Solar energy harvesting for smart farming using nanomaterial and machine learning

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Abstract: Farming is very labour intensive and needs timely action. In smart farming many activities of farming are conducted by machines which run on electricity. Electricity is one of the key elements of smart farming. The quality and cost of the agriculture produce are mostly determined by quality of the available energy and energy utilized. Though India is agriculture rich country, many rural areas are still not provided with sufficient electricity for the farming. In the current scenario of depleting natural energy resources like fossil fuels, using electricity generated from fossil fuels is expensive. Hence, there is a strong need to shift to nonconventional renewable and natural energy resources. Solar energy is one such energy available in abundance in India, however, the existing solar energy harvesting technologies which uses solar cell technology is able to convert very little portion of the available solar energy. The conversion efficiency of solar cells is found to be 16-18\%. The authors in this paper present a more efficient solar energy harvesting technology which uses nanomaterial for improving conversion efficiency and machine learning technology to maximize the collection of solar radiation by continuously tracking the path of the SUN in all the seasons.

Keywords: Smart farming, Energy conversion, Solar cells, SUN path, machine learning.

1. INTRODUCTION

Smart farming is an emerging trend in agriculture in which the electronics and communication technologies are used to improve the quality and quantity of agriculture produce with shift from labour intensive to technology orientation\cite{1}. Many activities of farming are being monitored and controlled by the smart devices which need uninterrupted electric supply\cite{2}. The smart farming utilizes optimum water as per the need of the plants. The water need of the plants will be sensed by soil moisture sensor placed at various places in the farm near to the plants. These sensors will transmit the moisture data using communication technology to the smart farm controller. The smart farm controller then switch on motor to supply the water and stops motor on receiving the water sufficiency message from the sensor as and when the moisture lever reaches to the required level. Providing the water in time as per the requirement of the plant enables the plant to grow healthy and the quality and quantity of the produce will be enhanced\cite{3}. The sensors along with Artificial Intelligence provide the information regarding the growth rate of the plant and the fertilizer requirement. The pesticides as per the requirement will be sprayed using drones\cite{4}. All these activities are implemented using the technology known as Internet of Things (IoT).

For all the above activities, various devices in the smart farming need continuous supply of electricity. However, many rural villages in India are not provided with electricity for farming due to various reasons like transmission losses, theft of electricity, non-return on investment\cite{5}. Solar energy is the better alternative to conventional electricity in the rural areas as the supply of electricity is not continuous in many rural places.
The existing method of solar energy converters uses solar cells for the energy conversion. The main drawbacks of these solar cells made up of silicon is low conversion efficiency and bigger in size so is the cost. The newer trend in solar energy conversion is using nanomaterial which has the higher conversion efficiency and smaller size than the silicon solar cells.

Another factor responsible for lower conversion is the smaller amount of solar irradiance captured by these solar energy converters. There can be little improvement in the captured solar radiation by the systems using solar tracking mechanism. These conventional solar tracking mechanisms will try to capture little more energy by following the SUN from east in the morning to west in the evening. However, this system cannot catch maximum energy from SUN as the path and angle of the SUN is different in different quarters and seasons. Maximum energy capture is possible only when the systems understands and follow the SUN path in all the seasons. However in conventional smart farming controllers, to follow, the systems need to be training using machine learning algorithms.

In this paper, authors address the issues of increasing the conversion efficiency of the solar energy systems using nanomaterial and the energy collection efficiency is increased by training the smart farm controllers using machine learning algorithms.

The rest of the paper is organized as follows, material and methods is presented in the section2, result and discussion is presented in section3, Conclusion is presented in section4.

2. MATERIALS AND METHODS

Solar energy on the surface of the earth is available in very dilute form. A very little portion of the solar energy that is incident can be converted to the electrical power using silicon solar cells. The efficiency of first generation solar cells is very low as they use single PN junction to convert Sun radiation into electric energy. Third generation solar cells with multiple band gaps are more efficient and absorb a wider range of light[6].

The losses in silicon solar cells are due to their structure, operating characteristics and external solid angle of absorption which contribute to losses and low conversion efficiency[7]. Pornima Muzumdar et.al studied simulation various techniques to increase solar energy harnnessing capacity of silicon solar cells[8]. A study on mixed-cation perovskite solar cells has been conducted and observed that a 17% efficiency of solar cells is enhanced by this technology [9].

Besides the other factors, the basic limitations of the Silicon based solar cell is its band gap which cannot convert all the photons falling on its surface into energy. The band gap of the silicon solar cell is 1.34ev and the wavelength of the solar radiation extends beyond visible region of 400nm to 700nm in both the sides. The photons having wave lengths greater than 700nm cannot be captured by the solar cell because of their energy lies below the band gap energy of solar cell. These photons simply pass through the solar cell without contributing to photon current. This limitation is also known as Shockely queisser limit.

One of the solutions to overcome the Shockely Quiesser limit is to reshape the solar spectrum above 700nm so that it overlaps on the visible spectrum so that more number of photons contributes to photon current. However, it increases the cost of the solar cell. The other alternative can be using nanomaterials which can convert maximum incident solar energy into photon current. The cost of nanomaterial is also less as compared to the silicon solar cell.

2.1. NANOTECHNOLOGY

Nanomaterial are the material with dimensions in the order of 100 nanometers or less. The internal structures are less than the external structures. Nanotubes, nanoparticles, nanofibers and nano rods are the general forms of the nanomaterial. Nanotechnology is the promising technology now in alternative energy approaches. The nanomaterial in solar cells can improve the efficiencies and contributes to higher output.

The Graphene and SiNH (silicon nanoholes) are the nanometerials having more conversion efficiency and can be used in solar energy harvesting.
2.1.1 GRAPHENE
Graphene is a thinnest semi-metal nanomaterial having atomic thickness of 0.345 nm with high electrical conductivity and incredible mechanical strength[10]. Graphene has very poor current holding capacity, though it’s conductivity is high. The graphene oxide has got better charge holding capacity and is more suitable for solar energy conversion. There cells can absorb upto 80% of the incident light[11]. Graphene is a super-capacitive biodegradable material and also cheaper than pure silicon. Graphene also absorbs the ultra violet radiation of solar energy which is neglected by Si solar cells\textsuperscript{12}. Graphene structure can convert energy of wide range of incident angles\textsuperscript{13,14}.

The graphene can bring a revolution in solar energy technology. It can give more solar radiation absorption in solar cells within 0.345nm. Solar cells need to be 100mm thick to absorb the same amount of solar energy as the 0.34 graphene does.

2.1.2 SiNH (Silicon Nanohole)
The Si nanohole arrays are available at lower cost and possess more efficient and superior sunlight-absorbing nanostructures\textsuperscript{15}. SiNH is the nanomaterial having very strong antireflection property. It is also a hybrid solar cell. A higher fill factor is need for the higher efficiency in energy harvesting The Silico Nanohole is having greater fill factor. It also has got efficient light trapping property. In the range of solar radiation wavelength SiNHs exhibit very low reflectance. The reflectance property is independent of the angle of incidence. Si nanowires arrays also produce a large surface-area-to-volume ratio. The larger surface area offers efficient light harvesting. It also forms a core-sheath p-n junction for higher charge collection.

2.2. THE ENERGY HARVESTING
Fig.1 is the nanomaterial solar cells based solar energy harvesting mechanism. It has also got a super capacitor battery for storage. The angle at which solar radiation fall on the solar cells decides the volume of energy generated. The solar cells need to be kept perpendicular to the angle of incidence of sunlight for harnessing maximum solar energy.

![Figure 1. Energy generation using nanomaterial solar cell](image)

The latitude and angle of declination are the factors influence the intensity of solar radiation. The seasonal temperatures of locations are dependent on angle of solar radiation. At the equator in tropical regions, solar radiation is concentrated over a smaller surface area. It is because of at the Equator, the sun’s rays strike Earth very close to a 90° angle.

At the Equator, the solar radiation is maximum. Maximum solar energy can be harnessed by the solar cells in these regions.
Fig. 2 Direct solar radiation receiving countries[16]

The countries receiving the direct solar energy radiation are as shown in Fig.2. The maximum solar radiation receiving countries are represented by dark red and violet colors. They are closer to the equator so, the higher solar radiance is available. The best places to build photovoltaic or solar thermal plants are Mexico, central America Australia, northern Chile, Saharan countries, Namibia, the Arabian Peninsula and the US Southwest the countries. These countries are lying in between tropic of cancer and tropic of Capricorn.

2.3. Improved Energy Storage mechanism

The key factor in improved energy storage mechanism is that the storage of harvested energy for a longer period of time. It also should be without any loss. The Solar energy received on Earth’s surface is not constant at all seasons. The solar radiation falling on the surface of the nanomaterial solar panel also keeps on varying with seasonal changes. It also has the variation between day and night shifts and many other factors.

As the energy generation is not same at all the times, we need a system with efficient storage capacity. The system needs to hold the electricity converted by solar cells for longer period of time. The stored energy can be utilized whenever required at later date as per the need. The graphene is the material with super capacitive properties is suitable for efficient storage of electricity. The Graphene Oxide which is considered as a super-capacitor can be used for long time storage of solar energy[17].

Graphene satisfies all the above properties required for long time storage of solar energy. The important characteristics of the material to store the energy for longer time are the material should be light in weight, high volume or surface area. Higher conductivity and smaller size are also very important parameter. The graphene oxide material satisfies all the above conditions. The main drawback of the conventional batteries is heavy losses of energy and low storage retention period. The graphene is a super-capacitor can be able to kick the energy in and out of the battery in quite less time, which is an essential property required for the super storage. The conventional batteries release toxic chemicals after being used and unfit for further use. The reactions produced are hazardous. The graphene being biodegradable in nature it is environmental friendly and does not have any hazardous impact on the environment.
2.4. Energy Maximization

The maximum energy can be harvested by understanding the solar radiation. Characteristics and the angles of incident of sun light on the Earth in different seasons. Another parameter in maximizing the energy harvesting is reducing the amount of solar energy reflected from the energy harvesting nano material panels. It is common and well known fact the Earth rotates around itself and also round the Sun. It rotates with a tilt of 23.5 degrees with its own axis[18].

12 hours is period required for the Earth to rotate itself and it is known as a day. It is also a well-known that the sun also traverses by 180 degrees from sunrise to sunset in a day. It gives us the data that sun changes its angle by 15° per hour in a day. To maximize the solar energy harvesting, the nanomaterial panels need to collect maximum energy from the sun. It is possible for the nanopanels by facing the sun all the time, so the solar cells can be rotated in such a way that the solar radiation is always perpendicular to the solar cells.

By this sun tracking process, we can extract maximum energy and also the the reflected radian can be minimized. Only some part of solar radiation is reflected back and rest all can be utilized to generate electricity.

![Figure 3. Microcontroller based energy harvesting system [19],[20].](image)

The Light sensor array gives the input to the microcontroller in which direction the maximum sun light is incident on the Solar Panel. The microcontroller then rotates the panel normal to the sun radiation with the help of the motor drivers and the motor to capture the maximum energy.

2.5. SUN PATH

![Figure 4. SUN Path during Summer and Winter[21]](image)
For maximization of Energy harvesting the conventional techniques of simply sensing the intensity of light falling on the solar panel will not be efficient as the path of the Sun is different at different seasons. Figures 4.5.6 and 7 shows the path of the Sun at different seasons.

Figure 5. SUN Path during Summer Solstice[21]

Figure 6. SUN Path during Spring Solstice[21]

Figure 7. SUN Path during Winter Solstice[21]
2.6. Machine Learning Technique
The Maximum energy harvesting is possible only when the Nano material solar panel can follow the Sun path. A Machine Learning technique is adopted to achieve this purpose.

Types of Machine Learning Algorithms
The three types of machine learning algorithms are:

a. Supervised Learning
b. Unsupervised Learning
c. Reinforcement Learning

a. Supervised machine Learning:
It is a machine learning algorithm for learning a function. It maps input to output based on example input output pairs. The machine can be given training with real world data and the learning can be tested with the test data which is the non overlapped part of the real world data. Basically this algorithm is used for classification of labeled data.

b. Unsupervised Machine Learning Algorithm: This algorithm is to draw the inferences from the data sets which are not labeled. Basically it is used to arrange the unlabelled input data into clusters of similar data at the output.

c. Reinforced Machine Learning: It learns from the environment using the feedback. A correct action will be rewarded and a punishment will be there for an incorrect action. It learns to follow the real world activity by trial and error with reward and punishment concepts.

This is the suitable algorithm for our purpose to continuously track the Sun path in all the seasons, though the Sun path is different at different seasons. The reinforcement algorithm learns from the environment.

Azimuth Lines are Azimuth angles run around the edge of the diagram. The dotted lined concentric circles shows the Altitude angles. The lines stretched from East to West in the graph represent Date lines. The figure-eight-type lines represent Hour Lines/Analemma. The data set is created using Sun path calculator app over period of 3 years. The data is divided into training set and test with 80% and 20% weightage. The system is trained using reinforcement technique.
3. RESULTS AND DISCUSSION
The machine learning model was trained on the dataset generated by Sun path calculator app. for three years 13140 data elements. The model was trained for 20 epochs with adam optimizer. The model showed promising results with 93% training accuracy and 94% validation accuracy.

![Model Accuracy](image)

Figure 9. Model Accuracy on Train and Validation Datasets

![Model Loss](image)

Figure 10. Model Loss on Training and Validation Datasets

Figure 10 shows the loss plot of the trained model. The maximum training and validation loss observed for the trained model is 10%.

4. CONCLUSION
The energy harvesting panels are to be of nanomaterial for maximum solar energy. The graphene material can increase the solar harvesting capacity by 40% when compared with silicon solar cells. A solar tracking system is developed using microcontroller and trained with machine learning technique to follow the Sun path to maximize the energy conversion efficiency. A 93% Training accuracy and 94% validation accuracy are obtained.
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