Maximum power point based Converter for efficient solar power conversion. Maximum power point tracking (MPPT) is used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and solar irradiation conditions and of the load electrical characteristics. A microcontroller based MPPT system has been proposed, consisting of a Buck-type DC-DC converter. Solar panel voltage and current are continuously monitored by a closed-loop control system, and the duty cycle of the buck converter will be continuously adjusted to extract the maximum power.

2. LITERATURE REVIEW
A number of MPPT control algorithms namely Perturb & Observe (P&O) ,Incremental conductance (INC), Parasitic capacitance (PC),Constant voltage (CV),Open circuit voltage (OCV) and Short circuit current (SCC)have been proposed and discussed in wide literature available[2,7].

One algorithm, the perturb-and-observe (P&O) algorithm, is by far the most commonly used in commercial MPPT[6]. However, there is as yet no consensus on which algorithm is 'best', and many authors have suggested that perhaps the P&O algorithm is inferior to others. This lack of consensus stems in part from the fact that the literature contains no comparisons of absolute efficiencies of MPPT algorithms, with all algorithms using optimized parameters and operating on a standardized MPPT hardware. Most of the reported comparisons are made between an MPPT algorithm and a direct coupled system or between an MPPT algorithm and a converter designed for a fixed operating point.

Following table shows the Summary of previously reported MPPT efficiencies for the four algorithms[5]

Sr.No	MPPT Algorithm	Reported Efficiencies
1	Perturb-and-observe	85%
2	Incremental conductance	88%
3	Constant voltage	73%
4	Parasitic capacitance	99%

3. SOLAR PHOTOVOLTAIC SYSTEM TOPOLOGIES
- Grid Connected System

The grid-connected systems operate in parallel with the electric utility grid and supply solar power to the utility via the grid. The inverter needs to be synchronized with the grid and additional protection features are essential in the inverter to prevent islanding. Grid-connected PV systems vary greatly in size, but all consist of solar modules, inverters which convert the DC output of the solar modules into AC electricity, and other components such as MPPT, wiring and module mounting structures etc. Most of the first grid-connected systems consisted of several hundred kilowatts of PV modules laid out in a large centralized array, which fed power into the local high voltage electricity grid in much the same way as a large thermal generator.

Another form of grid connected system is for small house hold application users, which connect the PV module at their house along with the grid connected supply. For these types of small grid-connected rooftop PV system, the power produced by the array during the day can be used to supply local loads, and the excess energy is fed into the local grid using micro grid inverters for other customers to use. At night, the local loads are simply supplied by the grid. If the PV system is large enough, it can supply more energy into the grid than is used by local loads. Instead of receiving a bill every month, the customer can generate revenue from their utility for generating this electricity.

On many electricity networks, peak loads coincide with peak solar power production. Example in many regions peak loads occur on summer afternoons because air conditioners are used extensively. Peak loads are more expensive to satisfy than other loads, and thus the electricity generated by a PV system during a peak load is of greater value than that generated at times of low demand. This is an major advantage of grid connected PV system.

A grid-connected PV system offers other potential cost advantages when placed at the end of a transmission line, since it reduces transmission and distribution losses and helps stabilize line voltage. PV systems can also be used to improve the quality of supply by reducing 'noise' or providing reactive power conditioning on a transmission line.[2]

- *Off grid Photovoltaic system*

The term off-grid refers to not being connected to a grid, mainly used in terms of not being connected to the main or local transmission grid in electricity. In electricity off-grid can be stand-alone systems or mini-grids typically to provide a smaller community with electricity. Off-grid electrification is an approach to access electricity used in countries and areas with little access to electricity, due to scattered or distant population. It can be any kind of electricity generation. The term off grid can refer to living in a self-sufficient manner without reliance on one or more public utilities.

The solar off grid system already represent an attractive economical alternatively to conventional diesel generators. In Off grid PV system, the PV energy is consumed upon generation or stored in battery banks for a later use. The main components involved in off grid systems are solar PV modules, MPPT charge controllers, Battery bank, DC to AC inverters, etc.

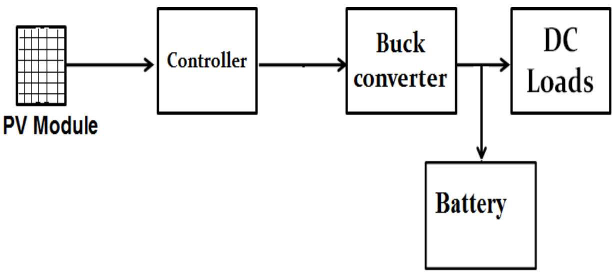


Fig 1: Block Diagram of Off grid Photovoltaic system

4. SOLAR PHOTOVOLTAIC ARRAY

Photovoltaic (PV) array essentially consist of a number of internal silicon based photovoltaic cells combined in series and in parallel, depending on the voltage or current requirements. These cells convert solar energy into electricity. This occurs when the photovoltaic cells are exposed to solar energy causing the cells electrons to drift which, in turn, produces an electric current. This current varies with the size of individual cells and the light intensity.

The most common materials used for construction of these modules are

1. Mono crystalline silicon
2. Polycrystalline silicon
3. Amorphous silicon
4. Copper – indium selenide (CIS)

These PV cells consisting of such semiconductor materials are capable of generating electricity from light sources and usually have efficiencies of 6% – 20% in commercial use.The most popular type of thin film photovoltaic technologies are CIS arrays and amorphous silicon arrays. These thin film panels consist of a layer of silicon sandwiched between a sheet of glass and a sheet of plastic. A laser scribe is then used to mark out individual cells. They have very good efficiency on sunny days, better then the crystalline silicon based cells. However they do suffer from a considerable drop in efficiency under cloudy conditions. Mono-crystalline and polycrystalline silicon arrays are constructed in much the same way, however are made up of individual 0.5 V cells connected together to achieve the desired voltage. They weigh less than the amorphous and CIS arrays, and are about half the size. Although mono crystalline cells attain as high efficiencies as the amorphous cells, they do perform better under cloudy conditions, making them very suitable for year round use.[4]

5. BATTERY

Batteries are used to store the excess charge developed during the day time electricity generation which can be used later in the non-sun shine hours. There are basically two types of battery which are mainly used i) Lead Acid battery and ii) Nickel Cadmium battery. The most commonly used is lead acid battery whereas nickel cadmium battery has many advantages such as long life, high energy density, good performance under low temperature etc. As the Ni-Cd batteries are much expensive, these batteries are less preferred. Avoid combining SI and CGS units, such as current in

6. CHARGE CONTROLLER

In PV systems charge controllers are designed for monitoring & controlling various dc to dc converters which are integrated in it. The charge controller operates the converters for extracting and managing generated power to achieve the maximum efficiency. The main functions of a charge controller in concern with battery are protection from reverse current and battery overcharge. Charge controllers are also designed to prevent battery over discharge, protect from electrical overload, and/or display battery status and the flow of power.

7. SOLAR INVERTER

A solar inverter, or PV inverter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. It is a critical component in a photovoltaic system, allowing the use of ordinary AC appliances. The solar inverters are basically classified into three main categories [5]

1. Stand-alone inverters
2. Grid-tie inverters
3. Battery backup inverters

8. MAXIMUM POWER POINT TRACKING

Solar cells are characterized by i) maximum Open Circuit Voltage (Voc) at zero output current and ii) Short Circuit Current (Isc) at zero output voltage. The solar power can be computed using equation:

$$P = I * V$$

A PV array under constant uniform irradiance has a current–voltage (I–V) characteristic like that shown in Figure1. There is a unique point on the curve, called the maximum power point (MPP) at which the array operates with maximum efficiency and produces maximum output power. When a PV array is directly connected to a load (a so-called 'direct-coupled' system), the system's operating point will be at the intersection of the I–V curve of the PV array and load line shown in Figure 1.In general, this operating point is not at the PV array's MPP, which can be clearly seen in Figure 1. Thus, in a direct-coupled system, the PV array must usually be oversized to ensure that the load's power requirements can be supplied. This leads to an overly expensive system.

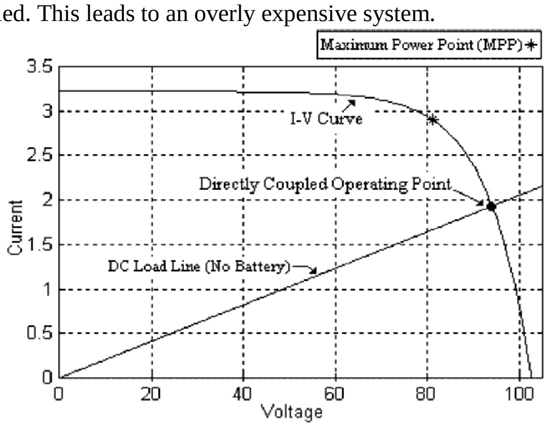


Fig 1: VI characteristic of PV cell

To overcome this problem, a switch-mode power converter, called a maximum power point tracker (MPPT),can be used to maintain the PV array's operating point at the MPP. The MPPT does this by controlling the PV array's voltage or current independently of those of the load. If properly controlled by an MPPT algorithm, the MPPT can locate and track the MPP of the PV array. However, the location of the MPP in the I–V plane is not known a priori. It must be located, either through model calculations or by a search algorithm. The situation is further complicated by the fact that the MPP depends in a nonlinear way on irradiance and temperature, as illustrated in Figure 2. Figure 2(a) shows a family of PV I–V curves under increasing irradiance, but at constant temperature, and Figure 2(b) shows I–V curves at the same irradiance values, but a higher temperature. Note the change in the array voltage at which the MPP occurs.

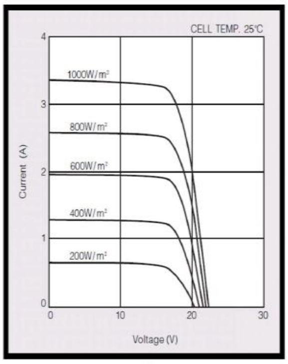


Fig 2(a)

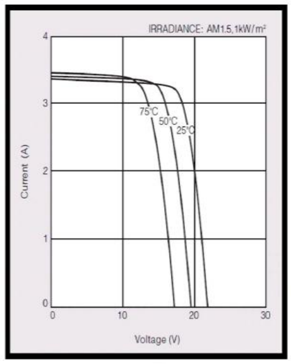


Fig 2(b)

There are many different approaches to maximizing the power from a PV system, these range from using simple voltage relationships to more complex multiple sample based analysis. Depending on the end application and the dynamics of the irradiance, the proper method is implemented. These are called MPPT algorithms. There are various algorithms to track the maximum power point and operate the PV module on that point to extract the maximum power. Some of the algorithms are listed below:

1. Perturb & Observe (P&O)
2. Incremental conductance (INC)
3. Parasitic capacitance (PC)
4. Constant voltage (CV)
5. Open circuit voltage (OCV)
6. Short circuit current (SCC)

Design of MPPT based Solar Charge Controller

The MPPT algorithm embedded in charge controller takes voltage and current feedback from the panel and adjusts the control signals to operate the panel at its peak power. In this project we are implementing Perturb & Observe (P&O) algorithm to obtain maximum power. The perturb and observe (P&O) algorithm is the most commonly used in practice because of its ease of implementation. Figure 3, shows a family of PV array power curves as a function of voltage (P–V curves), at different irradiance (G) levels, for uniform irradiance and constant temperature. These curves have global maxima at the MPP. Assume the PV array to be operating at point A in Figure 5, which is far from the Maximum Power Point. In the P&O algorithm, the operating voltage of the PV array is perturbed by a small increment, and the resulting change in power, _P, is measured. If _P is positive, then the perturbation of the operating voltage moved the PV array's operating point closer to the MPP. Thus, further voltage perturbations in the same direction (that is, with the same algebraic sign) should move the operating point toward the MPP. If _P is negative, the system operating point has moved away from the MPP, and the algebraic sign of the perturbation should be reversed to move back toward the MPP.

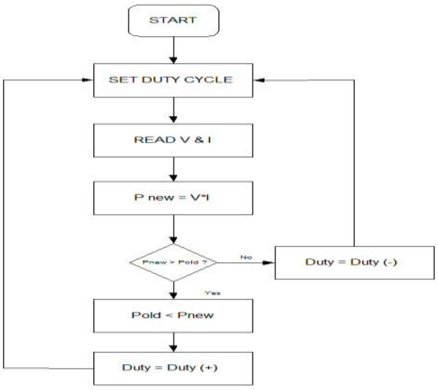


Fig 3 : P & O algorithm

- *Specifications of PV System*

The project work, the PV system will be designed for maximum load of 100Watts with the system operating voltage of 12 Volts DC with considering 5 hours of sunshine daily. Design is based on the thumb rules normally used for solar PV systems.

Load = 100Watts
Duty Factor = 1
No of battery backup hours = 4hours
Total watt-hour = 100×4 = 400Whr

- For Battery sizeing:

Supply Whr = 400 Whr

Depth of discharge (DOD) = It's a measurement of how much battery is discharged in a cycle before it is charged again. The optimum value generally suggested for longer life of battery is 60%. Hence Depth of discharge (DOD) = 0.6
Battery Efficiency factor (BEF) = 0.85 (for lead acid batteries)
AC system efficiency factor (ACEF) = This parameter is consider mainly for the losses occurring in the dc to ac conversion i.e. inverter efficiency & AC cable loss factor. For small system generally less than 1KW the ACEF is taken as 0.9 whereas for large systems it has to be calculated precisely.
Battery Whr= (Whr)/(DOD×BEF×ACEF)
= 400/(0.6×0.85×0.9) =872
Battery Voltage =12 volt
Battery Ampere Hour = 872/12 = 71 Ahr
Hence selecting one Battery of 12volt/120Ahr.

- Daily Energy Requirement:

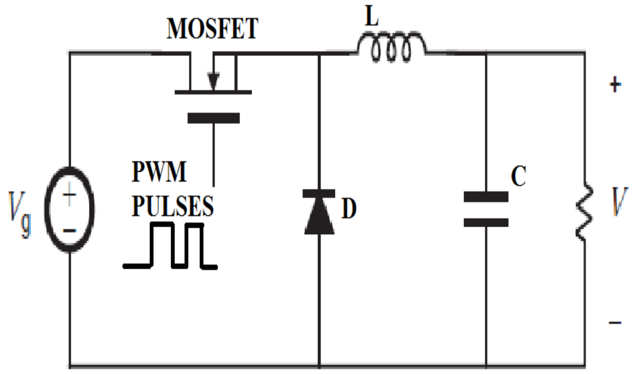
As calculated above the power to be supplied daily is 400 Whr, according to this load the required watts of PV module and number of PV modules as per availability is calibrated.
System Efficiency Factor (SYSEF) = The overall efficiency of the complete system which includes PV loss factors, DC and AC system losses along with battery efficiency factor.
SYSEF = DCEF × BEF × ACEF = 0.79×0.85×0.9 = 0.6
Peak PV watts, Wp = Whr/(4×SYSEF)
= 400/(4×0.6) = 130 Wp

Hence we need to connect the solar photovoltaic module which collectively will generate 130Wp. A wide range and rating of PV modules are available in market; accordingly we can connect them in series & parallel combinations to achieve the desired output.
Each PV module available is of 40 Wp
The number of PV modules Required = 3

- Charge Controller Ratings:

For 12 volt system, Load current = 100/ 12 = 8.33 Amp (max).

- *Design of Buck Converter*



2. For buck converter switching MOSFET will be used. Design parameters are as follows
   Input DC voltage = 17 volts (V_1)

Output voltage = 12 volts (V_0)
Maximum load current = 8.33 amp (I_L)

Assuming peak to peak ripple current in inductor = 1Amp (ΔI_L)
Peak to peak output ripple voltage = 100 mV (ΔV_0)
Operating frequency = 10KHz
Ambient temperature = 40°C

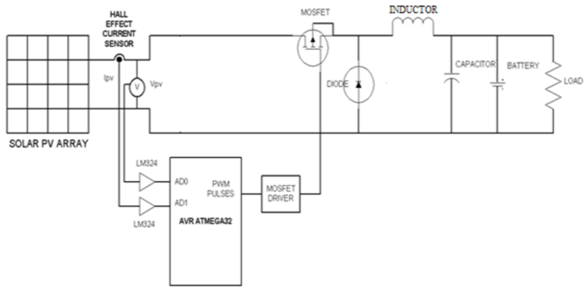
Duty Ratio, Dr = V_0/V_1= 12 / 17 = 0.7
Inductor L for V_1

$$L = \frac{V0}{V1} * (V1 - V0) * \frac{T}{\Delta IL}$$

L = 0.35 μH (For 10 KHz switching frequency)
Capacitor C for V_1

$$C = \frac{V0}{8*f*f} * \frac{(V1-V0)}{V1*L*\Delta V0} = 0.126\mu F$$

10. HARDWARE IMPLEMENTATION



The proposed design will be realized using hardware. Figure shows the hardware arrangement. The total hardware is divided in three main sections as follows:

1. Voltage and Current measurement section
2. Microcontroller Section
3. DC-DC converter section

A simple resister attenuator will be used for voltage attenuation and measurement while Hall effect current sensor ACS-712-30T will be used for measurement of current. Based on measured values of voltage and current. P&O algorithm will be implemented using the microcontroller. Microcontroller will be programmed to generate PWM signals to drive the MOSFET of DC-DC converter. firmware will set the duty ratio so as to ensure the operation of solar panel at maximum power point.[6]

10. CONCLUSION

The project work aims at the study of various MPP algorithms used in off grid solar systems. As per the literature, as P&O algorithm has low component count, good reliability and better efficiency, a solar charge controller will be developed using the same algorithm.

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