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EVALUATING THE EFFECTIVENESS OF SMART INVERTER CONTROL FOR SOLAR-POWERED EV CHARGING STATIONS

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Abstract
Solar-powered electric vehicle (EV) charging stations have gained significant attention as a sustainable solution to the growing demand for clean transportation. The integration of smart inverter control technology in these charging stations has shown promise in optimizing power flow and improving the overall efficiency of the charging process. This paper presents a comprehensive evaluation of the effectiveness of smart inverter control for solar-powered EV charging stations. The study examines the impact of smart inverter control on key performance indicators, including charging efficiency, grid integration, and cost-effectiveness

Introduction

Electric Vehicles (EVs) are playing a significant role in the transition towards more sustainable and low-carbon transportation systems worldwide. Governments and regions are setting ambitious targets for EV adoption as part of their efforts to reduce carbon emissions and mitigate climate change [1]. The integration of EVs into energy systems is seen as a crucial step towards achieving these goals.

The impetus for the promotion of electric vehicles (EVs) can be attributed to the overarching global climate agenda set forth by the Paris Agreement. The primary objective of the agreement is to mitigate carbon emissions on a worldwide level in order to effectively tackle the escalating problem of global warming [2]. The adoption of electric vehicles (EVs) by nations can yield substantial reductions in transportation-related emissions, thereby making a valuable contribution to the global endeavor of mitigating carbon emissions.

In addition to reducing carbon emissions, EVs also offer the advantage of creating less local air pollution compared to conventional vehicles. This improvement in air quality is particularly beneficial for densely populated urban areas, where poor air quality has adverse effects on public health [3]. By promoting the use of EVs, countries can mitigate the negative health impacts of air pollution and improve the quality of life for their citizens [4].

Moreover, the adoption of electric vehicles (EVs) is motivated by governmental initiatives aimed at diminishing the demand for oil and mitigating reliance on oil imports. The adoption of electric mobility presents an opportunity for nations to enhance their energy portfolio and mitigate susceptibility to oil price fluctuations and disruptions in supply [5]. Additionally, this transition presents prospects for the establishment and expansion of domestic electric vehicle manufacturing sectors, thereby fostering employment generation and facilitating economic advancement.

Another important aspect of integrating EVs into energy systems is their potential to support and stabilize the grid. EVs can provide valuable grid support services, such as load balancing and energy storage, which can help accommodate higher levels of renewable energy penetration [6]. By leveraging the battery capacity of EVs, excess electricity generated from renewable sources can be stored and utilized when needed, contributing to a more stable and resilient grid infrastructure.

Electric vehicle (EV) Technologies

Hybrid PowerDrive Vehicles

Hybrid power drive vehicles integrate an internal combustion engine with an electric motor and battery system. The batteries can be recharged by plugging them in, and they can also harness regenerative braking to recapture energy. Plug-in hybrid electric vehicles (PHEVs) possess the capability to function exclusively on electric power for shorter distances, while utilizing the internal combustion engine to support longer journeys, thereby offering increased versatility and an extended driving range.

Hybrid Electric Vehicles (HEVs)

HEVs combine the power of an electric motor and battery with that of an internal combustion engine. HEVs rely only on regenerative braking to charge the battery, as they cannot be plugged in like PHEVs. The electric motor helps the gas engine out at low speeds and while accelerating, which helps save gas and lowers emissions.

Fuel Cell Electric Vehicles (FCEVs)

Fuel cell electric vehicles (FCEVs) have hydrogen fuel cells that create energy to run an electric motor. The sole waste product is water, as hydrogen and oxygen from the air are mixed in on-board tanks to generate energy. FCEVs encounter difficulties with hydrogen infrastructure, despite their advantages over battery-powered EVs in terms of driving range and refilling time.

Wireless Charging

The purpose of this innovation is to make conventional charging connections superfluous. Energy is transferred from a charging plate on the ground to a receiver pad on the EV through electromagnetic fields. The energy is transformed into electricity by the receiver pad, which is then used to refuel the car's battery. Wireless power transfer has the ability to streamline and improve the charging experience.

Vehicle-to-Grid (V2G) Technology

V2G technology allows electric vehicles and the power grid to exchange energy in both directions. Electric vehicles with V2G capabilities may not only use the grid to recharge their batteries, but they can also discharge electricity back to the grid during times of high demand or as a backup power source. Electric vehicles may now contribute to grid stability by acting as mobile energy storage units thanks to this technology.

Solid-State Batteries

For electric vehicles, solid-state batteries represent the cutting edge of battery technology. Unlike lithium-ion batteries, which employ liquid electrolytes, they use solid electrolytes. The benefits of solid-state batteries include increased energy density, shorter charging periods, greater safety, and a longer service life. However, large production and widespread commercialization of solid-state batteries are still in their early stages of development.

METHODOLOGY

Solar system with energy storage and EV charging capabilities offers a comprehensive solution that harnesses renewable energy, stores it for later use, and powers electric vehicles. It combines clean energy generation, storage, and transportation, contributing to a more sustainable and environmentally friendly future.

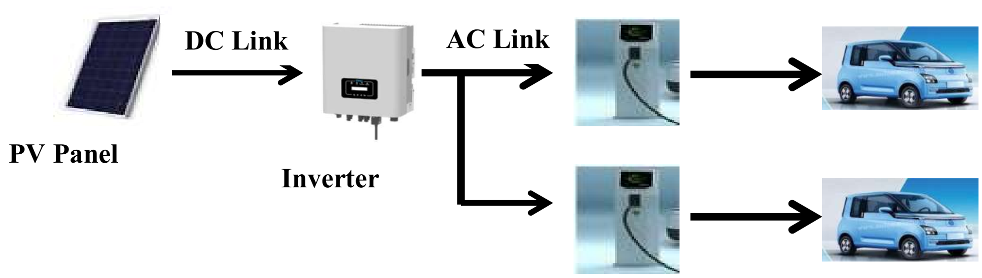

Figure 1. Proposed Methodology

Solar panels

Photovoltaic (PV) panels saturate sunlight and transform it into usable energy for the solar system. The majority of the time, the majority of the time, the majority of the time. Reducing reliance on fossil fuels and cutting carbon emissions, solar power generation is a clean, renewable energy source.

Inverter

A solar inverter is an essential part of a solar power system because it transforms the DC electricity produced by solar panels into AC electricity that is suitable for powering appliances and putting back into the grid. The solar power system must run smoothly and efficiently, and it plays a vital role in boosting energy production.

According to the data supplied, the solar inverter you described may provide a peak power of around 8.5 kW for a rather short period of time. As a result, it appears that the inverter can handle peak power demands during the few seconds when the solar panels are producing their highest output. However, inverters are typically optimized for operation within specified power ranges, thus maintaining such high power output for lengthy durations would not be possible. The inverter's efficiency and ability to transform solar energy into useful electricity are demonstrated by its ability to produce roughly 8 kW consistently over a longer time.

The properties of a solar inverter are shown in Figures 2 and 3, including the input DC voltage and current and the output AC voltage. The first graph displays the results of measurements conducted on a bright day, while the second graph gives an overall picture of the inverter's performance.

A measurement of the solar energy production, the solar inverter produced a total electrical output of 47.53 kWh. This number represents the inverter's efficiency and output quality.

Both the AC current and power output diagrams of the inverter and the DC current diagram are depicted in both figures. This structural similarity implies that the solar inverter is at its most efficient when exposed to direct sunlight. The DC voltage level is also seen to fall as the DC current increases. The current and voltage in an electrical system often have an inverse relationship.

In both cases, the output AC voltage averages out to about 253 V. The inverter's capacity to maintain a stable output, as seen by this constant AC voltage level, is independent of the DC voltage and current input.

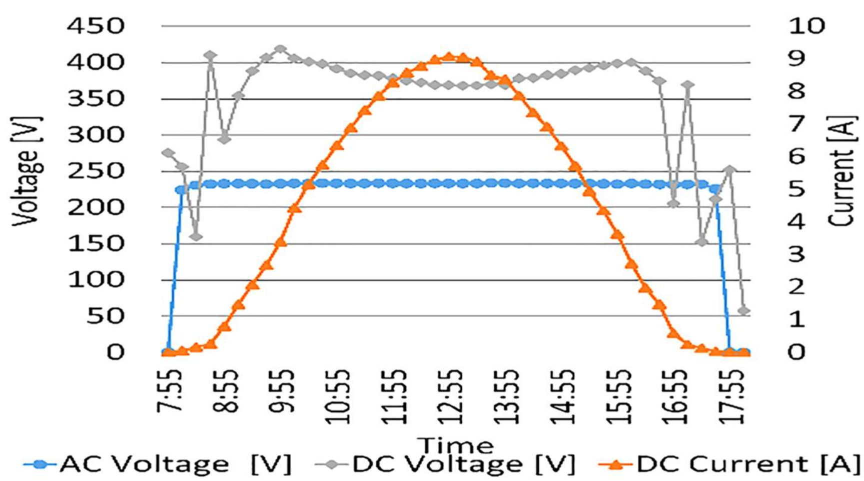

Figure 2. Solar Inverter Performance on a Sunny Day: Voltage and Current Diagrams

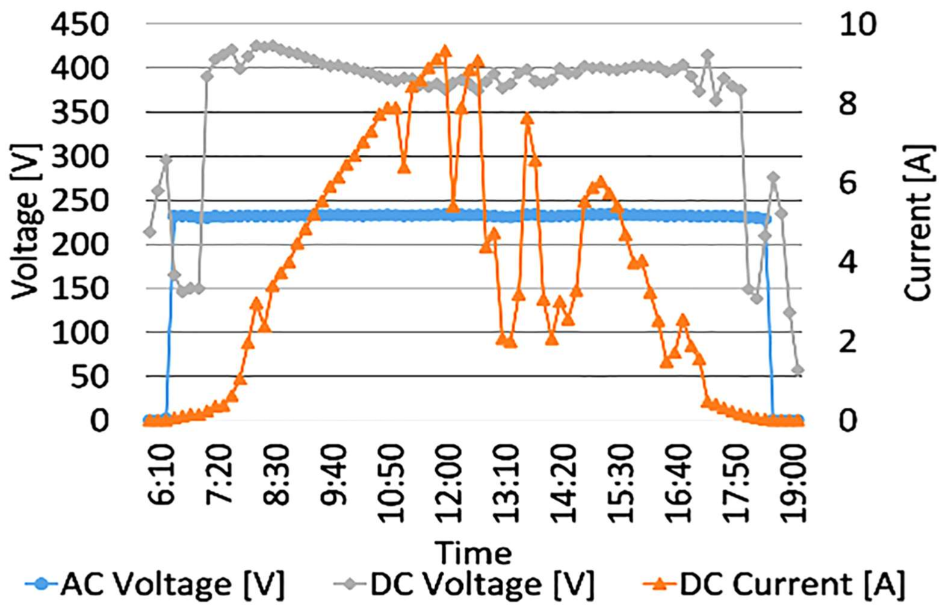

Figure 3. Analyzing Voltage and Current Diagrams: Solar Inverter Performance on a Cloudy Day

Results

The availability of solar energy depends on factors outside human control, such as the weather. Given this setup, the nominal capacity of the solar energy system is 8.68 kW. The estimated and actual energy production are quite similar, demonstrating the accuracy of the method. However, monthly energy production might fluctuate due to seasonal weather changes.

The highest discrepancy between actual and predicted energy production is shown in May, among the months analyzed. This discrepancy is likely attributable to the erratic weather patterns that month, which include some cloudy days. In May, there was a lot of variation in energy production, suggesting that it was difficult to anticipate. The highest amount of energy that can be produced by a given system is its ability to create electricity.

In May, there was a discrepancy between the predicted and actual energy production of 1,236.7 kWh and 1,140.27 kWh. This is because adverse weather has reduced the efficiency of the solar energy system. Lower actual energy output than predicted values are typically the result of cloudy days and erratic solar availability.

However, June showed greater consistency than anticipated, with actual energy production exceeding forecasts. June's energy production variability was noticeably lower than May's. In June, daily energy production ranged from a high of 50.09 kWh to a low of 34.76 kWh. More regular exposure to sunlight may account for June's minimum energy production being almost three times that of May.

In comparison to May's total of 1,901.3 kWh, June's total of 1,201.2 kWh in simulated energy production is a modest increase. The quantity of energy produced by the sun by the sun's beams was measured, and it was found to be 1,320 kWh. The 250.66 kWh difference between June's observed and simulated energy production is less than 3% of the total.

PV systems have stringent criteria for grid voltage restrictions to guarantee efficient integration into power network systems. A group of professionals monitors the PV system's daily operations to make sure it's running smoothly and efficiently. The maximum allowable grid voltage is determined by energy production peaks.

The solar inverter is made to switch off when the solar voltage is too high or too low in order to ensure grid stability. When the grid voltage drops below 180 volts or increases beyond 260 volts, Fronius inverters are specifically engineered to switch off. The inverter is protected by a thermal cutoff switch that activates when the device gets too hot to handle.

The following is a list of the most important factors to consider when deciding whether or not to use a power generator. Maintaining voltage stability is aided by keeping tabs on the amount of reactive and effective power being delivered into the grid. A solution may be to limit the amount of active power generation, however this would reduce the amount of energy supplied to the electrical grid.

Another possible solution is controlling reactive power transmission. Voltage stability is attainable by careful management and regulation of voltage levels. The voltage may be controlled and altered with this system. Because of its capacity to monitor and alter reactive power production based on grid voltage circumstances, intelligent inverters may be used to make voltage modifications.

These high-tech inverters help maintain a consistent voltage across the grid by automatically compensating for fluctuations. To ensure peak efficiency and effective energy transmission, they dynamically regulate power to keep reactive power within the grid limitations.

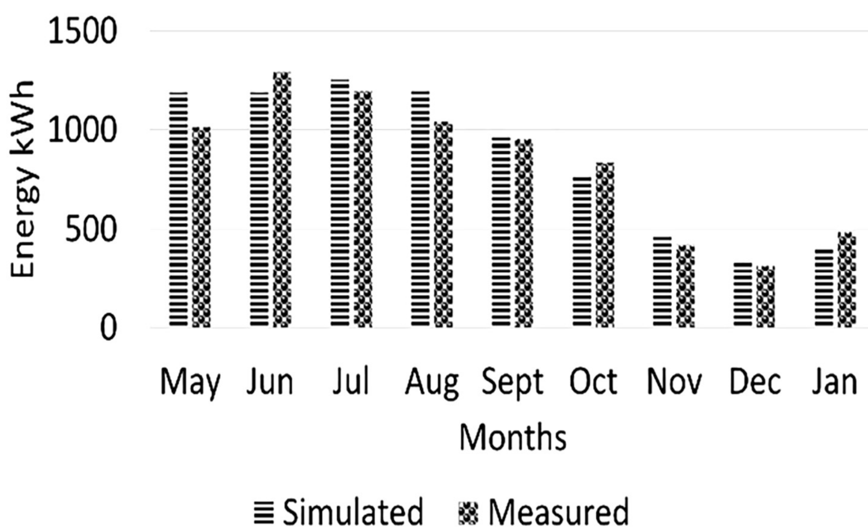

Figure 4. Comparison of Simulated and Observed Solar Energy Production

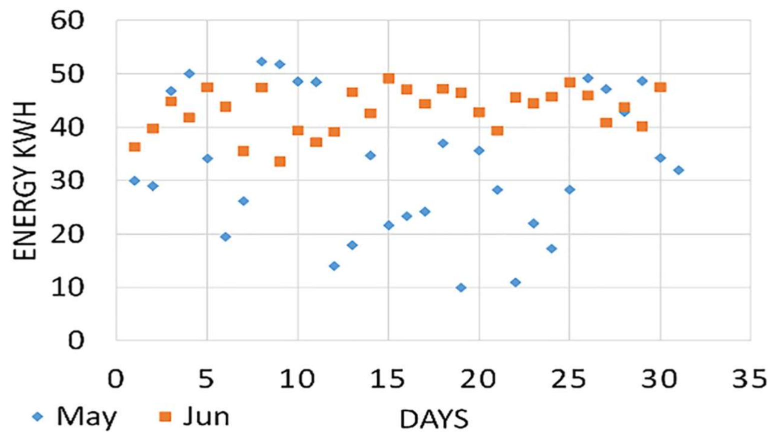

Figure 5. Comparing Energy Distribution: May vs. June

Conclusion

In conclusion, the investigation of the solar panel and inverter system, through measurements and simulations, demonstrates the impact of weather conditions on energy production. The results show that while the simulation data aligns well with the measured data in typical weather patterns, deviations arise on rainy and cloudy days, leading to decreased energy production. The analysis further reveals the relationship between weather conditions, active and reactive powers, and the need to account for these factors in optimizing solar panel system performance.

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