Enhancement of The Solar Energy Harvesting System for WSN Nodes Through INC-MPPT: A Review

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Abstract—**Solar energy is a sustainable and environmentally friendly kind of energy production. In recent years, research in the Internet of Things has focused on putting WSNs to use in conjunction with solar energy collecting techniques. The battery energy of a WSN node is very low, and its lifespan can be measured in just a few days at most depending on the working duty cycle. In this research, we propose a new SEH approach that can be used for WSN nodes that have limited energy resources. Nodes that are part of a Solar Energy Harvesting Wireless Sensor Network (SEH-WSN) will typically continue to function for many years to come. P&O Maximum Power Point Tracking was the method that was initially utilised for the development of the solar energy harvesting process in the past (MPPT). In this research, we will evaluate a solar energy harvesting system for wireless sensor network nodes that includes MPPT.**

Index Terms**—**Solar energy harvesting, INC, MPPT

I. Introduction

A wireless sensor network is a network of devices that can convey the information that they have gathered from a monitored field using wireless links. This type of network can be classified as a wireless sensor network. The data is transferred between numerous nodes, and then, with the help of a gateway, it is connected to other networks such as wireless Ethernet. WSN stands for wireless sensor network and refers to a type of wireless network that is made up of base stations and a number of nodes (wireless sensors). These networks are used to monitor physical or environmental factors like as sound, pressure, and temperature and to cooperatively send data over the network to a central point. Examples of these conditions are sound and pressure.

The deployment of compact, in-expansive and low-power wireless communication devices with compute capabilities is now a reality thanks to modern creative advancements, which have made this a possibility. These kinds of devices are typically referred to as sensor nodes [6], and they are dispersed throughout a sensor field. A Wireless Sensor Network, abbreviated as WSN, is a collection of sensor nodes that work together to carry out a certain activity. Typically, the sensor nodes are dispersed in a haphazard manner across an unattended environment. They contribute to the sensing process and collaborate in order to keep an eye on the surrounding environment and deliver accurate data. Each sensor node makes a choice based on the information it has sensed, the processing competence it possesses, its capacity for communication, and the energy resources it possesses. As indicated in Figure 1, sensor nodes collect data about their surrounding environment and transmit it to a sink for processing.

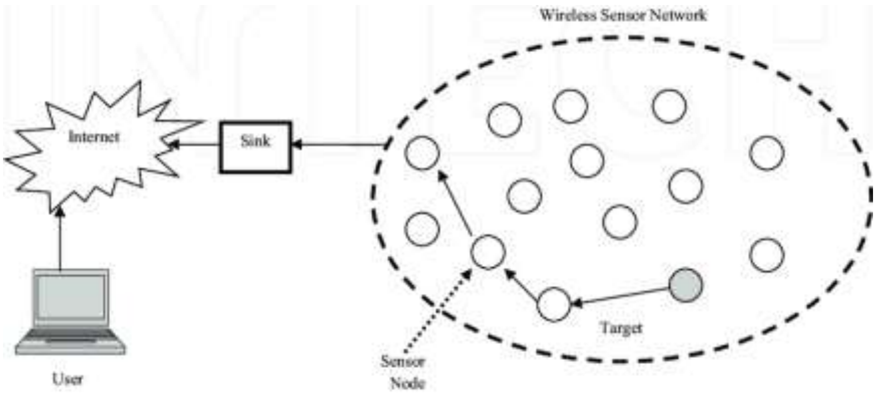


Figure 1: WSN architecture

One or more sensing devices, a microprocessor, a radio transceiver for receiving and transmitting information, and a source of energy such as a battery are all components that make up a wireless sensor node. A sensor node will have one or more sensing devices that will measure the environmental conditions of their surroundings and convert those readings into an electrical signal. The temperature, humidity, auditory and seismographic data of the environment, as well as the mobility and direction of living beings, can be considered to be examples of such ambient circumstances. These electrical signals are either compressed in order to reduce the communication overhead or processed in order to expose some attributes of the surrounding area, depending on the application and the capabilities. After gathering the information, the communication unit transmits it wirelessly to a centralized control either directly or indirectly through the use of other sensors. It's common practice to refer to this central control as either a sink or a base station. The term "Wireless Sensor Network" refers to the ad-hoc network that is produced by the connection of these sensor nodes (WSN).

Due to the continuously shifting wireless links and, consequently, network connectivity, wireless sensor networks, just like wireless ad-hoc networks, have a dynamic quality to them by their very nature. In addition, the topology of wireless sensor networks (WSNs) shifts whenever nodes leave or enter the network. WSNs and wireless ad-hoc networks exhibit communication characteristics that are quite similar to one another. Furthermore, communication in WSNs typically takes place in an ad-hoc fashion.

It is exceedingly difficult for sensor nodes to survive on small and limited sources of energy since they must communicate with one another across a wireless channel and they are remotely installed. When compared to the processing and sensing of information, communication in WSNs is responsible for the greatest amount of energy consumption. When using a centralised system, some of the sensor nodes are required to communicate over significant distances, which results in an even greater loss of energy. Since the sensor nodes in a WSN are densely deployed and may suffer from information redundancy, it would be a good idea to process as much information as possible locally in order to reduce the total number of bits that are transmitted. This would help to minimize the amount of data that is transmitted. Distributed processing is another requirement for sensor networks because of this reason.

A heterogeneous wireless sensor network is one that is made up of several kinds of sensor nodes. These sensor nodes are able to measure a variety of data and carry out a variety of functions. The following pieces of hardware are necessary for the operation of such a (sub) network:

Figure 2 presents a heterogeneous model of the data. There is always data for the nodes to send to a base station, which is typically located some distance away from the sensing region. This form of sensor network can be used to monitor remote environments or track military objects. It can also be used to track military objects. Assume, without giving away too much specific information, that the base station can be found in the exact middle of the square region. The network is structured into a hierarchical clustering structure, and the cluster-head nodes are responsible for carrying out the fusion function in order to reduce the amount of correlated data that is produced by the sensor nodes that are contained inside the clusters. The data that has been aggregated is sent straight to the base station from the cluster heads.

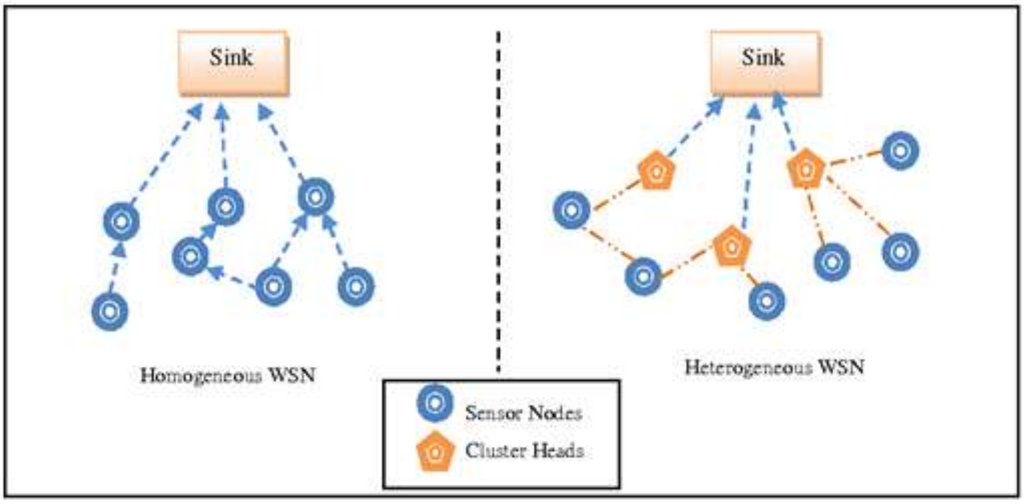


Figure 2: Heterogeneous Models for WSN

Battery replacement is a particularly challenging operation for many of the many applications that use WSNs, such as monitoring deep forests and managing disasters, because the sensor nodes in these applications cannot be reached by people and hence cannot be interfered upon. In these kinds of situations, the lifetime of the WSN is totally dependent upon the restricted capacity of the battery, which makes energy a precious resource. Therefore, energy that is gathered from the environment is currently one of the most promising fields of research, and a substantial amount of research effort is required to be done from every feasible angle in order to make the networks more energy efficient. After being deployed, sensor nodes may be movable either through the air or underwater, depending on the application. When something like this happens, the topology of the network is impacted, along with its performance and its lifetime. For military applications, it is also a goal to produce very small and affordable nodes that can be strongly stationed across a bigger region. This will allow for greater coverage. In addition, it is possible for WSN communication to be disrupted in either a mobile or stationary setting by other moving objects such as animals, automobiles, or even by a natural disaster.

The WSN hubs are hampered by the impacts of a substantial plan imperative in the sense that their battery power is restricted, and they are only able to function for a number of days at the most depending on the activity pattern of their obligations (Sharma H, Haque A, 2018). The energy that is generated from sunlight is often stored in solar cells; therefore, the capacity for energy storage needs to be increased. Through the photovoltaic effect, a solar-powered energy system can swiftly be converted into usable electricity by deploying PV boards (Mohamed, S. A., &Abd El Sattar, M., 2019). Regardless of this, the productivity of the transformation is low, and the cost of the developed intensity is comparable to that of a high cost. PV technology has a lot of advantages, such as low fuel prices, it doesn't produce any pollution, it needs very little maintenance, and PV framework includes a lot of diverse features (Ahmad, T., Sobhan, S., &Nayan, M. F., 2016).

The term "sunlight-based photovoltaic" (PV) energy collection refers to the conversion of light energy from the sun into electrical energy, which can then be used to power an electronic or electrical device. When it comes to wireless sensor networks (WSNs), light energy from the sun is converted into electrical energy and utilised to recharge the battery of a WSN hub at the location where the activity is taking place (Sharma, H., Haque, A. and Jaffery, Z.A., 2018). In this method, once the energy stored in the battery has been drawn out, it will be necessary to continually replace the batteries. It is possible to control a WSN hub with the electrical energy that is generated from solar power, and this is a perfectly lawful use of this energy. On the other hand, the amassed power may be stored in a battery-operated battery for use at a later time. The Self-Contained Energy Harvesting Wireless Sensor Networks (SEH-WSNs) are made up of miniature self-sufficient WSN hubs that are connected to little sunlight-based boards for their energy gathering needs. It has been determined that the maximum amount of sun-powered energy that can be collected at the surface level is 15 mW/cm2, with a productivity that can reach up to 30 percent (Rasheduzzaman, M., Pillai,2016). As a result, we have decided to gather energy from the sun in order to provide supplementary capacity to the WSNs because this method offers the greatest potential for powerful thickness and large productivity.

Choudhary, D., and Saxena, A. R. (2014) came up with a number of different strategies to follow the most extreme force purpose of a PV module. These tactics were proposed in order to beat the restriction of efficacy. The maximum power point tracking (MPPT) technique is applied to solar photovoltaic (PV) modules so that the maximum amount of energy can be extracted from them and then stored. The DC-DC converter acts as an interface between the heap and the PV module, effectively transferring the most power from the solar-powered PV module to the heap. It does this by converting direct current to direct current. By adjusting the duty cycle, the load impedance can be brought into alignment with the source impedance, which results in the generation of the maximum possible force from the PV board (Veerachary, M., &Saxena, A. R., 2011).

II. Literature Review

Power system networks take the PV-created energy by methods for matrix associated inverters. There is some of the time, no coordinating of the working particular highlights of the heap and PV clusters, which is an eminent trouble in PV power frameworks. In particular, with various ecological states, PV Module exhibit shows non-direct style for V-I bend and greatest force point on V-P bend. PV module productivity is in the scope of 10-25%.

The technological advancement in wireless communication has led to the development of wireless sensor networks. With the exceptional capability of not only sensing but processing as well, wireless sensor networks became popular and very much required for many applications. Sensor nodes are small and they are deployed in the monitoring area in large amount to detect events. But Sensor nodes are resource constrained. They are tiny nodes with limited storage capacity, low cost processor, and limited transceiver range and with limited battery lifetime. Sensor nodes sense the monitoring area such as forests, a field, underwater, cities, human body etc. and transmit the sensed data to the sink.

This transmission may take place via single-hop or through multi-hops. In single-hop networks nodes can directly send data to the sink. But generally, a sensor network field is large and the nodes transmission range is limited, so the nodes may send data to the sink via intermediate nodes or forwarding nodes, iwhich is called as the multi-hop network [38].

Sensor nodes deplete their energy due to direct data transmission in single hop whereas in a multi-hop, the forwarding nodes deplete their energy and reduce the network lifetime. The lifetime of sensor nodes mainly depends upon a finite source of energy like battery. Therefore, it is crucial to consider the energy efficient techniques to increase the life span of the network.

Heinzelman et al., (2000) discussed Low Energy Adaptive Clustering Hierarchy (LEACH) protocol in which nodes in the network are divided into clusters. Nodes that are more proximate to the Cluster Head join the respective cluster only when they receive strong signal strength. Data transmits from nodes to the base station via cluster head, which are randomly chosen. Cluster Head aggregates and compresses the data using different techniques and then forwards the data to the sink. Since CHs are randomly chosen, any node can get a chance to become a Cluster Head in the entire network.

LEACH uses distributive clustering mechanism which consequently leads to efficient energy utilization and longer lifetime of the network. It consists of two phases- steady state and setup phase. In steady state phase, sensor nodes join the cluster based on the signal strength received from the nearest CH. The TDMA slot has also been assigned to the sensor nodes in the cluster. In the steady state phase, the sensor nodes send their sensed data to the CH in their respective slot and then CH sends the processed data to the Base station. LEACH is not felicitous for large networks since nodes directly transmit data to the Base station and Cluster Head. Enhancement in LEACH includes TL-LEACH [32], E-LEACH [33], M-LEACH, LEACH-C [31], etc. Actual load balancing cannot be presented in LEACH. Also, dynamic clustering brings extra overhead.

Bandyopadhyay et al., (2003discussed a clustering protocol, with each cluster having a head node called cluster head. Sensors communicate information to cluster heads only which then communicate to the base station. Such a design may help increase WSN lifetime by saving energy. They compare several clustering algorithms and propose a fast, distributed and randomized clustering algorithm to organize the sensors in a WSN. This algorithm is shown to have lesser complexity and more energy savings.

The authors have used stochastic geometry to arrive at values of parameters for the algorithm that minimize the energy spent in the WSN, specifically by minimizing the communications to the base station. The authors also report that energy savings increases with the number of levels in the hierarchy of clusters. The proposed algorithm is said to be suitable for networks of a large number of nodes.

Qing et al., (2006) have introduced Distributed Energy Efficient Clustering (DEEC) algorithm for heterogeneous WSNs. In heterogeneous network, all nodes have different levels of energy and the distributed nature of the network protects single point failure. In DEEC, like LEACH, the CH role is rotated among all the nodes in the network. CHs are chosen based on residual energy and average energy of the network. Nodes with high initial energy and residual energy have a high probability to become a CH. DEEC assigns different epoch for each round of selection of cluster head by considering both the initial and residual energy. Residual energy is calculated on the basis of ideal value of a network lifetime and global knowledge of the network is not required by each node. DEEC controls the equal dissipation of energy in each round by controlling the rotating epoch in accordance with the current energy level and average energy of the network as the reference energy. Hence, nodes die at the same time.

DEEC results are more significant in terms of energy efficiency and longer lifetime of network than the other algorithms it is compared with. But advanced nodes always punished to become CH. Although after some rounds, the energy of advanced nodes is equal to that of normal nodes. Other limitation of DEEC is that the average energy is not directly proportional to the energy consumed in all iterations.

Lotf et al., (2008) introduced Extended Lifetime of Cluster Head (ELCH) that confirmed better results in terms of energy efficiency as compared with LEACH. It is a distributed protocol that combines multi-hop routing and cluster architecture for achieving the energy efficiency. Cluster heads collect the data and send it to the BS via intermediate nodes. Nodes in the clusters are chosen based on their location i.e. nodes which receive stronger signal strength are selected. Each node forwards the data directly to the cluster head.

Yong, Z. et al., (2012), The Authors claim that their proposed clustering algorithm DECSA (Distance-Energy Cluster Structure Algorithm) is an alternative to LEACH that prolongs 31% of network lifetime, reduces 40% of the energy consumption and has a better overall performance than the original LEACH protocol. Their critique of LEACH is that it does not consider the location and residual energy of nodes which leads to overall inefficiency in the network. DECSA, on the other hand, considers both distance and residual energy of the nodes. The node with greater residual energy is elected as the cluster head and their algorithm optimizes high power communication between cluster head and the base station. Cluster head is selected in two phases- 1) Election of an ordinary cluster head node 2) Election of base station cluster head node (CH closest to the Base station is BCH). In first phase, false cluster head nodes are selected based on a threshold value by considering distance and residual energy. If the random value is smaller than the threshold value, then it is considered as a CH node. In the next round of CH, if the threshold value of all nodes in the cluster is greater than the false CH value, then it is designated as CH.

In second phase, BCH are selected on the basis of a threshold value and if value is greater than the predefined threshold, Base station broadcasts the message and the CH, which has the maximum value of threshold, will be considered as next hop by the BCH. This way, it connects to the CH and forms a complete path to the destination and reduces the energy consumption of CH nodes with low residual energy.

Nikolidakis et al., (2013), This research paper acknowledged that WSNs are used in a very wide variety of applications such as agriculture, traffic control, environment and habitat monitoring, object tracking, fire detection, surveillance and reconnaissance, home automation, biomedical applications, inventory control, machine failure diagnosis and energy management. However, the use of WSNs is severely limited due to lack of energy management. This work proposes a routing algorithm termed ECHERP (Equalized Cluster Head Election Routing Protocol), which pursues energy conservation through balanced clustering in a homogeneous environment. These are compared in a detailed manner with existing algorithms of LEACH, PEGASIS, and BCDCP. ECHERP models the network as a linear system and computes the combination of nodes that can be chosen as cluster heads in order to extend the network lifetime. Cluster head selection is done through Gaussian elimination method in two steps.

The BS calculates the number of rounds for which a node can become a CH. Re-clustering process is not carried out which minimizes the energy wasted. For maximizing the network lifetime, current energy levels and estimated future residual energy levels of nodes are considered. Upper level CH nodes and lower level CH nodes are selected which establish the energy efficiency of their algorithm through simulation tests. But, multi-hop CH selection by BS and application of Gaussian elimination algorithm makes the design complex.

Lee et al., (2016) discuss the improvement in Leach protocol. LEACH (Low Energy Adaptive Clustering Hierarchy) is an algorithm that divides the entire network into a random cluster and manages by forming the head for each cluster. The Dual Hop method is used during transmission of LEACH to reduce the energy consumption of cluster heads for remote transmission and to increase the energy efficiency of sensor nodes. DL-LEACH changes the previous transmission method of LEACH to a dual hop (single-hop + multi-hop) transmission method. The multi-hop transmission of DL-LEACH is made of layer units. The member nodes send the data to the closest CH. The cluster head of DL-LEACH transmits its data to the closest cluster head near the lower level. This layer consolidates the above information with its own information and sends it to the lower layer. If a cluster head is absented in this layer then the data is sent to the Base Station. This way, the process uses both single-hop and multi-hop.

Smaragdakis et al. [41] are known for a Stable Election Protocol (SEP) which is a variation of LEACH. It is designed mainly for dual level heterogeneous networks composed of doublet types of sensors (particularly Advance and normal nodes).In general, advance sensors retain extra energy and this has to be turned CH's more frequently compared to normal nodes. Here CH's chosen pertain to sensors initial energy. The main disadvantage is that this decision of CH's is not dynamic. As a consequence, advanced nodes that are far flung with reference to the sink drain their energy faster and depart from their existence soon. SEP is not suitable for multilevel heterogeneous network.

Malluh et al. [42] have suggested an improved form of SEP. Here also, advanced nodes are selected as CH's more often than the normal sensors. In addition, the number of nodes connected with each CH is considered. Thus enables equitable distribution for the sensor nodes between the CH's. Also, in the event of an excess of one sensor accessible to be a CH at certain round, EM-SEP chooses the higher energy sensor as a CH. Those two factors protract the stable period of the sensor network. The main drawback in this method is that inter-cluster communication cost is not considered.

Georgious et al. [42], propose Stable Election Protocol (SEP), a heterogeneous-aware protocol to prolong the stability period and average throughput. SEP is based on weighted election probabilities of nodes to become CH according to the residual energy. Nodes are divided into two categories; based on their energy one are advanced nodes and other are normal nodes advanced node have more energy than normal nodes. The probability to become cluster head of advanced node is more than normal nodes.

III. Need of Solar Power Generation

The quantity and availability of conventional energy sources are not sufficient resources to meet up with the current day's power demand in the power sector in these modern times, which is one of the major concerns in the field of power sector in these modern days. The demand for power is steadily growing more each day. In light of the fact that conventional sources of power generation may not be available in the foreseeable future, it is of the utmost importance that conventional energy generation systems, in addition to renewable energy sources, be utilized in order to fulfill the requirements of the energy demand.

In order to fix the energy problem that we are experiencing right now, one renewable technique is the process of deriving power from the sun's incoming radiation. This process is referred to as solar energy, and it is available to everyone throughout the world at no cost. Solar energy is abundantly available on the surface of the planet as well as in space, allowing us to harvest its energy, transform that energy into a form of energy that is suitable for our needs, and appropriately utilize it with efficiency. Depending on the utility, the location of the demand region, and the availability of power grids nearby, solar power generation can either be connected to an existing grid or it can be an isolated or stand-alone power generating system. Both of these configurations are possible. Therefore, solar energy can be utilized to give power to locations where there is limited availability of grid connections or where connecting to a grid would be exceedingly difficult or expensive. The two most significant benefits of solar energy are that it does not release any greenhouse gases during its operation and has a fuel cost of exactly zero dollars per megawatt-hour (MWh). Another advantage of employing solar power for the generation of tiny amounts of power is that it is portable; meaning that it can be taken with us whenever and wherever there is a need for modest amounts of power generation.

Over the course of the past few years, the processes that convert solar energy into usable power have become much more compact. The advancement of research in the fields of power electronics and material science has been of great assistance to engineers in the process of developing such a system that is very small but effective and powerful systems that have the capability to withstand for the supply of high levels of electric power demand. In each and every nation, the demand for power density is growing on a daily basis. Solar power generation also has the capacity to handle voltage fluctuations very successfully by configuring the system to employ multiple input converter units. This is possible thanks to the system's ability to handle numerous inputs. However, solar power generation systems are unable to actively participate in the competitive power markets as a primary renewable source of power generation because of the high installation costs associated with these systems and the low efficiency of the solar cells.

In order to make solar cells more effective, researchers are always working to advance the technology used in their production in the field of solar cell research and development. That will unquestionably help to make the use of solar production as a habit for usage in everyday life as a primary renewable source of electrical power on a wider range basis than the conditions that exist in the present day. It has been shown that using the most up-to-date power control mechanisms, such as Maximum Power Point Tracking, also abbreviated as MPPT, can lead to an improvement in the overall efficiency of the system that generates electricity from solar cells. These mechanisms are currently being implemented in solar power generation systems. Therefore, the most important application for MPPT is in the sphere of the consumption of energy derived from renewable sources.

IV. PV Model with Parameters

A thin semiconductor wafer composed of two layers, typically comprised of highly pure silicon, makes up a single photovoltaic (PV) cell (PV cells can be made of many different semiconductors but crystalline silicon is the most widely used). The layers have been doped with boron on one side and phosphorous on the other, which has resulted in an excess of electrons on one side of the material and a deficiency on the other side.

A voltage differential is created between the two sides of the wafer as a result of the excess electrons trying to travel to the deficit side. This difference is caused by the photons in the sunlight, which are responsible for the bombardment of the wafer by the sunlight. The voltage at this point is 0.5 volts in silicon. Both sides of the semiconductor receive metallic connections from the outside world. When an external circuit is coupled to the contacts, the electrons are able to travel back to the location from which they originated, and this allows current to flow through the circuit. This photovoltaic cell does not have any storage space; all it does is operate as an electron pump. The number of electrons that are displaced as a result of sun photons is directly proportional to the quantity of current. More electrons will be delivered by cells that are either larger in size, more efficient, or that are subjected to stronger sunlight.

An amazing phenomenon known as photovoltaic impact is responsible for the conversion of light energy into electrical energy (Mathew, A., &Selvakumar, A. I., 2006). When semiconductor materials are exposed to light, a fraction of the photons that make up the light beam are absorbed by the semiconductor gem, which results in an essential number of free electrons in the gem. This is the primary goal of the distribution of power generated by photovoltaic effect. The photovoltaic cell is the basic building block of the photovoltaic system, which converts light energy into usable electricity.

When it comes to the construction of solar cells, the semiconductor material that is used most frequently is silicon. Valence electrons are present in the silicon molecule in four different positions. Every single silicon iota in a hard precious stone shares each of its four valence electrons with another silicon particle that is physically nearest to it. This results in the formation of covalent links between the silicon atoms. In this manner, the cross-sectional structure of the silicon precious stone is given the form of a tetrahedron. When a light beam impacts any substance, a portion of the light is reflected, a portion of the light is transmitted through the medium, and the remaining light is absorbed by the material. When light is shone on a silicon precious stone, a phenomenon quite similar to this one takes place. In the event that the power of the incident light is sufficiently great, adequate quantities of photons are consumed by the gem, and these photons, in turn, activate a portion of the electrons that are associated with the covalent bonds. At that point, the electrons that were previously excited obtain sufficient energy to transition from the valence band to the conduction band. Because the energy level of these electrons is in the conduction band, they depart the covalent bond, leaving behind a hole in the bond for each electron that they eliminate. These electrons, which are referred to as "free electrons," wander around at will within the precious stone structure of the silicon. These apertures and free electrons are extremely important components in the process of producing power in a solar cell. These electrons and apertures are referred to as light-created electrons and openings respectively from this point forward. These light-created electrons and apertures are not capable of delivering power by them within the silicon gem. It seems like there ought to be an additional way for doing that.

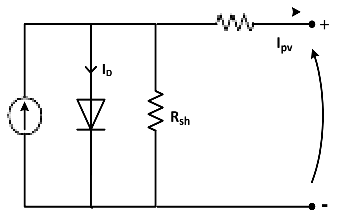


Figure 1: Single diode model of PV cell

Figure 1 is a PV cell in which one current source, one forward bias diode, 2 resistances are connected.
The electron-hole pair (EHP) is produced Incident of a photon of light energy (hv>Eg) over a solar cell. The newly created EHP relates to electric current denoted by (IL) termed light induced current. The ideal equation of a solar cell with current-voltage (I – V) is given as

$$Solar\ Cell\ Current\ (I) = I_{ph} - I_0\left[\exp\left(\frac{qV}{kT}\right) - i1\right] \quad (1)$$

Where, I = solar cell output current, I_{ph} = light produced by solar cell, Io = Reverse current of saturation because of reconjunction, q = electron charge ($1.6 * 10^{-19}$ C), V = Open-circuit voltage of solar cell, k= Boltzmann constant ($1.38 * 10^{-23}$ J/ K), T = solar cell temperature (300 K).
The circuit model in figure 1 represents equivalent of solar cell. It comprises light-produced source current (Iph), a Shockley equation-modeled diode (D), and two series and parallel resistances. Figure 3.11 shows the VI and PV characteristic in which on voltage shows and on y axis current lsft side and power right side shows.

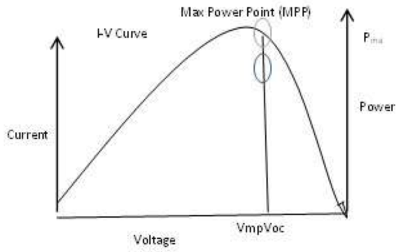


Figure 2: V-I and P-V Characteristic

The maximum power point (MPP) is a point on the Power voltage (P-V) characteristic of the solar cell, where the maximum power can be extracted from the solar cell as shown in Figure 2. Ideally, the solar cell efficiency should be high. But practically, it is limited to 5%–15%only (Green, M. A., Hishikawa, 2018).
In Figure 2, the current law of Kirchhoff (KCL) can provide characteristic equation of current for that corresponding circuit:

$$\text{Equivalent Cell Output Current } (I) = I_{ph} - I_D - I_P \quad (2)$$

Where,I_P= parallel resistance current, I_{ph} = Light produced current, and I_D = diode current.

$$Diode\ Current\ (I_D) = I_o\left[\exp\left(\frac{V+IR_S}{nV_T}\right) - 1\right] \quad (3)$$

Where, I_o = Reverse Saturation current because of reconjunction, V = solar cell open circuit voltage, R_s = series resistance, Ipv = solar cell output current, n = diode norm factor, (1 termed as ideal, 2 termed as practical diode), k = Boltzmann constant (1.38×10^{-23} J/K), V_T = Thermal voltage (kT/q), T = Solar cell Temperature (300 K). Q = electron charge (1.6×10^{-19} C). The parallel-resistance current is determined as:

$$Current\ in\ parallel\ resistance(I_p) = \frac{V+IpvR_S}{R_p} \quad (4)$$

Now, by placing the I_D and Ip value in the equation (4), we obtain complete equivalent circuit fourth equation of solar cell, under that all values are defined as connected with output current and voltage [9]:

$$Solar\ Cell\ Current\ (I) = I_L - I_0\left[\exp\left(\frac{q(V+IpvR_S)}{nkT}\right)\right] - \left(\frac{V+IR_S}{R_p}\right) \quad (5)$$

Where, Rp = Parallel Resistance and in Equation (5), the other parameters Io, I_L, V, I, q, Rs, n, k, T were already declared. The solar cell efficiency (η) is termed as:

$$Solar\ Cell\ Efficiency\ (\eta) = \frac{V_{OC}I_{SC}FF}{P_{in}} \quad (6)$$

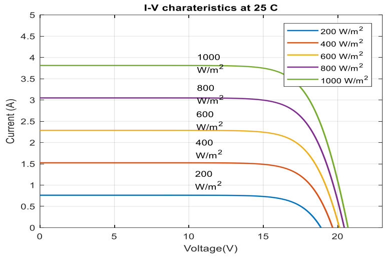
Where Isc is Current Short Circuit, Voc is called Open Circuit Voltage, FF = Fill Factor and Pin = optical incident power. A Solar Cell's Fill Factor (FF) is given as

$$Fill\ Factor\ (FF) = \frac{P_{max}}{P_{dc}} = \frac{I_mV_m}{I_{SC}V_{OC}} \quad (7)$$

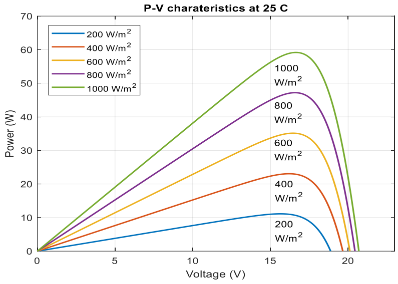
Where V_m is the solar cell's maximum voltage and I_m is called maximum current. There are practically many kinds of solar cells, like amorphous silicon solar cells (a-Si), mono-crystalline silicon solar cells (C-Si), thin film solar cells (TFSC), polycrystalline solar cells (multi-Si) etc. But the productivity of a-Si solar cells is greater than any other efficiency till 18 per cent.

- **Solar Radiation Effect (G)**

The efficiency of solar cell (η) is proportional to solar radiations variations. The efficiency of solar cell (η) increases, on increasing the solar radiation and vice versa. Figure 3 (a) displays the current-voltage (I–iV) properties of a commercial solar panel of 10 watts with varying values of irradiance.



(a)



(b)

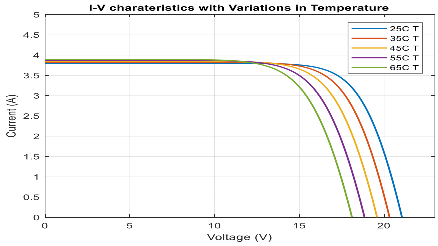
Figure 3: Solar Panel characterization with Irradiance level variations (Watts/m^2). (a) Characteristics of (I–V) (b) Characteristics of (P–V)

The solar panel of 10 watts 10 watts (Dow Chemical DPS 10–1000) is 232 mm * 546 mm in size and has 0.13 m^2 module area. By Figure 3 (a), it is identified that the solar panel current is increasing with increase in degree of irradiance. Here the solar cell current for solar irradiance of 1000 W/m^2 is optimum (6.2 A). Figure 3 (b) shows the Power-Voltage properties of Solar Panel in various radiation levels. For highest solar irradiance like 1000, the extracted power is the optimum (9.8 W).

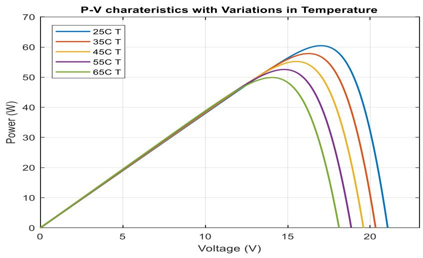
Figure 3 (a) shows solar panel irradiance variation IV characteristic in which x axis shows voltage and y axis shows current. In figure 3 (b) x axis is voltage and y axis is power.

- **The Temperature Effect (T)**

Such as the one in Figure 4 (a), if the temperature of the solar panel increases then the production value decreases and vice versa. And the increase in output is in direct accordance with the fluctuations in temperature. Similarly as the temperature in Figure 4 (b) increases, output capacity decreases, and vice-versa. Hence the output power is inversely proportional to the variations of temperature.



(a)



(b)

Figure 4:.Characteristics of solar panels with Temperature (^{o}C) variations. (a) Characteristics of (I–V); (b) Characteristics of (P-V)

Figure 4 (a) and (b) shows characteristic of solar panel with temperature variation in figure (a) x axis is voltage and y axis is current, in figure (b) x axis is voltage and y axis is power.

- **Systems for Harvesting Solar Energy**

A simple solar energy harvesting system is a combination of rechargeable battery, solar panel, DC-DC converter, Battery Management System (BMS) safety charging circuit and DC-DC converter control unit. For DC-DC converters, control methods are generally maximal power point tracking control (MPPT). The SEH unit in Figure 3.14 contains rechargeable battery, DC-DC buck converter, maximum power point (MPPT) solar panel and transmitter, and a WSN sensor node attached to the DC.

Solar energy from the natural sun is collected in solar panels and transformed into electricity. The DC-DC Buck converter is shut off and this caused voltage magnitude is controlled and transferred to the same rechargeable unit. An MPPT sensor controls the Solar Panel's current and voltage, changing the duty period as a Buck MOSFET DC-DC converter (Mathews, I., King, 2015).

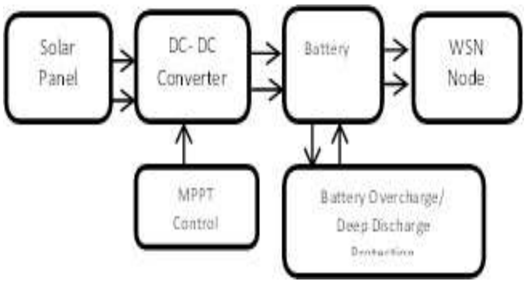


Figure 5: Solar energy recovery (harvesting) system block diagram, using input from MPPT capacity

Figure 5 shows block diagram of solar energy harvest and it has DC-DC converter, battery, WSN node, solar panel etc.Finally, the wireless sensor node is regulated by the voltage of the batteries. The WSN performs the role of detecting, analyzing and interacting the same characteristics with other nodes. Thus, as with vibration, temperature, acceleration and humidity, the SEH-WSN nodes can be used to track and control any physical phenomenon autonomously. In this scenario, solar harvester circuit's efficiency exhibits a very significant function. If solar power harvester's performance is low, battery will not be recharged sufficiently, thereby reducing the lifespan of the wireless sensor network.

V. Maximum Power Point Tracking (MPPT) Modeling Technique

The efficiency of a solar cell is very low and also when solar cells are connected together to form a panel then its efficiency is still not increased [8]. In order to increase the efficiency (η) of solar cell or solar panel we have to use maximum power transfer theorem.

The maximum power transfer theorem says that the maximum power is transfer when the output resistance of source matches with the load resistance [18] i.e. solar cell or solar panel impedance. So all MPPT technique's principles are based on maximum power transfer theorem that always trying to matching the impedance of load to source.

The effectiveness of MPPT is given by following equation. [15]

$$\eta_{MPPT} = \frac{\int_0^t P_{measured}(t)dt}{\int_0^t P_{actual}(t)dt} \quad (8)$$

Because the V-I characteristics of PV power generation systems are nonlinear, it can be challenging to supply a constant amount of power to a particular load. As a result, the maximum power point tracking (MPPT) has become standard practice in PV power generation systems that are connected to the grid, and it is also gaining popularity in power generation systems that are isolated from the grid or that operate independently.

Many individuals have the misconception that the MPPT is a mechanical device that tracks the sun, rotates the solar panel or solar cells, and tilts it in the direction of the sun where there is a greater amount of solar irradiance. This belief contributes to the confusion that exists regarding the MPPT. However, the MPPT is a piece of electronic equipment that is used to harvest the maximum amount of power possible from solar panels. It does this by adjusting the duty cycle of the DC/DC converter, which matches the impedance of the load to that of the PV cells, so altering the electrical working point of the panel. While a mechanical tracking system can be utilized with MPPT, it is important to note that these two tracking methods are not at all similar to one another.

Consider a solar panel as a starting point for our exploration of the MPPT's operation. Because the photovoltaic effect is how solar panels produce electricity, it should come as no surprise that solar panels have a P-V characteristic. This implies that depending on the operating point of the solar panel, it is possible to achieve a variety of levels of power output. Therefore, the solar panel will produce the most amount of electricity when it is working at only one particular operating point on the P-V characteristic of the solar panel. This will allow the panel to produce the most amount of power feasible. The Maximum Power Position is the name given to this particular point on the P-V characteristic (MPP). This MPP shifts whenever there is a change in either the temperature or the amount of solar irradiation, as well as while the solar panel is partially obscured [13]. Therefore, whenever any one of these three factors is altered, the working point of the solar panel will also shift. A tool known as a Maximum Power Point Tracker is required in order to monitor the MPP, which is in a state of constant flux (MPPT).

Solar cells typically have a relatively poor efficiency rating. Methods need to be implemented in order to correctly match the source with the load in order to achieve the goal of increasing efficiency. The Maximum Power Point Tracking technique is one example of such a strategy (MPPT). This is a method that is used to obtain the highest amount of power that may be obtained from a variable source. Because the I-V curve in solar systems is non-linear, it is difficult to use these systems to power a specific load. This is because photovoltaic systems are not linear. This is accomplished through the utilization of a boost converter, the duty cycle of which is adjusted through the application of an MPPT algorithm. Under specific circumstances, maximum power point tracking, or MPPT, is an algorithm that is included in charge controllers and is used to collect the greatest amount of available power from PV modules. The voltage at which a PV module is capable of producing the most amount of power is referred to as the "peak power voltage" or "maximum power point." The maximum potential of MPPT is realised in conditions resembling chilly weather, gloomy skies, or hazy days. A wide variety of different algorithms have been developed that are capable of tracking MPPs. Some of them are straightforward, such the methods that are based on voltage and current feedback, such as the P&O approach.

The P&O algorithms operate by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage or current and comparing the PV output power with that of the previous perturbation cycle. If the PV array operating voltage changes and power increases (dP/dV PV>0), the control system moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way. When the maximum power point is reached, the output power will oscillate around the maximum, which will cause power loss in the PV system. This is a common issue with P&O algorithms because it causes the array terminal voltage to be perturbed during each MPPT cycle. This is especially the case when the atmospheric conditions are either stable or only slightly variable. In addition, the P&O methods might not work in environments where the weather is constantly shifting (Figure 6). Starting from an operating point A, if atmospheric conditions remain approximately the same, a perturbation V the voltage V will bring the operating point to B, and the perturbation will be reversed due to a decrease in power. This is assuming that the operating point A will remain approximately the same. The operating point will change from A to C if the irradiance is increased, which will shift the power curve from P1 to P2 within the same sampling period. This results in an increase in power while maintaining the same level of perturbation. As a consequence of this, the operating point moves away from the MPP, and it will continue to move away from the MPP if the irradiance continues to gradually increase.

The literature presents a wide variety of different P&O methodologies to choose from. In this work, we look at three different weight comparison algorithms: the traditional one, the optimized one, and the three-points one. The PV operating point is subject to perturbations of a fixed magnitude when using the traditional P&O technique, also known as P&Oa. According to our research, the level of disturbance accounts for 0.37 percent of the total VOV of the PV array (around 2V) An average of several samples of the array power is utilized in the optimized P&O technique, also known as P&Ob, in order to dynamically adjust the magnitude of the perturbation that occurs at the PV operating point..

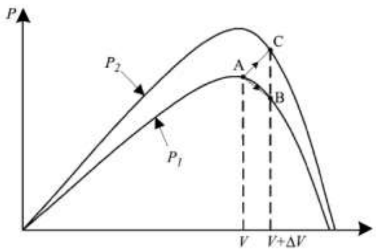


Figure 6: Divergence of P&O from MPPT

In the three-point weight comparison method (P&Oc), the perturbation direction is decided by comparing the PV output power on three points of the P-V curve. These three points are the current operation point (A), a point B perturbed from point A, and a point C doubly perturbed in the opposite direction from point B. All three algorithms require two measurements: a measurement of the voltage VPV and a measurement of the current IPV (Figure 7)

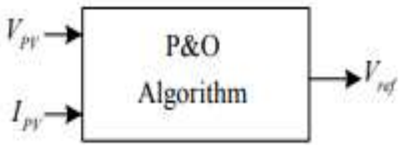


Figure 7: P&O block diagram

VI. INCREMENTAL CONDUCTANCE (INC) ALGORITHM

In the case of photovoltaic (PV) systems, the incremental-conductance (INC) method is also utilised. It does this by contrasting the instant conductance of the PV array with the incremental conductance. The problem with the INC system is relatively close to P&O's. In most cases, the fixed step size is applied, which determines both the speed and the accuracy of the MPPT's response. Because of this, a choice needs to be made regarding the balance between tracking speed and steady state efficiency. A problem of this sort with the architecture can be made stable using MPPT strategies with variable step duration.

The Power respect to Voltage derivative, abbreviated as dP/dV, is what's used to adjust the MPPT phase scale. The Incremental Conductance (IC) technique eliminates the disadvantage of perturbation and identifies a method for monitoring peak power in environments where the atmosphere is constantly shifting. This method will determine whether or not MPPT has passed the MPP and will also stop perturbing the point of service once it has reached that decision. It is feasible to establish the direction in which that MPPT operating point is to be disturbed by using the relation between dl/dVi and -I/V if the condition is not true. This relation can be deduced from the observation that dP/dVi is negative when MPPT is to the right side of MPP, whereas it is positive when MPPT is to the left side of MPP. When the operating point is further away from the MPP, the phase size grows larger; conversely, the phase size gradually shrinks as the operating point draws closer to the MPP.

By adjusting the phase size, it is possible to simultaneously obtain the quick tracking velocity and steady performance. However, the MPPT method convergence requires the use of a scaling factor, and the factor has the effect of drastically slowing response time whenever there is a sudden change in the atmospheric conditions. The incremental-resistance (INR) feature of an MPPT algorithm is going to be evaluated alongside an adjusted step variable size (Ibrahim, R., Chung, 2017). A threshold function is applied in order to transition between the fixed step mode and the variable step mode. The variable step phase is sensed through the variation of the scaling factor.

This method achieves quick response and precisely steady state output, but its implementation is constrained by a high computing load and the best non-linearity of scaling factor. Despite these constraints, the method is still useful. There are two phase size alteration coefficients in (Li, Y., & Shi, R., 2015) to minimise the perturbation effects (duty ratio) under the drastic shift in irradiation with less computing, but the influence of the basic step size upon on method efficiency is not taken into consideration. This is done so in order to minimise the effects of the perturbation on the duty ratio.

While P&O toggles around MPP itself, this algorithm determines when MPPT will hit MPP. This blatantly demonstrates a benefit in comparison to P&O. The incremental conductance could also monitor conditions of irradiance that are rapidly increasing and decreasing with greater accuracy than the disturbance, and it could observe method (Praveen, K., Pudipeddi, M., 2016). In contrast to P&O, the algorithm is more difficult to understand and implement. This is a drawback of the algorithm.

VII. Conclusion

The maximum power point tracking (MPPT) method is an algorithm that is included in charge controllers and is used to collect the maximum amount of available power from PV modules. The voltage at which a PV module is capable of producing the most amount of power is referred to as the "peak power voltage" or "maximum power point." In this review study, the principles of INC-MPPT were examined in conjunction with PV modules and the Solar Energy Harvesting System for WSN nodes.

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