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Enhancing Solar PV Performance: Advanced Converters for Efficient Green Energy Conversion and Grid Compatibility

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Abstract - This paper delves into the vital role of converters in enhancing the efficiency and reliability of solar photovoltaic (PV) systems. With the escalating demand for renewable energy sources, solar PV systems emerge as a sustainable solution, necessitating advanced power electronics for optimal performance. The study highlights various DC-DC converters, such as buck, boost, and buck-boost converters, analyzing their functionalities in achieving maximum power point tracking (MPPT) and their implications on system cost, efficiency, and limitations. Further examination of grid-connected PV systems underscores the necessity for sophisticated inverter designs to ensure high efficiency, minimal harmonic distortion, and effective power management. Through MATLAB SIMULINK simulations, the paper evaluates the performance of solar PV systems equipped with different converter and inverter configurations, addressing the challenges posed by power fluctuations and the integration of solar energy into the grid. The research contributes to the ongoing discourse on renewable energy integration, presenting innovative solutions for grid synchronization, voltage regulation, and harmonic distortion reduction in solar PV systems.

Keyword-: Green Energy, Solar-photovoltaic system, controllers, MATLAB.

1 Introduction

The emergence of green r renewable energy sources such as wind, hydro, solar, and fuel cells can be linked to environmental worries and growing energy use. Due to its availability,

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sustainability, low maintenance costs, and clean nature, photovoltaic (PV) power manufacturing processes are growing more and more significant [1].Applications of photovoltaic (PV) in distributed generating systems are expanding as a result of power electronics technological breakthroughs and environmental concerns. Solar photovoltaic energy is abundant, clean, and limitless. For grid-connected photovoltaic systems that want high efficiency, minimal harmonic distortion, maximum power point tracking, and regulated power injection, inverters must be carefully designed and operated [2].The usage of DC-DC converters, such as buck, boost, and bucks-boost converters, in photovoltaic, or PV, systems is covered in [3]. Along with discussing their uses for recording maximum power points, it also goes into their benefits and drawbacks in terms of price, parts, effectiveness, and constraints.The growing need for fossil fuel-based electricity, which raises carbon emissions, is covered in [4]. It suggests a solar photovoltaic system that can supply electricity in remote areas or when used alone. A PV solar panel, a DC-DC converter, and a two-level inverter are all part of the system. MATLAB SIMULINK is the program used for doing simulations. The study in [5] presents a thorough review of the design, parts, and control methods of grid-connected photovoltaic, or PV, systems. For academics, designers, and engineers working on solar energy integration into the electric grid, it offers a wide range of information.

2 Replacement of Traditional Energy Sources with Green Energy Sources

Although there is yet no clear solution for replacing traditional energy sources with alternative energy sources, attention was piqued by solar energy's steady increase in generation of electricity over the thirty years prior. Unfortunately, the poor converting effectiveness of solar power plants makes a rigorous examination of elements that increase efficiency necessary. The study in [6] examines the fundamental components of solar cells, the MPPT methods, and DC-DC converters.Alternatives to traditional energy sources that are pollution-free, readily constructed, and endless include renewable energy sources like solar, wind, and hydro. Solar panels are widely used since they are lightweight, hygienic, and simple to install. The study in [7] describes the interface between an inverter for the voltage source and a DC-DC boost converter that is used for a three-phase grid-connected photovoltaic system. The suggested controller for the photovoltaic system that is connected to the grid has been validated by thorough simulation and practical application.

Over the past five years, solar power has expanded at an annual rate of 60%, exceeding the capacity for wind power. Traditional PV power converters have evolved as a result of this increase, with an emphasis on dependability, efficiency, and power extract. The study in [8] highlights the potential benefits of upcoming technologies whilst addressing research, actual applications, and current systems.Performance, especially in photovoltaic, or PV, systems, is greatly impacted by the power conversion selection. In order to satisfy utility/load needs from low voltage, non-linear, and sensitive power sources, tremendous advancements in electrical electronics have been accomplished throughout the previous 20 years.In [9], a new grid synchronization approach and INC control strategy for maximum energy tracking are used to examine the Single-Phase Solar Pv Rooftop System using MATLAB. Hysteresis current loop control is used for synchronizing the resultant voltage with the grid; significant testing has confirmed the feasibility of this approach and shows encouraging results [10].In order to fulfill their growing energy demands and preserve a sustainable environment, more than 170 nations have established objectives for renewable energy. Globally, multi-megawatt solar photovoltaic (PV) power plants are increasingly being chosen as the best option for modernizing and expanding electricity networks. In comparison to fossil fuel-based plants, they can be erected more rapidly, and direct medium-voltage integration with the grid is becoming a growing priority for medium-voltage inverters without step-up transformers.In order to connect solar PV power plants to grids, [11] addresses the design of medium-voltage power electronic converters, including circuitry topologies and control strategies.

Power fluctuation is a typical problem with PV systems, which can operate in both stand-alone and grid-connected modes. Hybrid grid-tied or battery storage systems are viable options for off-grid systems seeking a consistent power source. Off-grid systems provide freedom from power quality problems and electricity bills, while grid-connected systems need energy access by net meters. The operational behaviour of photovoltaic (PV) panels in off-grid and grid-tied systems, including power unbalancing, demand circumstances, and environmental factors, is covered [12]. It discusses simulation and shifting control techniques for photovoltaic P-fed multiple-layer inverters in islands areas. The findings shed light on solar power plants that are off-grid and linked to the grid.A single phase multilevel inverter architecture, specifically for photo-voltaic systems, is suggested in [13] for use in renewable energy applications. This setup uses a half bridge inverter, raises output voltage levels, and uses fewer power supplies for semiconductor switches to decrease overall distortion from harmonics and switching losses. One way to illustrate the efficacy is to swap out isolated DC sources with standalone solar panels.Through transient operation & MATLAB or Sim simulations, the suggested system is effectively validated. Without filters, it achieves a total harmonic distortion of 9.85%, and with filters, it reaches 3.91%. Its efficacy is shown by results from experiments and theoretical computations

The European Union wants to consume 20% of its energy from renewable sources by 2020, and the output of clean energy has increased quickly. The environment is not as impacted by solar electricity, but choosing the appropriate conversion is essential. In order to reach desirable voltage levels on grid output, [14] covers many converter typologies, such as boost, buck-boost, fly back, and SPIC.In order to minimize the number of silicon switches, [15] provides a control circuit design for a solar provided cascaded multilevel inverter. In order to accommodate different PV sources of input, the layout employs binary, trinary, and modified multilayer connection topologies. Appropriate switching sequence are used to ensure comparable voltage output values.There are three types of 15-level inverter that are utilized: MMC, binary, urinary, and conventional. By increasing stages, these designs reduce overall harmonic distortion. Comparing and simulating a 3 kilowatt photovoltaic system was done..

3 Proposed Methodology

Several modeling strategies have been created by scholars for modeling Hybrid green energy systems elements. The effectiveness of individual components is either probabilistically or indeterminately modeled. When produced electricity is consumed by AC loads (inverters) or transferred to the grid, DC-AC conversion devices are necessary. The output inverters are available in three-phase and single-phase configurations. Grid embedded inverters for solar systems can be classified into four categories: microgrid inverter (AC module), multi-string converter, centralized plant inverter, and string inverter.

A substantial number of PV modules were connected to the grid through centralized inverters in the previous technologies, centralized plant inverters. A string, or series connection, is made between the solar panel modules. To attain high power levels, such strings are linked in parallel using string diodes. The controller's precise design is determined by both the frequency and the amplitude characteristics of the triangle waveform, which were previously discussed. The purpose of the suggested controller is to make the inverter switch at a set frequency.

The parameters for an inverter , are crucial power electronic device in the conversion process of green energy resources. This particular inverter utilizes Insulated Gate Bipolar Transistors (IGBTs) and Diodes in its construction. To ensure the smooth operation and protection of these components, a snubber resistance of 5000 ohms is included in the design. This resistance helps in dampening voltage spikes and transient voltages, safeguarding the semiconductor devices from potential damage. The forward voltages of the diodes are specified as 0, which likely indicates an ideal scenario in the context of this table. Lastly, the on-state resistance (Ron) for the IGBTs is given as a very low value of 1x10^-3 ohms, which implies that the power loss due to resistance in the conducting state is minimal, enhancing the inverter's efficiency in energy conversion processes.

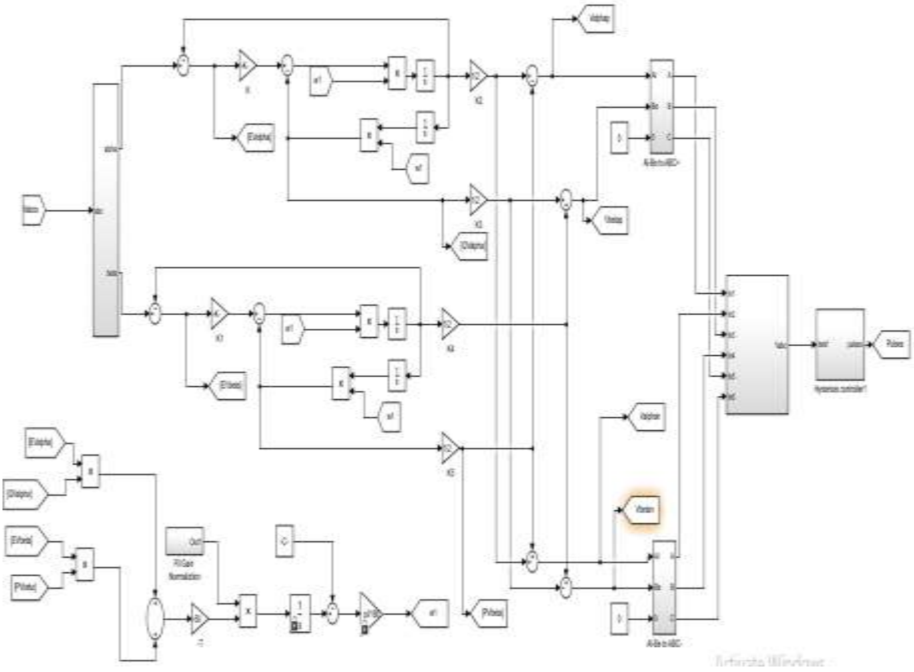

Fig. 1: Modelling of the proposed work

The traditional hysteresis current controller's shortcomings are addressed by combining it with the PI controller. The error in current among the reference current along with the photovoltaic framework's current-output is the PI controller's input for each phase. This controller's realistic insensitivity to voltage ripple, quick transient response, instantaneous peak current limitation, and ease of installation are among its benefits.

4 Result and Discussion

Several modules of a solar panel array are modeled in this study and their temperatures and irradiances are varied. Different arrays are exposed to different amounts of irradiation, which causes each device's output power to vary. Solar panels are adjusted to account for temperature and irradiance fluctuations so that their power output is improved.

4.1 Scenario 1: Green energy system (solar) with fluctuating radiation and simple inverter control regulation

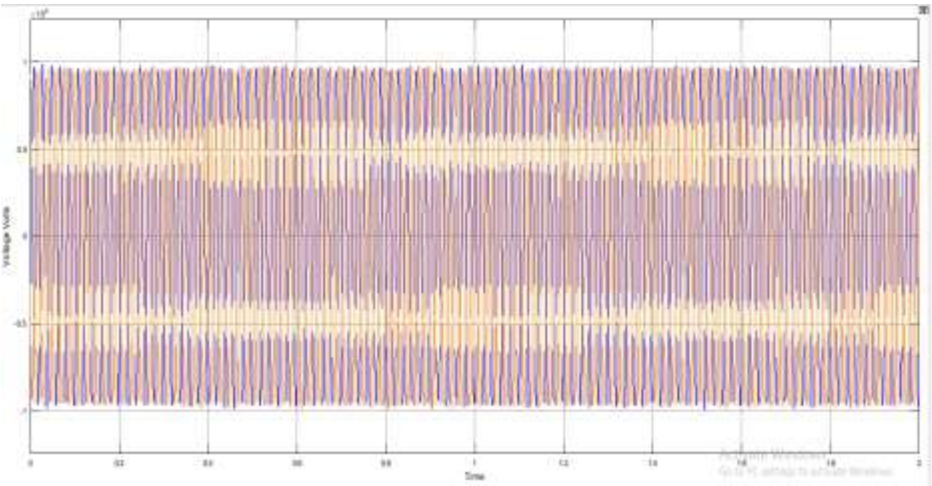

Fig. 2: Basic inverter control system voltage output

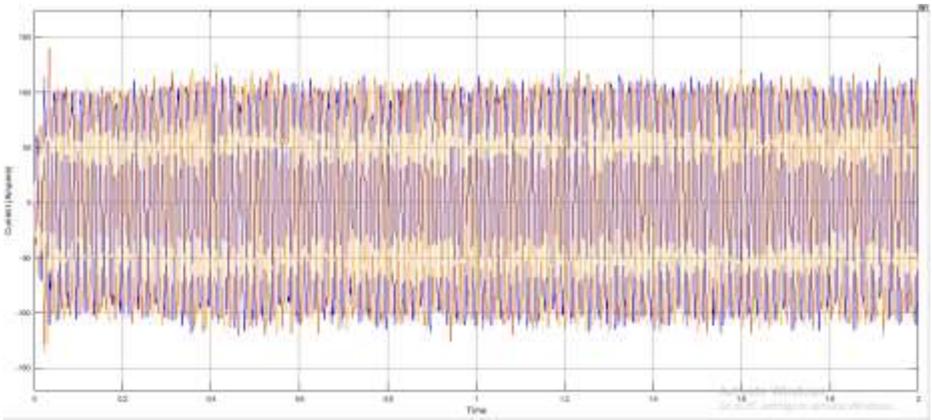

Fig. 3: Basic inverter control system current output

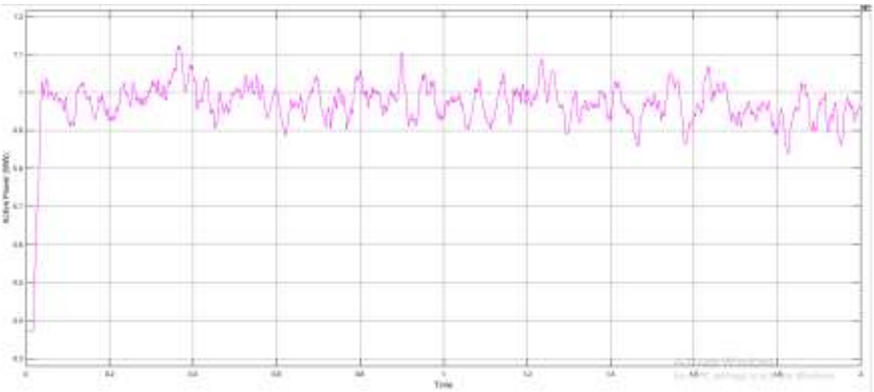

Fig. 4: Output of Active Power from the entire system utilizing basic inverter control

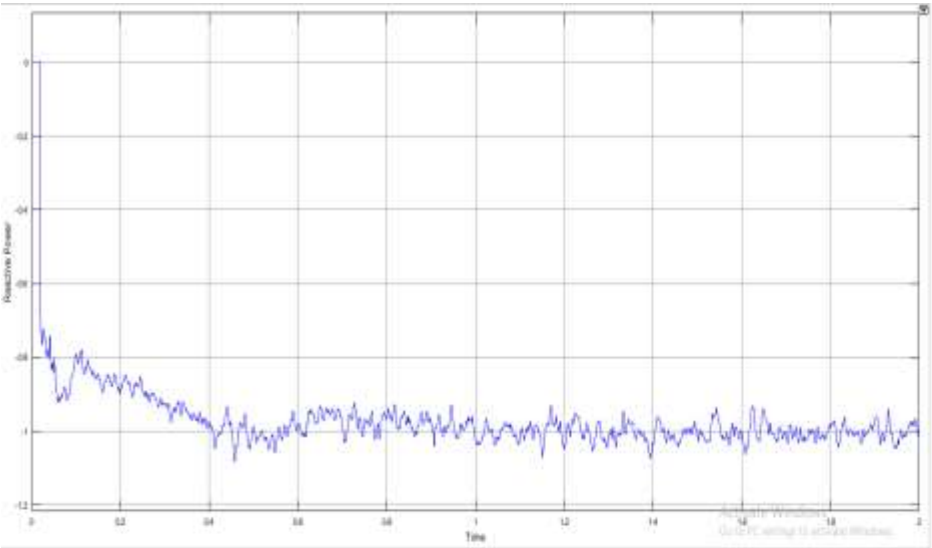

Fig. 5: Output of Reactive Power from the entire system utilizing basic inverter control

Model 1, a green energy system harnessing solar power, is engineered to deliver an impressive active power output of 0.9 Megawatt as shown in Fig .2, underpinned by a voltage provision of 10 Kilovolts as depicted in Fig. 3 and a current capacity of 100 Amperes. As shown in Fig. 4. This model operates amid the inherent variability of solar radiation, incorporating a straightforward inverter control regulation mechanism to manage the fluctuations and ensure a stable energy supply to the grid

4.2 Scenario 2: A suggested photovoltaic system with a power normalizing hysteresis regulator

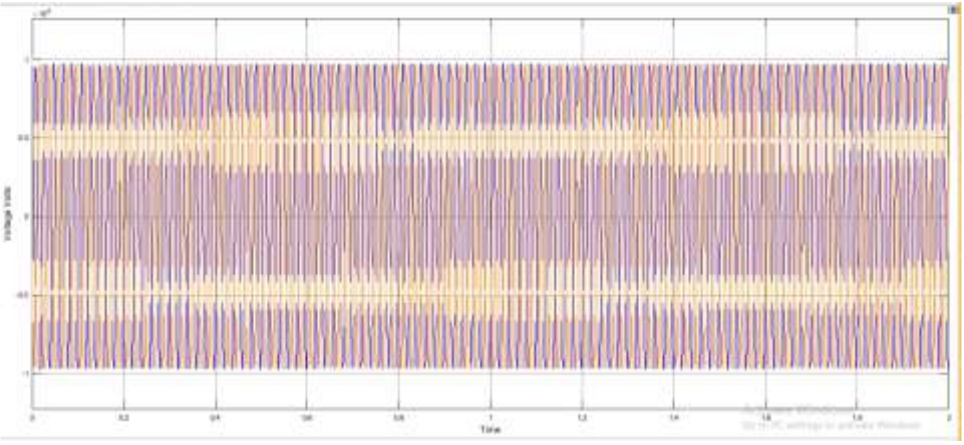

Fig. 6: Voltage Output from the Power Normalizing Hysteresis Controller-equipped System

When a system has a power normalizing hysteresis controller, the voltage output is controlled to keep the voltage level constant. According to Fig. 6, the value of output voltage is 10 KW.

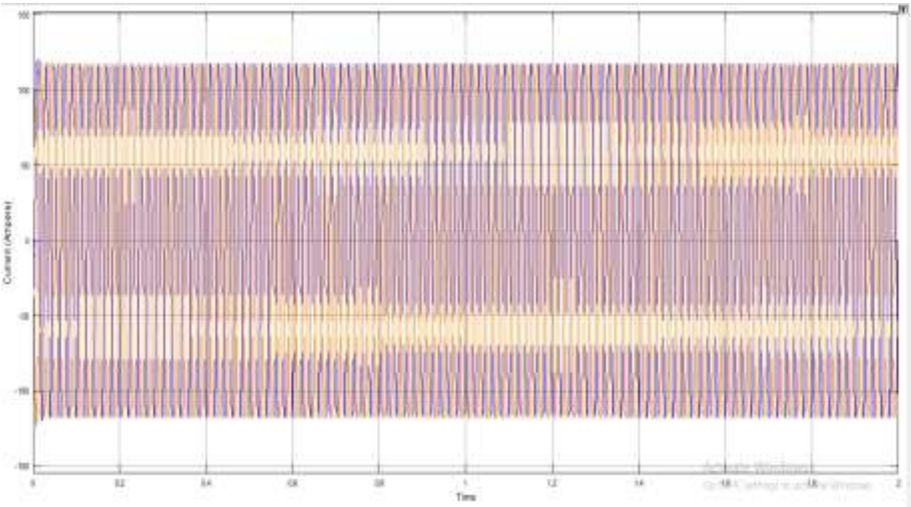

Fig. 7: Output of the Power-Normalizing Hysteresis-Controller

The current output from a system equipped with a power normalizing hysteresis controller reflects the controller's ability to maintain the current within a desired range. The value of current output is 121 Amperes, as presented in Fig. 7.

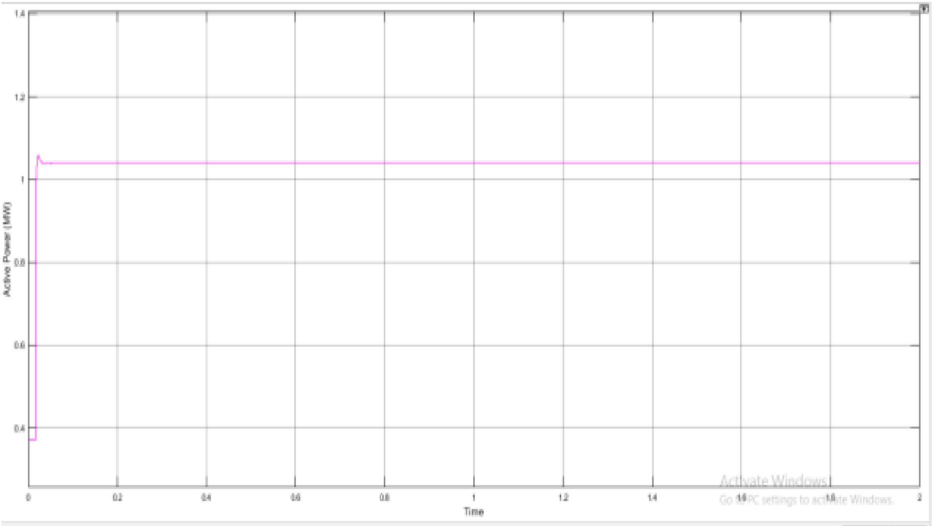

Fig. 8: Power normalizing hysteresis controller-equipped system's active power output

When a system's active power output has a power normalizing hysteresis controller, it guarantees that the power output closely tracks a setpoint or reference within the hysteresis band. Reduced variations in active power delivery as a consequence lead to a more consistent and effective energy supply, particularly in systems that use variable power sources like renewable energy. From Fig. 8, it is clear that value of active power is 1.02 MW.

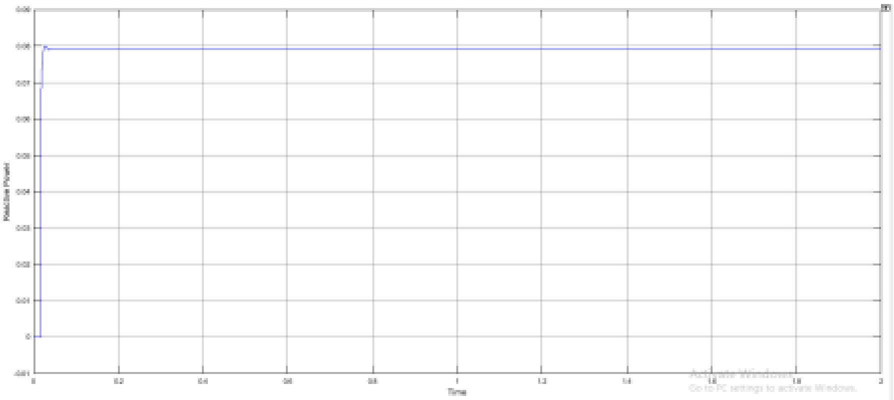

Fig. 9: Power normalizing hysteresis controller-equipped system's reactive power output

For reactive power output, a system with a power normalizing hysteresis controller actively controls and keeps the reactive power within predetermined limits. This controller ensures that the system runs effectively and within its designated reactive power band by quickly responding to changes in load or generation and modifying reactive power to stabilize the voltage and power quality. The value of reactive power depicted in Fig. 9, is 0.079 MW**.**

5 Conclusion

The comprehensive analysis of converters in solar PV systems underlines their vital role in the attainment of high system efficiency as well as making seamless integration with electrical grids. The paper reveals that, by comparing different converter topologies and control strategies, proper choices and design of DC-DC and inverters are of key importance in addressing the inherent challenges pertaining to solar PV systems, particularly with the aspect of power variability and its quality issues. These power electronic technologies, with their effective control mechanisms, give promising directions for optimization performances of solar PV systems to be a more viable source of sustainable energy. Like this study, which will not only contribute to the development of technical knowledge for converting solar energy but will also take part in the development of ever more resilient and much more efficient renewable energy systems throughout the globe.

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