INC-MPPT based Optimization of Solar Energy Harvesting System for WSN Nodes

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Abstract—**Solar photovoltaic power generation system is one of the burning research fields these days, even governments are also making plans toward increasing the amount of power generation from renewable energy sources because in future viability and crisis of conventional energy sources will increase.Solar energy is the energy source which is clean and sustainable. The implementation of WSN with Solar energy harvesting technique has been in research in IoT in recent times. The WSN node battery energy is minimal and can last for just a few days depending on the operating duty cycle. In this paper we are proposing a new SEH technique for energy constrained WSN nodes. Solar Energy Harvesting Wireless Sensor Network (SEH-WSN) nodes will usually run for years to come. In the past, the harvesting of solar energy was developed using the technique of P&O Maximum Power Point Tracking (MPPT), which yielded very good results. However, INC (Incremental Conductance) does produce better effects than P&O. We're using the INC-MPPT technique to apply SEH-WSN and compare it with the methodology of P&O-MPPT.**

Index Terms—Solar energy harvesting, INC, MPPT, DC-DC Converter

I. Introduction

A basic some portion of Internet of Things (IoTs) is the remote sensor organization (WSN). These organizations have been generally utilized in different applications, for example, protecting in military, crisis recuperation, tolerant wellbeing checking, air quality observing and so on [1]. Headway in late remote innovation has set off the requirement for gadgets to run on free force sources. This is clear particularly with the remote sensor organization (WSN). This can be refined through reaping energy from the general climate, for example, sun oriented, wind and so forth. These energy reaping gadgets can control the remote sensor hubs either straightforwardly of related to a battery [2]. The WSN hubs experience the ill effects of a significant plan imperative that their battery energy is restricted and can work just for a couple of days relying on the obligation pattern of activity [3].

The sunlight based energy generally put away in sun powered cells so the energy putting away proficiency must be expanded. Sunlight based energy framework can be changed over quickly into power utilizing PV boards through the photovoltaic impact [4]. Be that as it may, the transformation productivity is low and the expense of intensity created is similarly high. PV age has numerous favorable circumstances, for example, it has low fuel costs, doesn't create contamination, requires little upkeep, and PV framework has more different highlights [5]. Sunlight based photovoltaic (PV) energy collecting alludes to changing over sun based light energy into electrical energy to work an electrical or electronic gadget.

As applied to WSNs, sun based light energy is changed over into electrical energy and is used to revive the battery of a WSN hub at the activity site itself [6]. In this manner, battery substitution is required over and over once the battery energy has been released. The electrical energy gathered from sun based energy can likewise be utilized legitimately to control a WSN hub. Then again, the gathered energy might be warehoused in a battery-powered battery for future purposes.

The SEH-WSNs comprise of little self-sufficient WSN hubs connected to little measure sunlight based boards for their energy collecting needs. It is seen that the greatest conceivable gathered force from sun powered energy at outside is 15 mW/cm^2 with productivity up to 30%[7]. Accordingly, we have picked sun based energy gathering for providing substitute capacity to the WSNs as it has the most powerful thickness and great productivity.

Various techniques to follow the most extreme force purpose of a PV module have been proposed [8] to beat the restriction of effectiveness. MPPT is utilized for removing the most extreme force from the sun oriented PV module and moving that capacity to the heap.

DC-DC converter goes about as an interface between the heap and the PV module as it effectively transfer greatest force from the sun powered PV module to the heap. By changing the obligation cycle the heap impedance is coordinated with the source impedance to accomplish the most extreme force from the PV board [9]. Here we compare the INC-MPPT and P&O-MPPT techniques with the respect of efficiency and the best result will be shown.

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%.

This means greatest force point following (MPPT) calculations are gotten together with the whole framework to augment their capacity and lessen modules cost. Different key research findings available in the literature are summarized in Table 1.

Table 1: Summarization of different key approaches proposed in literature

Paper Ref	Objective	Strategy
(Baci, A. B., Salmi, M.,2020)	Here the creator has depicted the length of daylight outperforms 2000 hours every year and can arrive at 3900 hours on the good countries and the Sahara. The significance of this work depends on misusing sun oriented energy to create power..	The model of new counterfeit sun based tree is proposed tentatively by utilizing material accessible in the nearby market: 25 sun based panels,metal uphold, electrical lines, controller, and battery.
(Akinaga, H., 2020)	Energy reaping innovation is standing out as "empowering innovation" that extendsthe utilization and chances of IoTusage,enhances lives and improves socialflexibility. This innovation harvests energythat disseminates around us, aselectromagnetic waves, heat, vibration, andso on and changes it into simple over toutilize electric energy.	Here creator depicts the highlights of the energy reaping advancements, late subjects and significant difficulties, and strongly predicts the future possibilities of the turn of events.
(Sharma, H., Haque, A.,2018)	The WSN hubs experience the ill effects of a significant plan limitation that their battery energy is restricted and can turn out just for a couple of days relying on the obligation pattern of activity.	we propose another answer for this plan issue by utilizing surrounding sun based photovoltaic energy. Here, we propose a profoundly productive and special sunlight based energy reaping framework for battery-powered battery based WSN hubs.
Akinaga, H., KapoorS, 2020)	The principle commitment of thisexploration article is to propose an effective sun based energy gathering answer for the restricted battery energy issue of WSN hubsby using surrounding sun basedphotovoltaic energy. Preferably, theOptimized Solar Energy HarvestingWireless Sensor Network (SEH-WSN) hubs ought to work for an endless organization lifetime.	It propose a novel and effective sun based energy collecting framework with heartbeat width adjustment (PWM) and greatest force point following (MPPT) for WSN hubs. The exploration center is to expand the general collecting framework proficiency, which further relies on sun powered board effectiveness, PWM productivity, and MPPT effectiveness.
(Koech, R. K., Kigozi, M.,2019)	With an end goal to make sun oriented energy bridling more effective and moderate, different advances have been created. The sun based warm innovations have accomplished amazing sun oriented transformation efficiencies and are completely popularized. Notwithstanding, PV innovation is as yet going through quick development with an end goal to accomplish high efficiencies and to lessen the expense.	New materials, ideas and approaches in sunlight based cell advancement have become the focal point of exploration in this field. This article gives a survey on the advancement of PV innovation with a distinct fascination on the arising PV materials that hold the possibilities for accomplishing high efficiencies at low expenses.
(Eseosa, O., & Kingsley, I., 2020).	The paper is on reenactment of MPPT utilizing P&O also, INC techniques. Numerical model of 100KW PV framework was created utilizing Matlab M-document. The two models were planned and reenacted utilizing MATLAB/SIMULINK. t is shown that PV framework yield power increments with ascend in sun powered illumination and in lower cell temperature. Accordingly, sun based cell performs preferred in warm climate over virus climate.	It is suggested that the MPPT The framework should comprise of partial, three-point, temperature-based MPPT for more successful and improved examination. Moresothe annoy and noticed technique ought to be enhanced by fluctuating of the irradiance to keep an increment consistent voltage.
(Liu, L., Oza, S.,2015)	To create cause-explicit mortality parts, we included new crucial enlistment and verbal examination information.	We utilized fundamental enlistment information in nations with satisfactory enrollment frameworks. We applied indispensable enlistment based multicar use models for nations with low under-5 mortality however insufficient essential enrollment, and

		refreshed verbal dissection based multi cause models for high mortality nations
(Kumar, R., Choudhary, A., 2017)	This paper manages reproduction/demonstrating, controlling of greatest force point following (MPPT) utilized in PV frameworks to augment the yield force of photovoltaic framework, light conditions independent of the temperature of VI attributes of burden.	In this exploration a significant greatest force point following method has been created, comprising a lift converter, which is controlling heartbeat given by a microcontroller-based unit.
(Kinjal, P., Shah, K. B.,2015)	Of late, sustainable power innovation has had critical impact in energy application. One commendable sort of sustainable energy will be energy from the sun that creates electrical power straightforwardly by utilizing PV modules helped by MPPT calculations to make as extensive as conceivable the sunlight based yield power.	More or less, by changing the yield force of the inverter, the objective of accomplishing MPPT in PV frameworks is to change the conceivable working voltage of PV boards to the voltage at MPPT.
(Kumar, M. Kapoor, S. R., 2015)	The Solar force differs chiefly relies upon the climate conditions. Numerous new calculations have been projected to follow the most extreme force point (MPPT) of the close planetary system. This paper, presents a similar investigation of two astute control techniques to enhance the proficiency of the sun powered PV framework.	This paper presents in subtleties near investigation between Incremental conductance calculation and fluffy Logic regulator calculation applied to a DCDC Boost converter gadget. The Boost converter expands yield voltage, it is relies upon the obligation pattern of switch gadget.

The table 1 has three columnsfirst one shows reference numbers, second one shows objective of the related work and third column shows strategy of the work that how the perform.

III. PV Model with Parameters

Silicon is the most generally utilized semiconductor material for developing the photovoltaic cell. The silicon molecule has four valence electrons. In a strong precious stone, every silicon iota shares every one of its four valence electrons with another closest silicon particle thus making covalent connections between them. Along these lines, silicon precious stone gets a tetrahedral cross section structure. While light beam strikes on any materials some part of the light is mirrored, some bit is sent through the materials and rest is consumed by the materials. Something very similar happens when light falls on a silicon precious stone. On the off chance that the power of episode light is sufficiently high, adequate quantities of photons are consumed by the gem and these photons, thus, energize a portion of the electrons of covalent bonds. These energized electrons at that point get adequate energy to move from valence band to conduction band. As the energy level of these electrons is in the conduction band, they leave from the covalent bond leaving a gap in the bond behind each eliminated electron. These are called free electrons move arbitrarily inside the precious stone structure of the silicon. These free electrons and openings have a fundamental part in making power in photovoltaic cell. These electrons and openings are henceforth called light-created electrons and gaps separately. These light created electrons and openings can't deliver power in the silicon gem alone. There ought to be some extra system to do that.

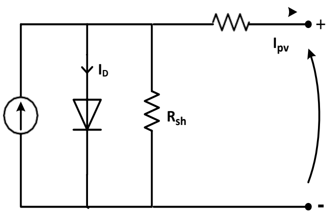


Figure 1: Single diode model of PV cell

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.

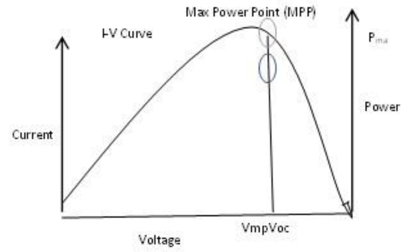


Figure 2: V-I and P-V Characteristic

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:

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

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

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

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:

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

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]:

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

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:

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

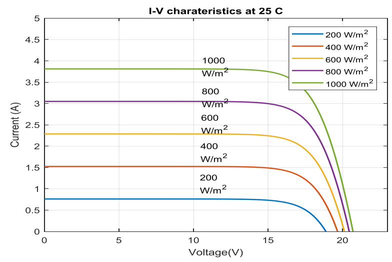
Where Isc is Current Short Circuit, Voc is called Open Circuit Voltage, FF = Fill Factor and Pin = optical incident power. A Solar Cell's Fill Factor (FF) is given as

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

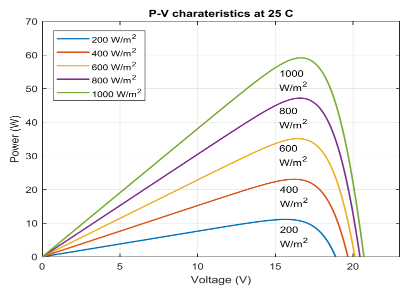
Where V_m is the solar cell's maximum voltage and I_m is called maximum current. There are practically many kinds of solar cells, like amorphous silicon solar cells (a-Si), mono-crystalline silicon solar cells (C-Si), thin film solar cells (TFSC), polycrystalline solar cells (multi-Si) etc. But the productivity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

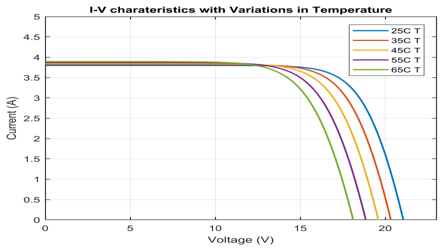
Figure 3: Solar Panel characterization with Irradiance level variations (Watts/m^2). (a) Characteristics of (I–V) (b) Characteristics of (P–V)

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).

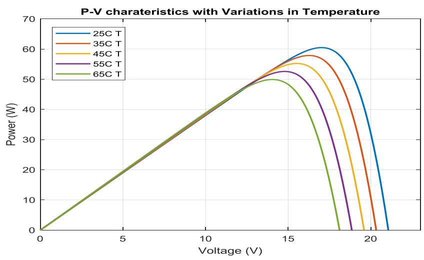
Figure 3 (a) shows solar panel irradiance variation IV characteristic in which x axis shows voltage and y axis shows current. In figure 3 (b) x axis is voltage and y axis is power.

➢ **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 (^oC) 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).

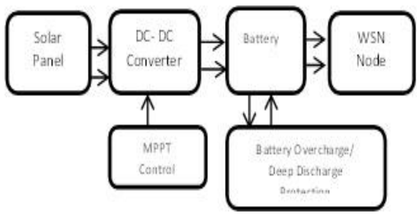


Figure 5: Solar energy recovery (harvesting) system block diagram, using input from MPPT capacity

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.

IV. Maximum Power Point Tracking (MPPT) Modeling Technique

MPPT techniques (Hauke, B. (2009) are mostly used in formation of solar photovoltaic (PV) systems to get maximum extraction of power from Sun under various solar irradiance values and is a kind algorithm that continually tests current (IPV) and voltage (VPV) from solar panel and computes quantity of the duty cycle (D) for supplying to DC-DC buck converter MOSFET switch. In photovoltaic applications typically the following algorithms are used as (Texas, 2018),

- Incremental Conductance (INC)
- Fraction Open Circuit Voltage (OCV).
- Perturb and Observe (P&O)

The P&O method is mainly utilized in all forms of harvester systems with solar energy. Figure 8 shows flow diagram for P&O algorithm. This algorithm's output is having duty cycle (DD) variation that depends on the irradiance (W/m2) input. If irradiance decreases then the service cycle shifts and the voltage and current of the solar panel changes (Haque, A. 2014). MPPT technique senses those alterations and adjusts solar panel impedance to the maximum point of power. So even if the irradiance changes, maximum power (P) may continue to extract by solar panel. It produces a PWM waveform of 0.7 initial duty cycle (ranging from 0 toi1) given as seed value for simulation.

The P&O method operates on theory of balancing impedance between charge and solar panel. The impedance matching is important for optimum power transfer. Utilizing DC-DC converter this impedance matching is accomplished. Through utilizing DC-DC converter, impedance is changed by adjusting the MOSFET switch's service cycle (DD). The input voltage, output voltage and duty cycle is given as

$$V_o = V_{in}.D \quad (8)$$

$$R_{in} = R_L/D^2 \quad (9)$$

But if the duty cycle is varies (DD), and then changes output voltage of solar energy harvester (Vo). The output voltage (Vo) is therefore increased when the duty cycle (D) is prolonged, and vice versa. The impedance of load resistance (RL) may be compared to impedance of the solar panel input by adjusting the duty cycle (D) for efficient transfer of power to the load for optimal output.

A flowchart displays the steps in the P&O algorithm, and MATLAB codes are depicted in Algorithm-1 respectively.

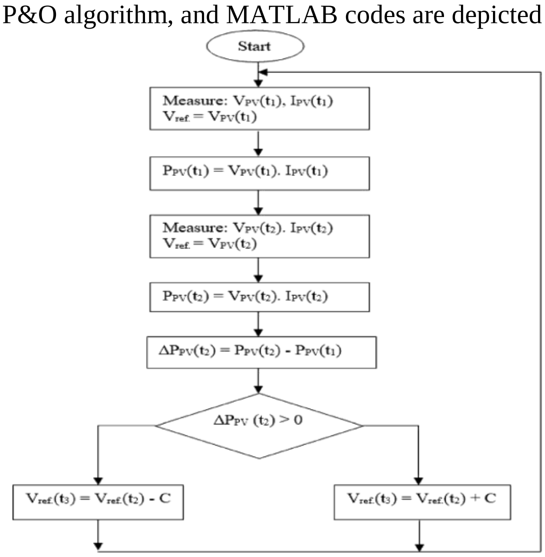


Figure 6: Flowchart for the P&O Method

The figure 6 is a flow chart of P&O method.

V. Result and Discussions

The figure 7 shows P&O-MPPT Managed 10 s SEH System in which x axis shows time and y axis shows battery voltage. The figure 8 shows INC-MPPT Managed 10 s SEH systems in which x axis shows time and y axis shows battery voltage.

In Figures 7 and 8 above, for simulation time of 10s, three parameters of the regulated P&O-MPPT and INC-MPPT Battery charger solar energy harvesting means state of charge (SOC), battery currentand voltage are obtained. The P&O-MPPT SOC dropped to 8%, while the INC-MPPT SOC dropped to 19%. SOCs view the INC-MPPT differently than P&O-MPPT.

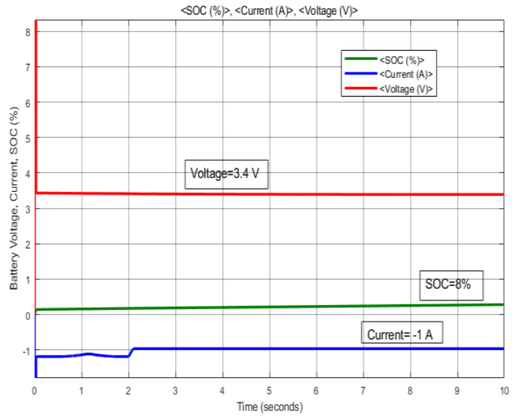


Figure 7: P&O-MPPT Managed 10 s SEH System

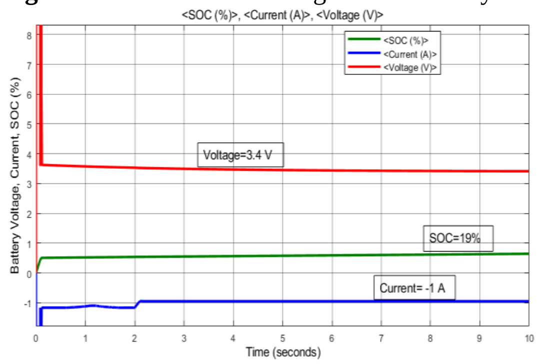


Figure 8: INC-MPPT Managed 10 s SEH systems

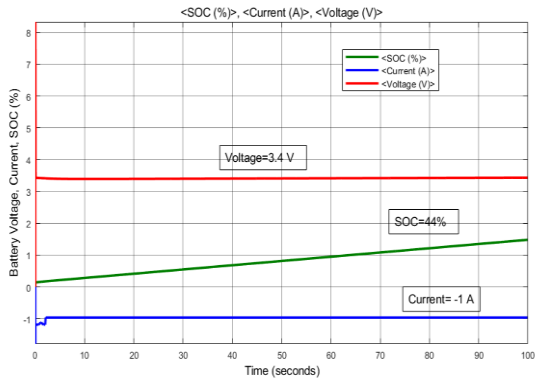


Figure 9: P&O-MPPT managed 100 s SEH system

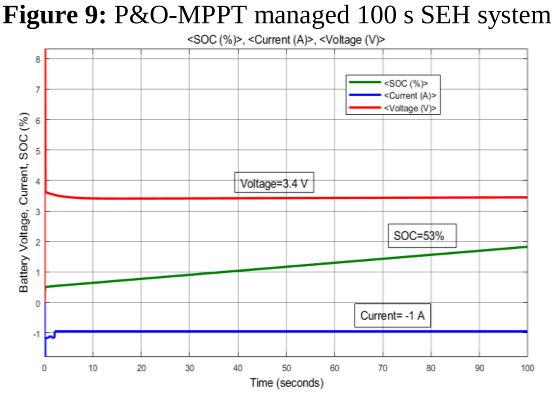


Figure 10: INC-MPPT managed 100 s SEH system

The figure 9 shows on x axis time of P&O-MPPT managed 100 s SEH system and y axis shows battery voltage current. The figure 10 shows INC-MPPT managed 100 s SEH system and y axis shows battery voltage.

In above figure 9 and 10, again all the three parameters are obtained for simulation time of 100s for P&O-MPPT and INC-MPPT. Both shows increment in battery state of charge. P&O-MPPT SOC reaches to 44% while INC-MPPT SOC reaches to 53%. Again INC-MPPT shows better increment than P&O-MPPT on different simulation time.

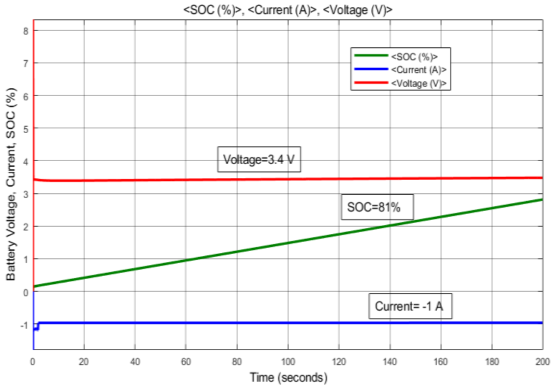


Figure 11: P&O-MPPT Controlled 200 s SEH system

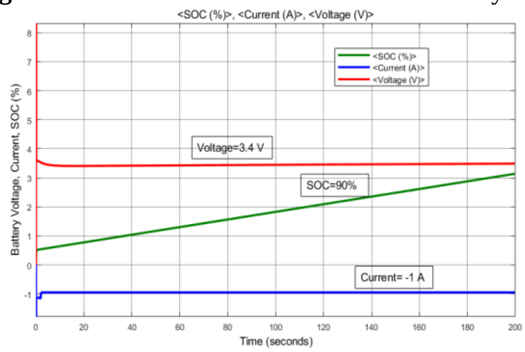


Figure 12: INC-MPPT Controlled 200 s SEH system

The figure 11 shows on x axis time of P&O-MPPT managed 200 s SEH systems and y axis shows battery voltage current. The 12 shows INC-MPPT managed 200 s SEH system and y axis shows battery voltage.
In figure 11 and 12, again all the three parameters are simulated for P&O-MPPT and INC-MPPT both for simulation time of 200s. Since the time increases the SOC automatically increases. For this increased simulation time the SOC of P&O-MPPT reaches to 81% and SOC of INC-MPPT reaches to 90%. The rate of increment of SOC is quite good in INC-MPPT in comparison to P&O-MPPT.

VI. Conclusion

In this work, Modeling, Simulation and Optimization are executed for SEH-WSN nodes. The two control methods for harvester system with solar energy, means, analysis and comparison of P&O-MPPT and INC-MPPT have been performed by MATLAB simulation. On various simulation times, INC-MPPT and P&O-MPPT are simulated and in every simulation time INC-MPPT gives better result than P&O-MPPT. Also, the overall efficiency of P&O-MPPT is 89.27% and INC-MPPT is 92.8% which is better than efficiency of P&O-MPPT SEH Controlled technique. Thus, INC-MPPT is quite promising technique. For the future work the other parameters also will be used to increase the efficiency. The other algorithm also will be used to increase efficiency.

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