Research Article

An Innovative AgNP-based Solar Panel Coating and Farmland Fertility Optimization (FFO) based Power Extraction Methodology for Grid Systems

Priya Palanichamy* and Rajesh Krishnasamy
Department of Electrical and Electronics Engineering, Kalasalingam Academy of Research and Education, Krishnankoil - 626126, Tamil Nadu, India

Senthil Muthu Kumar Thiagamani*
Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil - 626126, Tamil Nadu, India

* Corresponding author. E-mail: priya.p@klu.ac.in; tsmkumar@klu.ac.in DOI: 10.14416/j.asep.2024.07.006
Received: 13 March 2024; Revised: 17 April 2024; Accepted: 21 May 2024; Published online: 8 July 2024

Abstract
In the power electronic system, coated solar panels attracted a lot of interest in present times. The proposed work aims to achieve two key objectives: maximal power extraction and solar panel coating. To reduce the cost of coating material for solar panels, Silver Nano Particles (AgNPs) are first collected from the leaves of Rose periwinkle plants. This strategy aims to achieve maximal power extraction by coating solar panels with green synthesized silver nanoparticles. To reduce the cost of coating material, Rosy periwinkle plant leaves are used to synthesize silver nanoparticles or AgNPs. To ascertain the framework's capacity for measuring energy both before and after the panels are coated with AgNP, this study theoretically analyses the data. The power current and voltage-current characteristics of the study were validated, enabling an examination of the study's effectiveness. The coated type outperformed the normal solar panel by 2%, according to the results. With a new approach called Farmland Fertility Optimization – Maximum Power Position Tracking, the precise peak site for increased energy yield is discovered. The bi-directional converter is also utilized to mitigate stress and increase voltage gain. To improve the power quality with fewer harmonics, the 3-phase inverter and the LC filtering circuits are used. Finally, a variety of performance measures are used to confirm the results of coated solar panels using power-tracking control techniques. The findings suggest that AgNP-coated solar panels provide the best possible electrical energy with improved voltage, current, and power quality. Performance evaluation shows that the coated solar panel's power tracking efficiency has increased to 99% with decreased harmonics of 2.52%.

Keywords: Farmland fertility optimization, Grid system, Maximum power point, Nanomaterials, Photovoltaics, Solar panel coating

1 Introduction

A field of study called nanotechnology or nanoscience focuses on the chemical composition of nanoparticles. A collection of atoms or molecules of various materials that have a size equal to one billionth of a meter are put together to create nanoparticles [1]–[3]. Metallic nanoparticles are one of these nanostructured particles, and they are being studied extensively for usage in technological devices, fabrics, gauges, and nanomedicine. The most frequently used metal nanoparticles in a variety of fields, including biomedicine, are nano-sized particles of silver and gold. The science of nanotechnology [4] is expanding quickly and involves the development of new materials. Many methods, such as chemical, physical, and biological processes, are used for generating nanoparticles. In place of chemical synthesis, the biosynthetic methodology has gained popularity as a result of its simplicity of use, low toxicity, and safe handling. A variety of biological systems, including microbial, fungal, and extracts from plants, have been applied to create nanomaterials [5]–[7]. Because of the way that their particle size enhances medicine stability and therapeutic efficacy, researchers have been studying nanoparticles, especially in the scientific, medical, and therapeutic delivery sectors. Various biological applications have been influenced by the distinctive properties of silver nanoparticles (AgNPs), which vary based on their size, shape, and charged surface. Moreover, AgNPs are recognized for their heightened antibacterial properties against a variety of infectious microorganisms, including infectious agents, fungi, microbial organisms, and plants [8], [9].

There are several methods for producing AgNPs, including chemical, biological, and organic methods. Since more than 2000 years ago, silver has been employed in medicine due to its broad-spectrum antimicrobial characteristics. The detrimental activity of silver against microorganisms manifests in multiple ways. Products made using silver have a lower cost and are less prone to cause antibiotic resistance [10]. The production of silver nanoparticles often involves the utilization of several sources, including bacteria, fungi, plants, and biopolymers. In this process, the functional aspects of various plant extract elements interact electronically with Ag^+. Nonetheless, the usage of AgNPs is severely constrained by their quick oxidation properties as well as their dependence on the surface charge of the supporting medium for stability [11]. AgNPs have thus been added to nanocomposites to improve resilience and address constraints about fast deterioration. It is important to remember that the synthesis processes play a major role in determining the dimension, shape, electrical conductivity, and compatibility of AgNPs for certain applications.

The hourly variations in the solar azimuth angle cause natural variations in the intensity of solar radiation throughout the day. On sunny days, the horizon will be lower than the sun even on the cloudiest days [12]–[14]. The PV panel's ability to create energy varies based on its resistive load, which reduces the generation of electricity even while the panel's irradiance and temperature remain the same. It is difficult to locate and compute the Maximum Power Point (MPP) [15] for a given load value because of temperature changes and irradiance variations that occur during the day. A method for determining the exact location of MPP to optimize the quantity of energy that can be harvested from the solar cells is the Maximum electricity Point Tracking (MPPT) methodology. Several intelligence-based MPPT controlling systems [16], [17] have been created in the past to extract the maximum energy from PV panels. Still, it suffers from poor convergence rates, large time costs, and inefficient computations [18], [19]. Therefore, the goal of the present study is to formulate a novel and economical system for coating solar energy systems using plant leaf-extracted silver nanoparticles [20]. In our previous work [4], the AgNPs extraction and solar panel coating processes are all performed with improved cost efficiency. As a continuation, in this work, we have used the coated panel to satisfy the electrical energy demand of low-scale grid applications. Also, the coated panel can be used to obtain the electrical energy from the solar with the MPPT controlling and converter circuit models. The main objectives of this paper are that a AgNP based coating methodology has been used to effectively coat the solar panels at low cost, The current characteristics of the coated solar panel have been validated and tested using different parameters such as VOC, ISC, VMP, IMP, and efficiency, The Farmland Fertility Optimization (FFO) algorithm has been utilized to track the available electrical energy under various irradiations and determine the maximum peak point for getting increased energy production, In addition, a bi-directional converter is employed to increase voltage gain while lowering switching stress, To reduce the number of harmonics at the grid side, the 3-phase inverter and LC filtering circuit models are also utilized.

This section examines some of the most recent literature approaches for coating solar panels, discussing each model's issues and difficulties with its voltage and current characteristics. Tabrizi *et al.* [21] developed a silicon thin film integrated with AgNPs for solar cells. This configuration aims to let light enter the cell from any direction with the least amount of absorption and reflection within the 300–1100 nm spectral range. The researchers took into account the impacts of scattering between silicon substrates and various other substances when calculating several significant performance measures of a solar cell, including short-circuit current, open-circuit voltage, fill factor and photoelectric efficiency. Lee *et al.* [9] conducted a comprehensive literature on the synthesis and modeling of AgNPs. The primary goal of the researchers' research is to outline the molecular, substance, and biological synthesis pathways for AgNPs as well as their distinct physiological and chemical characteristics. Additionally, they talk about the complex chemical pathways that underlie their optoelectronic property, possible cellular/microbial cytotoxicity, and plasmonic features on mono- and bimetallic structures. Rahul *et al*. [22] intended to improve the solar panel efficiency with the use of double integral sliding mode control. To overcome the shortage of steady-state error voltage in the least amount of time for the system to settle, the double integral sliding mode control technique is devised and demonstrated in this article. Through the adoption of an efficient dynamic sliding switching mechanism, this process raises the switching duty cycle ratio and optimizes solar panel efficiency in situations where there is partial shadowing. Hussein *et al*. [23] provided a detailed overview of the NPs with the different types of synthesis models. It includes both the top-down and bottom-up approaches such as mechanical milling, sputtering, electro-spinning, laser ablation, chemical vapor decomposition, hydro-thermal methods, and sol-gel method. Pryshchepa *et al*. [24] investigated the different types of synthesis models, techniques, and characteristics for obtaining AgNPs. A full understanding of AgNPs' properties about synthesis methods and exploitation circumstances is necessary for their successful application. Additionally, this work proved the physicochemical and biological features of AgNPs. It was demonstrated that the basic properties of AgNPs, such as size, shape, and chemical composition, influence their features. Vankudoth *et al*. [25] conducted a comprehensive study of green synthesis and characterization models to extract the silver nanoparticles from plant leaves. The purpose of this study is to extract the AgNPs from the leaves with proper characterization and synthesis operations, which include XRD, SEM, FTIR, and EDX.

He *et al*. [26] investigated the anti-viral properties of AgNPs for an effective surface coating. The majority of reports have been made concerning the virucidal effects of AgNPs. As a result, researchers looked at the protection and virucidal effects of ten distinct sorts of AgNPs with varying-sized particles and surface alterations. Jeevanandam *et al*. [27] examined and demonstrated different synthesis methods for making AgNPs and nanocomposites, offering scientific perspectives on methods for choosing ways to make antiviral AgNPs. The assessment of silver nanoparticles' potential as an antiviral agent and their antiviral mechanism in different AgNP formulations are also covered in this study.

According to the review of the literature, numerous green synthesis models have been developed in the past for the extraction of AgNPs, serving a range of purposes. However, prior research on the sustainable synthesis of AgNPs for solar panel coating remained scarce. Given that one of the sought and significant areas of research in electronic application systems is the deployment of cost-effective panel coating. To extract AgNPs from plant extracts for panel coating, a new, cost-effective green synthesis paradigm is what the suggested work seeks to establish.

The remaining portions of this paper are segregated into the following sections: Section 2 gives the complete explanation for the proposed panel coating and power extraction models along with the circuit models. Section 3 validates the simulation results of the proposed work by using voltage, current, time, and other parameters. Finally, the paper summary is provided along with the findings, results, and future scope in Section 4.

2 Materials and Methods

This section includes a detailed explanation concerning the intended work, a suitable block diagram, and illustrations. The original contribution of this paper is to develop an effective coating methodology for solar panels and to use the coated panel for maximum electrical energy production. The effective coating of solar panels with silver nanoparticles derived from pink periwinkle plant leaves is the main contribution of this research. This research work's unique contribution is to maximize the energy output of solar panels by an economical coating process using AgNPs that are derived from plant leaves. Additionally, it helps to maximize the current produced by highly tracking-efficient solar cells. Also, the coated solar panel has been used to extract the possible electrical energy. In addition, the bi-directional converter topology is also used to improve the PV output with reduced loss and switching stress. In this study, the simulation is conducted with the available rosy periwinkle plants in the study region, and the AgNPs coated panel has been further used to yield maximum electricity with the use of an MPPT controlling model.

2.1 *Silver extraction, synthesis and coating*

Silver metal ion solution and a reducing biological agent are essential for the sustainable synthesis of silver nanoparticles. The simplest and least expensive way to produce silver nanoparticles is to decrease and stabilize silver ions by the fusion of biomolecules, such as proteins, amino acids, supplements, alkaloid substances, and phenolics. In general, chemical extracts are made from several plant species' leaves. In this study, silver nanoparticles for solar panel coating are extracted from the leaves of the rosy periwinkle plant. Because of its significant medicinal content, the rosy periwinkle is immediately distinguishable from other plants and lowers the bacterial and fungal composition. In order to obtain silver nanoparticles for the demanded work, it is precisely chosen and employed. The plants with leaves used in this case study were gathered from the nearby area in Srivilliputtur. Furthermore, ethanol solution was acquired by Ganapathy Scientific Equipment, located in Srivilliputtur, India. $AgNO_3$ is made by Sigma Aldrich Pvt ltd in Mumbai, India. The proposed study approach differs from the current one in that AgNPs are obtained by the usage of readily available rosy periwinkle flowers. Furthermore, the proposed model's distinct features include guaranteed efficiency, affordability, and ease of implementation. In earlier studies, various plant species have been used to extract AgNPs; however, these methods presented challenges related to plant collecting, high costs, and longer processing times. Therefore, the goal of the proposed work is to extract AgNPs at a minimal cost from the leaves of a widely available plant. The nanoparticles can be identified by using their optical properties in a colloidal form, which are determined by their size, shape, and number as well as their collection state and refractive index at the surface. These features make UV-Vis spectroscopy an essential preliminary method for colloidal characterization and testing. Before panel coating, the following procedures are carried out to make an accurate characterization, Analysis using an ultraviolet visible spectrometer, Energy dispersive X-ray spectroscopy and scanning electron microscopy, Infrared analysis using Fourier transform, Power diffraction of X-rays, Test for conductivity, Characteristics study of IV and PV.

Following an examination of the attributes, the solar panel's layer is covered with silver nanoparticles. The limited plasmon excitation and the polaritons of the surface plasmons will help provide excitons to finish the cell configuration with accurate approximation. Furthermore, because Ag nanoparticles ingrain silicon solar cells absorb sunlight at higher layers and absorb less silicon substrate, the cells perform significantly better. Simulation analysis and testing are used to analyze the IV and PV properties before and following panel coating for validation and assessment.

2.2 *Silver extraction, synthesis and coating*

PV systems are commonly used to convert solar energy into electrical power by collecting photons of light and releasing electron charges. A PV panel is made up of several PV cells linked in parallel and series to produce the desired output power [28], [29]. Usually, the most important step in optimizing power tracking efficiency is the coating of solar panels. In this work, the primary power source for tracking the greatest amount of solar-generated electrical energy is the solar panels covered with AgNPs. Given its sustainability, the power produced by a photovoltaic system is one of the most dependable natural energy resources. The solar panel modeling Equations (1)–(6) are given below

$$I_{pv} = I_{ph} - I_D - I_{SH} \tag{1}$$

$$I_{ph} = \frac{G}{G_r}(I_{sc,\mathrm{Re}f} + K_{sc} + \Delta T) \tag{2}$$

$$I_{sc,\mathrm{Re}f} = I_{ph,ref} - I_{o,ref}[\exp(\frac{V_{oc}}{\tau}) - 1] \tag{3}$$

$$I_D = I_o(\exp(\frac{V + I \times R_S}{\tau})) \tag{4}$$

$$\mathrm{I_o} = \mathrm{I_{o,ref}}\ (\frac{\tau}{\tau_{\mathrm{ref}}})^3 \exp[(\frac{\mathrm{cB}}{\mathrm{A.K}})(1/\tau_{\mathrm{c,ref}} - 1/\tau_{\mathrm{c}}] \tag{5}$$

$$I_{SH} = \frac{V + I \times R_s}{R_p} \tag{6}$$

Where, I_{pv} indicates PV current, I_{ph} is the photo absorption current, I_D represents the diode current, I_{SH} indicates the solar shunt current, G indicates the irradiance, G_r is the reference irradiance, $I_{sc,Ref}$ is the short circuit current, K_{sc} indicates the cell temperature coefficient, T is the temperature, $I_{0,Ref}$ denotes the reverse saturation current with reference, V_{oc} indicates the open circuit voltage, R_s is the series resistance, τ is the ideality factor, B is the band gap, c is the charge of an electron, and R_p is the parallel resistance. The circuit modeling of the PV panel is shown in Figure 1.

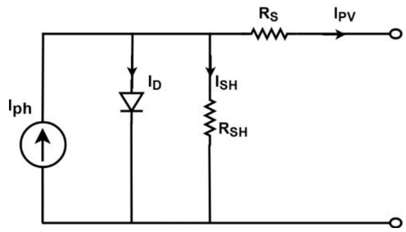


Figure 1: PV panel circuit model.

2.3 *Farmland Fertility Optimization (FFO)*

In this work, maximizing the amount of electricity harvested from the PV panels is essential to achieve the best potential degree of efficiency. The most recent method, called Farmland Fertility Optimization (FFO), has been used to model the PV panel and then locate the maximum peak point for recording the maximum amount of electrical energy that can be extracted from the panels. Many meta-heuristic methods [30]–[32] have been established for MPPT controlling in the literature. The goal of this work is to use a novel and distinctive optimization approach for tracking the maximum power output from coated solar panels. The suggested FFO-MPPT technique offers several advantages over traditional algorithms, including strong optimization outcomes, high efficiency, the ability to avoid local optimum problems, and ease of implementation. The FF algorithm mimics farmer behavior while distributing various fertilizers to farmland that have different soil quality, hence solving the optimization problem effectively. This algorithm compares the soil quality to the individual's fitness value and the land's fertilization plan to that of an individual. The most appropriate fertilization plan is determined for the property with the lowest soil quality, while a random fertilization plan is determined for the other land. Farmland's soil quality might be substantially raised by making periodic changes to the fertilization schedule. This algorithm comprises the following stages: Population initialization, Farmland segregation, identifying the region having poor soil quality, Memory updating, Soil optimization, and Soil fusion. The temperature, irradiance, and duty cycle of the PV cells are the input parameters in this FFO-MPPT controlling system, and the output is the MPP, which is used to extract electrical energy from the solar panel. In terms of convergence reliability, stability, and quickness, the FFO is a revolutionary bio-inspired meta-heuristic method that outperforms many popular meta-heuristic methods. Additionally, it finds the optimal value with the fewest iterations and lowest time complexity for the given problem. Owing to these advantages, the suggested works employ this method to extract the most electrical power possible from the coated solar panels.

2.4 *Bidirectional DC-DC converter*

In this instance, a bi-directional DC-DC converter is used to charge the storage devices, and the grid system can receive increased power [32]–[34]. Figure 2 displays the suggested bidirectional converter's circuit diagram. Three switching devices $S1$, $S2$, and $S3$, three capacitors $C1$, $C2$, and $C3$, and two inductors $L1$ and $L2$ are included in the design of this converter to significantly increase the power going to the load. Due to its transformer less circuit design and smaller circuitry model, this converter generates a lower power loss. Both the charging and discharging durations of the inductive and capacitor components have a significant impact on how well this converter operates. Here, modes 0 and 1 can be used to operate the analogous circuit of a bidirectional converter. In addition, the way that the switching elements transmit current allows for an identification of the operating modes of toggles. Moreover, this converter has two modes of operation, such as mode 0 and mode 1 as represented in Figure 3(a) and (b), respectively. The voltage and current flow during mode 0 are computed as represented in the following Equations (7)–(10):

$$V_{L1} = V_{PV} - V_{RS} \tag{7}$$

$$V_{L2} = V_{PV} - V_{C1} \tag{8}$$

$$I_{C1} = I_{C3} = I_{PV} - I_{RS} \tag{9}$$

$$V_{C3} = I_{L2} - \frac{V_{R2}}{R_L} \tag{10}$$

Where, $L1$ and $L2$ are the inductors, $C1$, $C2$, $C3$ are the capacitors, RS is the series resistance, V_{pv} is the PV voltage, I_{C1} is the capacitor current, and R_L is the resistive load. During mode 1, the voltage and current are estimated as represented in the following Equations (11)–(13):

$$V_{L1} = V_{PV} - V_{C1} - V_{L2} \tag{11}$$

$$I_{C1} = \frac{I_{L1} - I_{L2}}{2} \tag{12}$$

$$I_{C4} = i_{L2} - \frac{V_{R2}}{R_1} \tag{13}$$

The grid system receives the AC power supply from the PV at the inverter phase. As a consequence, the most appropriate combination of capacitive and inductive rates in the filter is used to transform discrete voltage samples into AC power through the LC filtering method.

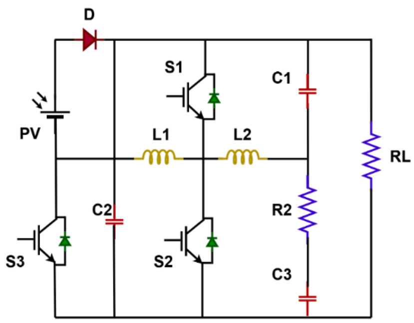
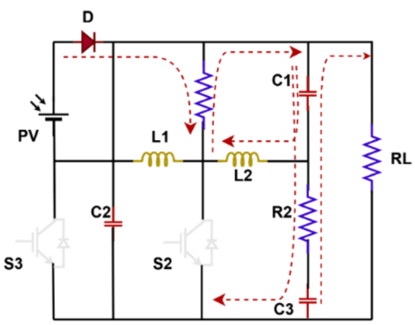
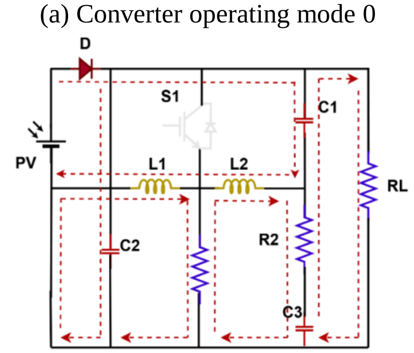


Figure 2: Bi-directional converter.



(a) Converter operating mode 0



(b) Converter operating mode 1

Figure 3: Converter mode of operations.

By cycling the switching devices faster and producing higher frequency pulses, this kind of device circuit lowered the harmonics in the output power. This ends up resulting in the activation of the switching pairs and the output of isolated AC power. Here, the discrete waveform's harmonics are filtered out using a combination of L and C filtering procedures, resulting in clean AC power at the point of output. Table 1 presents the switching states of the converter, where a comprehensive overview of how the converter's switches transition between ON and OFF states over specific time intervals is provided.

Table 1: Switching states of converter.

States	S1	S2	S3	Output Voltage
1	0	0	1	Vdc
2	0	1	0	2Vdc
3	1	0	0	3Vdc

3 Result and Discussion

Several performance measures are used in this part to validate the simulation results of the proposed methodology. This study's primary goal is to coat solar panels efficiently using AgNPs for optimal power tracking. The Rosy Periwinkle plant leaves are used to extract the chemical extract needed for this purpose, and layer coating is then carried out using the appropriate green synthesis and characterization procedures. In the proposed work, we are using the Rosy Periwinkle plant leaves for extracting AgNPs, since it is adequately available in our study area at a low cost. Also, the coated solar panels with AgNPs are used here to extract the maximum possible electricity from the panels, hence the power is effectively improved with low-cost consumption [35], [36]. This study deals with simulation testing to validate the outcomes and effectiveness of the proposed strategy. Additionally, factors including efficiency, VOC, ISC, VMP, IMP, and VMP are taken into account when assessing how well the suggested system tracks. Moreover, the coated panel has been used to yield the maximum electrical energy from the solar. To improve the power tracking performance and amount of electricity, the FFO-MPPT controlling technique has been used in this work. Consequently, the bi-directional converter is also implemented to improve the output voltage and power fed to the grid system. For examining the results of power tracking, a 50W solar panel has been used in this study, and the simulation parameters are given in Table 2.

Table 2: Simulation parameter setting.

Parameters	Specification
Solar Panel	50 W
Open circuit voltage Voc	21 V
Short circuit current Isc	5.8 A
Series resistance Rs	0.45Ω
Parallel resistance Rp	310Ω
Temperature T	298 K
Maximum voltage V	18V
Maximum current I	5.3 A

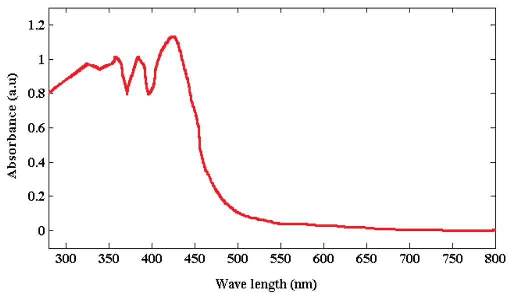


Figure 4: UV spectra of the deposited AgNPs.

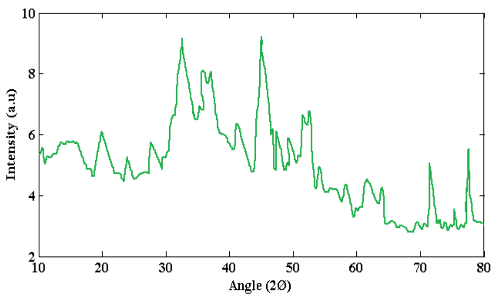


Figure 5: Synthesized AgNPs' XRD pattern.

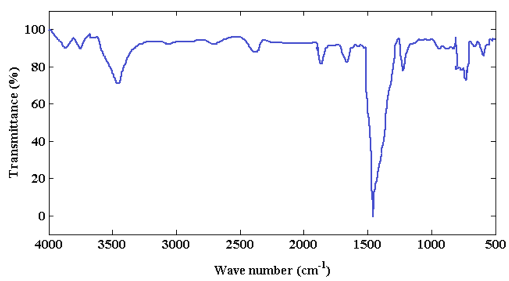


Figure 6: Synthesized AgNPs' Fourier Infrared (FTIR) Spectral Analysis.

By using Rosy Periwinkle leaf extract and UV-vis spectrophotometers, the AgNPs' UV-vis spectrum is analyzed as shown in Figure 4. Similar to silver, metal nanoparticles have extremely tight conductance and valence structures that permit unrestricted electron mobility. These unbound electrons create a surface plasmon resonance (SPR) absorption band while the electrons in the metal nanoparticles vibrate together in resonance with a light wave [37]. The characteristics of AgNP's surface plasmon resonance are rendered visible by the peaks' appearance. The UV-visible spectra of the AgNP-containing solution revealed an absorption peak illustrated in Figure 5. The XRD patterns demonstrated that AgNPs were formed by $AgNO_3$'s reduction of Ag^+ ions in the Rose Periwinkle leaf extract. AgNPs have been decreased and encapsulation was accomplished by employing biomolecules found in the leaf extract's FTIR spectra. Scanning electron microscopy (SEM) revealed many aggregates and single hexagonal AgNPs in the generated AgNPs. The EDX pattern of the generated AgNPs indicated the presence of silver. Overall, the manufactured product that is less damaging and more sustainable has been examined using a range of characterization methodologies. AgNPs are thus sprayed on solar panels as a coating to boost their efficiency.

As shown in Figure 6, Aromatic groups have been accountable for the peak at 790 cm^{-1}. AgNPs made with Rosy Periwinkle leaf extract also included amine, carboxylic acid, and alkene functional groups, among others. It has been demonstrated that the majority of these functional groups, which are members of important chemical group classes, work as reducing agents during the production of AgNPs. Moreover, the IV and PV characteristics of coated and non-coated panels are validated and compared as shown in Figures 7 and 8, respectively. Generally, the PV and IV characteristics have been used to calculate the solar panel's power-tracking efficiency. These parameters are estimated for the coated and non-coated panels in this investigation. When comparing the coated panel with the non-coated panel, the obtained results show that both the power and the current are significantly improved. The coated panel exhibits improved IV and PV characteristics and an overall increase in power tracking efficiency due to the effective use of AgNPs. The comparison graph shows that the AgNPs-coated solar panels perform better than the uncoated ones.

Thick mono-crystalline polished wafers have been used to conceal the silver extract on silicon semiconducting solar cells with a 300 µm thickness. The produced solution has protected the glassy surface of the solar cells with the use of the screen-printing technique. The solar panel used in this study has been doped with AgNP ions to improve its distinguishing characteristics. The efficiency and accuracy of the solar panel are closely correlated with the concentration of silver doping.

The voltage gain of the bi-directional converter used in this investigation, wherein the measured and computed voltages are estimated about the duty cycle, is validated in Figure 9. By using the bi-directional converter, the voltage gain is significantly improved to 99%. The most important factor in determining the DC-DC converter's overall efficiency is the voltage gain. The results show that the suggested system's bi-directional converter model might significantly increase the voltage gain by up to 90%.

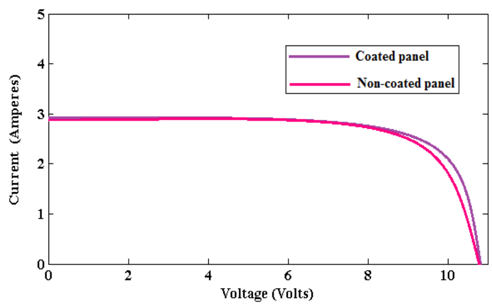


Figure 7: IV characteristics for coated and non-coated panels.

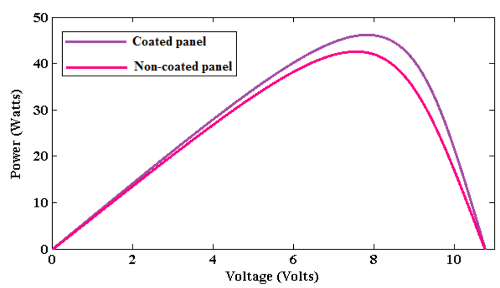


Figure 8: PV characteristics for coated and non-coated panels.

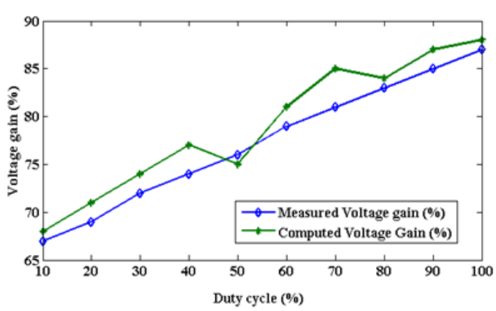


Figure 9: Voltage gain of converter.

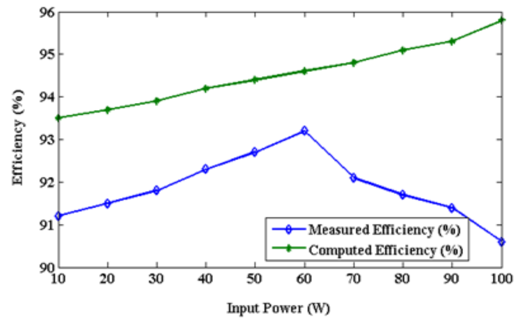
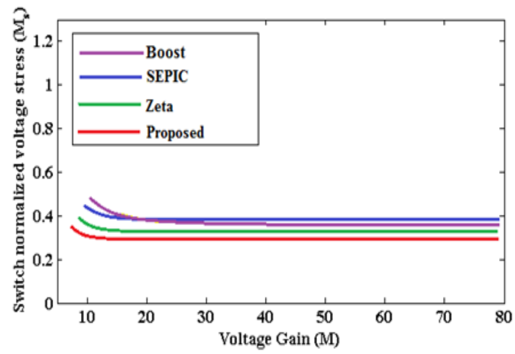


Figure 10: Converter efficiency.



.

Figure 11: Voltage stress analysis among the existing and proposed converters.

As a result, as illustrated in Figure 10, the converter's efficiency is also verified by changing input power. It is clear from the data that the bi-directional converter's efficiency has also increased to 96%.

As shown in Figure 10, the efficiency of the converter is validated for the coated and uncoated panels, where the green-colored line indicates the uncoated panel and blue denotes the coated panel. According to the outcomes, it is observed that the efficiency of the coated panel with a bi-directional converter is increased to 96% when compared to the non-coated panel. with alternative converter topologies. The comparative assessment leads to the conclusion that, in comparison to other converters, the bi-directional converter model employed in the proposed study could significantly lower the voltage stress. Based on the analysis, it has been concluded that the suggested converter offers better voltage gain and conversion efficiency while causing less stress.

Furthermore, the VOC, ISC, VMP, IMP, and efficiency for the AgNP-coated and non-coated solar panels are validated in Figure 11. The result demonstrates that, in comparison to the non-coated panel, the coated panel's performance and efficiency have significantly increased. Moreover, the comparison among coated and non-coated panels provided in Table 3 is significantly improved, when compared to other irradiation conditions. The amount of solar energy per unit area that strikes a solar panel, or the irradiance level, does affect the panel's efficiency. Intuitively, more efficiency would be suggested by higher irradiance since it suggests that more energy is as shown in Figure 12, the performance of coated and non-coated solar panels is Validated based on accessibility for conversion into electricity. It is not frequently obvious how efficiency and irradiance relate to one another, though. There's When the irradiance value is 1000 W/m^2, the values of efficiency, power, and voltage above this threshold, an increase in irradiance may not result in a corresponding rise in efficiency.

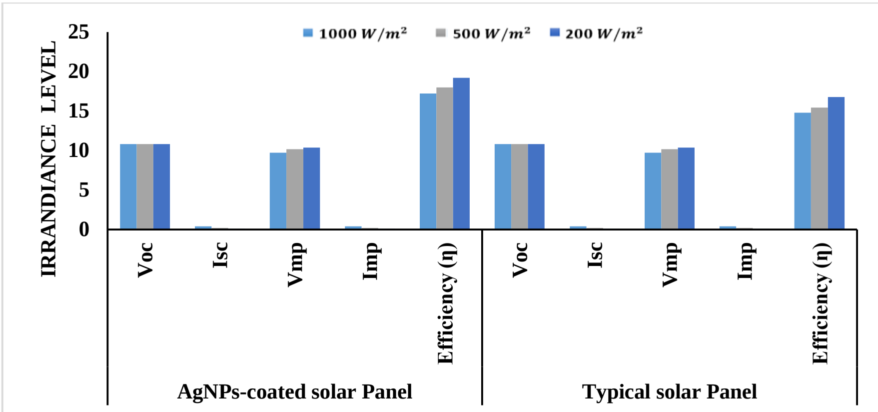


Figure 12: Performance analysis of non-coated solar panel.

Table 3: Simulation results of various irradiance for coated and non-coated solar panels.

S. No	Irradiance Level (W/m^2)	AgNPs-Coated Solar Panel					Typical Solar Panel				
		Voc	Isc	Vmp	Imp	Efficiency (η)	Voc	Isc	Vmp	Imp	Efficiency (η)
1.	1000	10.8	0.391	9.72	0.391	17.20	10.8	0.383	9.72	0.383	14.77
2.	500	10.8	0.1955	10.152	0.195	18.00	10.8	0.1915	10.152	0.191	15.42
3.	200	10.8	0.0782	10.368	0.0781	19.20	10.8	0.077	10.368	0.0765	16.76

Rather, it could lead to other variables that diminish efficiency. According to the findings, the efficiency, power, and voltage of the solar panels are higher at an irradiance level of 1000 W/m^2 than they are at other irradiance levels. This might be caused by some of the factors:

Effects of temperature: High irradiance levels may raise panel temperatures, which may lower efficiency. In general, mild temperatures are ideal for solar panel performance. The temperature may be greater than ideal at 1000 W/m^2, which would result in a drop in efficiency. Incompatibility losses: When solar panel and electrical load mismatch at very high irradiation levels, total efficiency might be reduced.

Material characteristics: At high irradiation levels, some materials used in solar panels may show non-linear behavior, which can cause efficiency to plateau or even drop below a specific point [38], [39]. Shadow and shade: As irradiance levels rise, shadowing and shading effects may become more noticeable. This may decrease the solar panel's overall efficiency by lowering the effective area exposed to sunlight.

The Total Harmonic Distortion (THD) of the suggested PV-Grid system is used to assess its power quality performance, as illustrated in Figure 13. Here, the THD value before and after coating solar panels is illustrated Suppressing the degree of noise at the grid side is crucial since harmonics in the output power typically have the potential to lower the system's overall power quality. The suggested design uses the inverter and LC filtering components for this reason, greatly decreasing the impacts of harmonics by lowering them to a level of 2.52% at the grid side. When compared to the THD value before coating, the THD value is effectively suppressed with the use of solar panels after coating. The harmonic distortion that occurs in the electrical signal when it interacts with the uncoated surfaces or components is reflected in the THD measurement that was made before coating. Greater distortion is indicated by higher THD values, which imply that the signal departs from a pure sinusoidal waveform more. Impedance mismatches, electromagnetic interference shielding, and nonlinearity mitigation are just a few of the many changes the coating may have on the electrical characteristics of the surfaces. The coating ought to maximally aid in reducing THD, producing a signal that is cleaner and has fewer harmonic distortions.

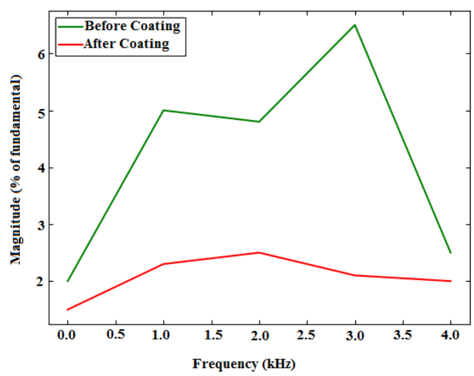


Figure 13: THD analysis before and after coating.

4 Conclusions

The innovative contribution of this work is to develop an effective solar panel coating method and apply it to maximize electrical energy production. The effective coating of solar panels with silver nanoparticles made from pink periwinkle plant leaves is the main contribution of this work. The primary goal of this research is to maximize the energy output of solar panels using a low-cost coating method that uses plant-derived AgNPs. Additionally, it helps to maximize the current produced by solar cells with exceptionally high tracking efficiency. Furthermore, the covered solar panel has been used to extract potential electrical energy. Additionally, by employing the bi-directional converter architecture, the PV output is enhanced with less loss and switching stress. Using an MPPT controlling model, the AgNPs coated panel has been further utilized in this work to produce the maximum amount of electricity. The study region's readily available rosy periwinkle plants are used for the simulation. AgNP extraction, solar panel coating, power extraction, and voltage boosting are the key phases of the suggested system. To satisfy the demands of the grid system, coated solar panels are used to create as much electricity as feasible. Here, the precise peak location for higher energy yield is determined using the novel FFO–MPPT regulating approach. Additionally, this study uses the bi-directional converter to boost voltage gain and reduce stress. To further enhance power quality with fewer harmonics, LC filtering circuits, and a 3-phase inverter are employed. Using a range of performance criteria, the outcomes of coated solar panels are ultimately confirmed and contrasted using power-tracking controlling methods. The comprehensive results indicate that solar panels coated with AgNP offer optimal electrical energy and higher voltage. The application of the 3-phase inverter and LC filtering circuits improves the grid-side power quality performance by up to 2.52% in terms of reduced harmonics. By developing novel controlling algorithms for grid-PV systems that harvest PV electricity, the current work can be enhanced in the future.

Acknowledgements

The authors thank the Sir C.V. Raman – Krishnan International Research Centre (IRC) for providing test facilities

Author Contributions

P.P.: conceptualization, investigation, methodology, data analysis, writing an original draft, reviewing and editing; R.K: conceptualization, research design, supervision; S.M.K.T.: conceptualization, data curation, writing—reviewing and editing, funding acquisition, project administration. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] K. C. Tam, H. Saito, P. Maisch, K. Forberich, S. Feroze, Y. Hisaeda, C. J. Brabec, H.-J. Egelhaaf, "Highly reflective and low resistive top electrode for organic solar cells and modules by low-temperature silver nanoparticle ink," *Solar RRL*, vol. 6, 2022, Art. no. 2100887.

[2] C.-T. Wang, S.-W. Wu, and C.-C. Kuo, "Silver nanoparticle-embedded titania nanobelts with

tunable electronic band structures and plasmonic resonance for photovoltaic application," *Materials Science in Semiconductor Processing*, vol. 138, 2022, Art. no. 106317.
[3] K. Kumar, B. S. Babu, and J. P. Davim, *Coatings: Materials, Processes, Characterization, and Optimization*. Berlin, Germany: Springer Nature, 2021.
[4] P. Palanichamy, R. Krishnasamy, U. M. Sundaram, S. M. K. Thiagamani, R. Ilyas, and A. M. Hassan, "A practical green synthesis method of Ag NPs using rosy periwinkle plant leaves for solar panel coating," *Heliyon*, vol. 9, no. 12, 2023, Art. no. E22893.
[5] M. M. Bhatti, O. A. Bég, and S. I. Abdelsalam, "Computational framework of magnetized MgO–Ni/water-based stagnation nanoflow past an elastic stretching surface: Application in solar energy coatings," *Nanomaterials*, vol. 12, p. 1049, 2022.
[6] S. M. Rangappa, S. Siengchin, and H. N. Dhakal, "Green-composites: Ecofriendly and sustainability," *Applied Science and Engineering Progress*, vol. 13, no. 3, pp. 183–184, 2020, doi: 10.14416/j.asep.2020.06.001.
[7] R. K. Arya, G. D. Verros, and J. P. Davim, *Functional Coatings: Innovations and Challenges*. New York: John Wiley & Sons, 2024.
[8] S. M. Rangappa, S. Siengchin, and H. N. Dhakal, "Green-composites: Ecofriendly and sustainability," *Applied Science and Engineering Progress*, vol. 13, no. 3, pp. 183–184, 2020, doi: 10.14416/j.asep.2020.06.001.
[9] S. H. Lee and B.-H. Jun, "Silver nanoparticles: Synthesis and application for nanomedicine," *International Journal of Molecular Sciences*, vol. 20, no. 4, 2019, Art. no. 865.
[10] F. Jalilian, A. Chahardoli, K. Sadrjavadi, A. Fattahi, and Y. Shokoohinia, "Green synthesized silver nanoparticle from *allium ampeloprasum* aque- ous extract: Characterization, antioxidant activities, antibacterial and cytotoxicity effects," *Advanced Powder Technology*, vol. 31, no. 3, pp. 1323–1332, 2020.
[11] P. Prasher, M. Sharma, H. Mudila, G. Gupta, A. K. Sharma, D. Kumar, H. A. Bakshi, P. Negi, D. N. Kapoor, and D. K. Chellappan, "Emerging trends in clinical implications of bio-conjugated silver nanoparticles in drug delivery," *Colloid and Interface Science Communications*, vol. 35, 2020, Art. no. 100244
[12] N. Grebenchikov, D. Varlamov, S. Zuev, R. Maleev, A. Skvortsov, and A. Grebenchikov, "Study of solar panel charge controllers," *Journal of Communications Technology and Electronics*, vol. 65, pp. 1053–1061, 2020.
[13] J. Zeng, J. Ning, X. Du, T. Kim, Z. Yang, and V. Winstead, "A four-port dc–dc converter for a standalone wind and solar energy system," *IEEE Transactions on Industry Applications*, vol. 56, no. 1, pp. 446–454, Feb. 2019, doi: 10.1109/TIA.2019.2948125.
[14] S. Keeratianant, S. Chirarattananon, A. Nathakaranakule, and P. Rakkwamsuk, "Cost-effectiveness of solar cooling for office and hypermarket," *Applied Science and Engineering Progress*, vol. 14, no. 1, pp. 31–43, Jan. 2021, doi: 10.14416/j.asep.2019.09.004.
[15] D. Kurniawan, A. Priharta, and N. S. F. Putri, "Solar panel modeling and simulation with MPPT technique on micro grid," in *2021 7th International Conference on Electrical, Electronics and Information Engineering (ICEEIE)*, pp. 1–6, 2021.
[16] R. Kumar M, S. Satya Narayana, and G. Vulasala, "Advanced sliding mode control for solar PV array with fast voltage tracking for mpp algorithm," *International Journal of Ambient Energy*, vol. 41, no. 10, pp. 1192–1200, 2020.
[17] E. M. Salilih and Y. T. Birhane, "Modeling and analysis of photo- voltaic solar panel under constant electric load," *Journal of Renewable Energy*, vol. 2019, 2019, Art. no. 9639480.
[18] M. Premkumar and R. Sowmya, "Certain study on mppt algorithms to track the global mpp under partial shading on solar PV module/array," *International Journal of Computing and Digital Systems*, vol. 08, no. 04, pp. 405–416, 2019.
[19] J. Linares-Flores, A. Hernández-Mendez, J. A. Juárez-Abad, M. A. Contreras-Ordaz, C. García-Rodriguez, and J. F. Guerrero-Castellanos, "MPPT novel controller based on passivity for the PV solar panel-boost power converter combination," *IEEE Transactions on Industry Applications*, vol. 59, pp. 6436–6444, Oct. 2023, doi: 10.1109/TIA.2023.3274618.
[20] C. S. Durganjali, S. Bethanabhotla, S. Kasina, and S. Radhika, "Recent developments and future advancements in solar panels technology," *Journal of Physics: Conference Series*, vol. 1495, no. 1, 2020, Art. no. 012018.
[21] A. A. Tabrizi and A. Pahlavan, "Efficiency improvement of a silicon- based thin-film solar

cell using plasmonic silver nanoparticles and an antireflective layer," *Optics Communications*, vol. 454, 2020, Art. no. 124437.

[22] I. Rahul and R. Hariharan, "Enhancement of solar PV panel efficiency using double integral sliding mode mppt control," *Tsinghua Science and Technology*, vol. 29, no. 1, pp. 271–283, 2023.

[23] H. S. Hussein, "The state of the art of nanomaterials and its applications in energy saving," *Bulletin of the National Research Centre*, vol. 47, no. 1, 2023, Art. no. 7.

[24] O. Pryshchepa, P. Pomastowski, and B. Buszewski, "Silver nanoparti- cles: Synthesis, investigation techniques, and properties," *Advances in Colloid and Interface Science*, vol. 284, 2020, Art. no. 102246,

[25] S. Vankudoth, S. Dharavath, S. Veera, N. Maduru, R. Chada, P. Chiru- mamilla, C. Gopu, and S. Taduri, "Green synthesis, characterization, photoluminescence and biological studies of silver nanoparticles from the leaf extract of *muntingia calabura*," *Biochemical and Biophysical Research Communications*, vol. 630, pp. 143–150, 2022.

[26] Q. He, J. Lu, N. Liu, W. Lu, Y. Li, C. Shang, X. Li, L. Hu, and G. Jiang, "Antiviral properties of silver nanoparticles against sars-cov-2: Effects of surface coating and particle size," *Nanomaterials*, vol. 12, no. 6, 2022, Art. no. 990.

[27] J. Jeevanandam, S. Krishnan, Y. S. Hii, S. Pan, Y. S. Chan, C. Acquah, M. K. Danquah, and J. Rodrigues, "Synthesis approach-dependent antiviral properties of silver nanoparticles and nanocomposites," *Journal of Nanostructure in Chemistry*, vol. 12, pp. 809–831, 2022.

[28] M. N. Habibi, N. A. Windarko, and A. Tjahjono, "Hybrid maximum power point tracking using artificial neural network-incremental conduction with short circuit current of solar panel," in *International Electronics Symposium (IES)*, 2019, pp. 63–69.

[29] S. Ngo, C.-S. Chiu, T.-D. Ngo, and C.-T. Nguyen, "New approach-based MPP tracking design for standalone PV energy conversion systems," *Elektronika Ir Elektrotechnika*, vol. 29, no. 1, pp. 49–58, 2023.

[30] K. Y. Yap, C. R. Sarimuthu, and J. M.-Y. Lim, "Artificial intelligence based mppt techniques for solar power system: A review," *Journal of Modern Power Systems and Clean Energy*, vol. 8, no. 6, pp. 1043–1059, 2020.

[31] A. Ulinuha and A. Zulfikri, "Enhancement of solar photovoltaic using maximum power point tracking based on hill climbing optimization algorithm," *Journal of Physics: Conference Series*, vol. 1517, no. 1, 2020, Art. no. 012096

[32] W. Laoraksakiat and K. Asawarungsaengkul, "Bi-objective hybrid flow shop scheduling with family setup times using hybrid genetic and migrating birds optimization algorithms," *Applied Science and Engineering Progress*, vol. 14, no. 1, pp. 19–30, 2021.

[33] A. Raj, S. R. Arya, and J. Gupta, "Solar PV array-based dc–dc converter with mppt for low power applications," *Renewable Energy Focus*, vol. 34, pp. 109–119, 2020.

[34] T. W. Hariyadi and A. Adriansyah, "Comparison of dc-dc converters boost type in optimizing the use of solar panels," in *2nd International Conference on Broadband Communications, Wireless Sensors and Powering (BCWSP)*, 2020, pp. 189–194.

[35] R. Klinjapo and W. Krasaekoopt, "Application of microencapsulated bamboo leaf extract powder to control the rancidity in moo yor (vietnamese-style sausage) during refrigerated storage," *Applied Science and Engineering Progress*, vol. 14, no. 1, pp. 13–18, 2021, doi: 10.14416/j.asep.2020.02.004.

[36] S. Keeratianant, S. Chirarattananon, A. Nathakaranakule, and P. Rakkwamsuk, "Cost-effectiveness of solar cooling for office and hypermarket," *Applied Science and Engineering Progress*, vol. 14, no. 1, pp. 31–43, 2021, doi: 10.14416/j.asep.2019.09.004.

[37] S. Areeya, "A review on chemical pretreatment of lignocellulosic biomass for the production of bioproducts: Mechanisms, challenges and applications," *Applied Science and Engineering Progress*, vol. 16, no. 3, Aug. 2023, Art. no. 6767, doi: 10.14416/j.asep.2023.02.008.

[38] N. A. Basha, T. Rathinavel, and H. Sridharan, "Activated carbon from coconut shell: Synthesis and its commercial applications- A recent review," *Applied Science and Engineering Progress*, vol. 16, no. 2, Feb. 2023, Art. no. 6152.

[39] G. O. Young, "Synthetic structure of industrial plastics," in *Plastics* (vol. 3), 2nd ed., J. Peters, Ed. New York: McGraw-Hill, pp. 15–64, 1964.