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ADVANCING PV SYSTEM EFFICIENCY THROUGH INTEGRATED SOLAR CONCENTRATION AND FORECAST BASED MPPT CONTROL

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ABSTRACT- An adaptive control design for maximum power point tracking (MPPT) in a photovoltaic system (PV) is presented in this study. MPPT techniques are employed in the PV system to provide the load with the most power possible in the face of variations in ambient temperature and solar radiation. A novel method called concentrated photovoltaics (CPV) aims to increase the efficient utilization of solar energy. Because they can absorb a lot of solar energy, photovoltaic solar cells are growing in popularity. However, their widespread application is hindered by PV solar cells' higher initial costs and relatively lower conversion efficiency when compared to other non-renewable energy sources. CPV technology employs optical devices to concentrate solar energy into a smaller area of solar cells in order to maximize solar-to-thermal conversion. This aids in getting around these limitations. The primary advantages of CPV systems are their great efficiency, affordability, and environmental sustainability. This paper also examines the challenges associated with CPV system implementation, the factors influencing their performance, and the latest developments. Although CPV systems typically have efficiency levels of up to 15%, some advanced designs have shown efficiencies as high as 25–28%. There is still significant room for improvement, even though current research indicates that CPV efficiency may reach up to 38.5% at optimal solar radiation levels. One of the challenges with CPV technology is the potential increase in solar cell temperature caused by concentrated sunlight. The longevity and electrical efficiency of the system may suffer as a result. Scientists have looked at a variety of cooling techniques for effective temperature

The state-of-the-art methods, incremental conductance (INC) and perturb & observe (P&O), are compared using MATLAB/Simulink under different operating circumstances based on convergence time, tracking efficiency, PV current & voltage ripple, overall efficiency, and error rates.

Keywords: Solar photovoltaic Model reference adaptive control MIT rule Maximum power point tracking Boost converter.

I. INTRODUCTION

The basis of human existence is energy. The demand for more energy rises with population growth, creating a problem that is made worse by the urgent problems of pollution and climate change. For example, India's growing economy is severely impacted by its heavy reliance on fossil fuel imports. In order to meet its energy demands, the nation urgently needs sustainable energy sources [1]. Although significant efforts are being made to create clean and renewable energy technology, development in this sector has been rather gradual, according to a November 2019 study published by the International Energy Agency. Fossil fuels continued to hold a commanding 80% of India's energy balance as of 2018, with renewable energy making up just 10%.

The Earth serves as a massive solar collector, absorbing electromagnetic waves that the sun continuously transmits into space and converting them into different types of energy [1]. According to the Earth's energy balance, around 30% of this radiation is reflected back into space, with the remainder being absorbed by clouds, oceans, and landmasses [3]. The majority of solar light that reaches the surface of the Earth is visible, with a little portion falling into the ultraviolet frequency range.

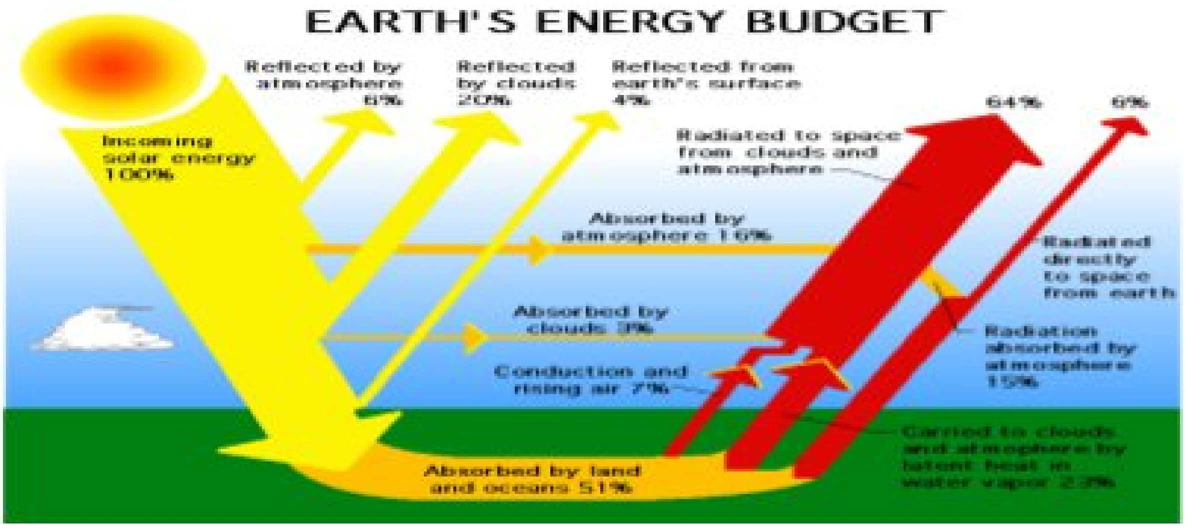

Figure 1.1: Earth's Solar Energy Balance

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1.1 CONCENTRATED SOLAR TECHNOLOGY (CST)

Concentrated Solar Technologies (CSTs) have two noteworthy areas of application:

1. Process heat: Solar concentrators are deemed commercially viable for process heat applications at temperatures below 400°C. Non-concentrating collectors are suitable for temperatures up to 80°C, while concentrating collectors prove practical for process heat requirements starting from 100°C and higher.

2. Solar cooling: Solar heat can also be effectively utilized for cooling purposes. In many regions of India, the peak demand for cooling aligns with the period of high solar irradiance, making solar cooling an ideal application match.

1.2 TYPES OF CST

Concentrated Solar Technology (CST) employs reflective materials to concentrate solar radiation, generating temperatures ranging from 100°C to 450°C or even higher. These devices are typically equipped with tracking mechanisms to ensure continuous alignment with the sun's rays, utilizing direct normal radiation rather than diffused radiation [4]. Several types of CST devices include:

1. Flat plate collector (Non-concentrating): This widely used device is primarily employed for water heating applications up to temperatures of 75°C.

Figure 1.2: Flat plate collector

2. Parabolic Trough (PTC): High temperatures can be produced by focusing sunlight onto a receiver tube positioned along the focal line using a curved, trough-shaped reflector. This kind of line focusing concentrates solar energy at a parabolic collector's focus. Typically, absorber placement in cylindrical parabolic concentrators occurs along the focus axis.

Figure 1.3: Parabolic trough collector

3. Compound Parabola: This CST device employs a combination of parabolic and hyperbolic reflectors to concentrate solar radiation onto a receiver. CPC derives its name from two parabolic reflectors located on the left and right of the absorber plate [5]. The construction of a CPC makes it feasible to harness solar radiation with a wide angular spread.

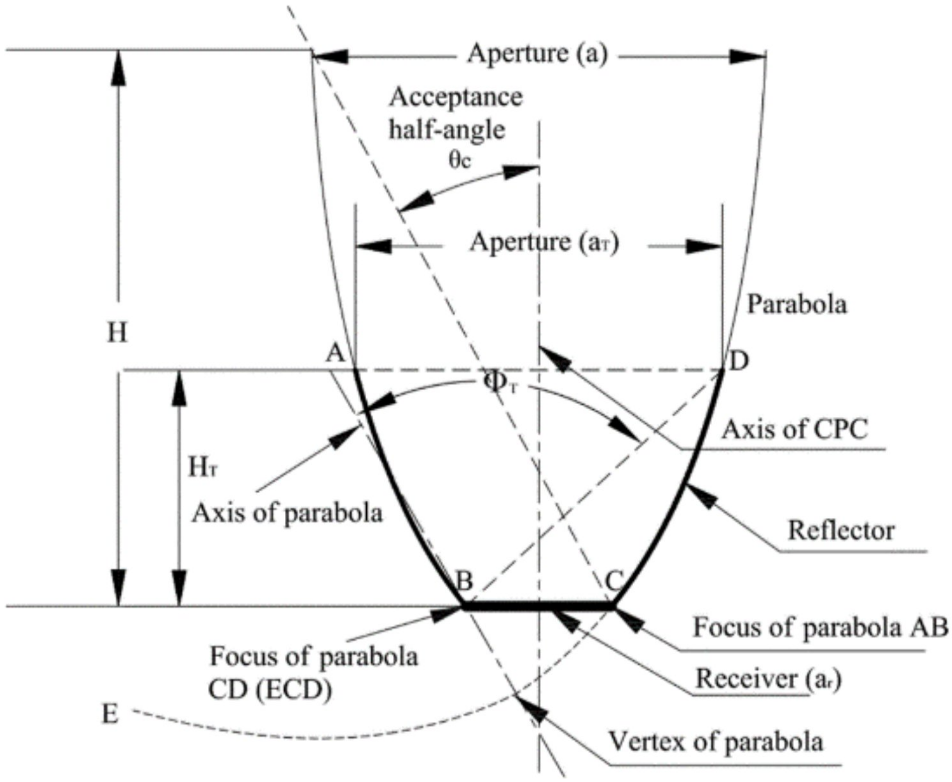

Figure 1.4: Compound parabola concentrator

4. Fresnel Reflector based Dish (ARUN): This dish-shaped device utilizes Fresnel reflectors to concentrate sunlight onto a central receiver, capable of achieving high temperatures. The ARUN Dish is a paraboloid solar concentrator that has a point focus. It can be used with various heat transfer fluids like steam, oil, water, or air at pressures of up to 25 bar and temperatures of up to 350oC.

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Figure 1.5: Arun dish (HELI SCSP Solar Thermal Energy news)

1.2 RENEWABLE ENERGY POWER GENERATION

Renewable energy comes in many forms and is readily accessible. India is a tropical country with an abundance of natural resources, such as wind, solar, tidal, and geothermal energy. These resources have a great deal of potential to meet the electrical demands of both rural and urban areas. Many factors, such as resource availability, accessibility, and location, affect the choice of renewable energy source. Among the alternatives, photovoltaic (PV) power generation is especially appropriate [14]. The efficient production of power ranging from a few kilowatts (KW) to several megawatts (MW) is made possible by connecting solar panels in series and parallel configurations. This allows the voltage and current to be adjusted as needed.

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II. DESIGN EXPERIMENTATION

2.1 DESIGN OF BIG SCHEFFLER CONCENTRATOR FOR REFLECTOR AREA

The calculation of the reflector area was based on the amount of heat required to boil a specific quantity of water for steam generation. The details of the calculation are provided below:

Receiver water capacity: 8 kg

Heat required for boiling 8 kg of water:

$Q1 = M * Cp * \Delta T$

$= 8 * 4200 * \Delta T$

$= 2284800$ J

Heat required for vaporizing 4 kg of steam (Q2):

$Q2 = 4 * 2.2 * 10^6$ J

$= 9040000$ J

$= 3147$ W

Receiver losses:

The total receiver heat loss coefficient calculated through heat transfer analysis is 8 W/m2K.

$Q\ loss / A_r = h_w * (T_r - T_a) + \varepsilon * \sigma * (Tr^4 - T_{sky}) + U_{cond} * (T_r - T_a)$

$= (h_w + h_r + U_{cond}) * (T_r - T_a)$

$= 495.6$ W

Total heat required per hour = 3145.7 W.

Power needed for boiling = 3145.7 W + 495.6 W

= 3641.3 W

Applying the solar insolation and mirror reflectance for the design, the effective solar beam is calculated as:

$IG = 0.85 * 740$

$= 629\ W/m^2$

Applying a design factor of 1.5 to calculate the reflector area:

$A = (3641.3 / 629)^{1.5}$

= 8.7 m2

The area of the Scheffler dish selected, closest to a standard size, was determined to be 9.7 m2.

2.2.1 Scheffler set up specifications

The chosen standard size for the Big Scheffler dish was 9.7 m2, as indicated in below table, in order to optimize costs. The construction of the dish involved the use of individual mirrors with a reflectivity of 0.89. These mirrors were mounted on a frame to facilitate maintenance and replacement of parts [53]. The manufacturing and installation of the Scheffler dish were carried out by Prince India, a reputable concentrator manufacturer known for their expertise in this field. The dish was equipped with automatic tracking functionality.

Figure 2.1: Big Scheffler with cylindrical receiver

The system was designed with receivers of the same size as those used in the Big Scheffler dish. However, due to the lower concentration ratio of the Small Scheffler dish, it was anticipated that it would not be able to generate steam using 8 liters of water in the receivers [54]. Consequently, the receivers were filled to only half their capacity, with 4 liters of water. Unlike the Big Scheffler dish, the Small Scheffler dish was constructed without a steam tank, focusing solely on the receivers. The construction of the dish involved individual mirrors with a reflectivity of 0.89, which were mounted on a frame to facilitate maintenance and replacement of parts. Unlike the automatic tracking employed in the Big Scheffler case, the tracking mechanism for the Small Scheffler dish was manual.

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Figure 2.2: Small Scheffler with conical receiver

To achieve thermal balancing in the system, the receivers were filled with water up to half of their capacity, while the remaining half was reserved for steam accumulation. This arrangement ensures an optimal distribution of heat within the system. For safety purposes, a pressure relief valve was installed at the top of the receiver, while a pressure gauge was mounted at the bottom [55]. These components allow for monitoring and controlling the pressure levels within the system, ensuring its safe operation.

Solar Radiation

The parameters with more influence during the observations were global, diffuse and direct solar radiation. On each day of experiments, global and diffuse radiations were measured using the pyranometer, while direct radiation was calculated. Since direct solar radiation data is the useful entity in computing thermal efficiency, the hourly trends for direct radiation on selected days.

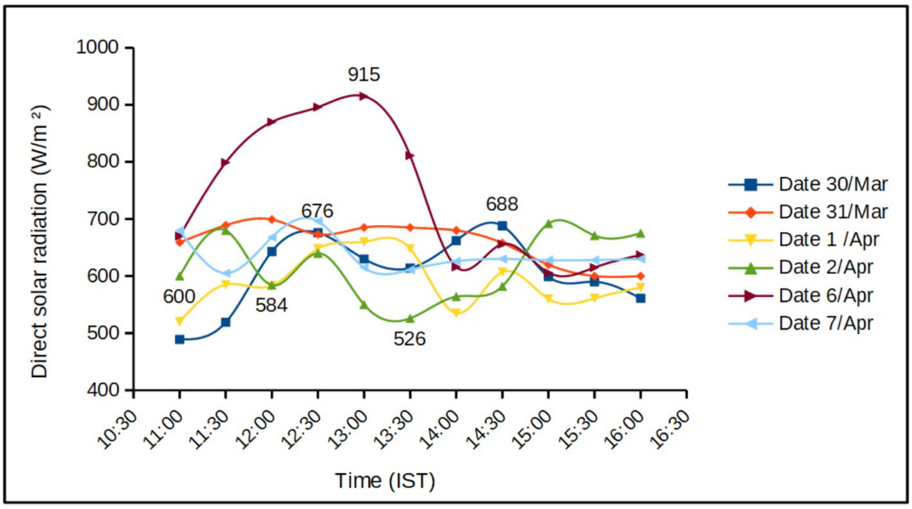

Figure 2.3: Direct Solar Radiation 1 (W/m^2)

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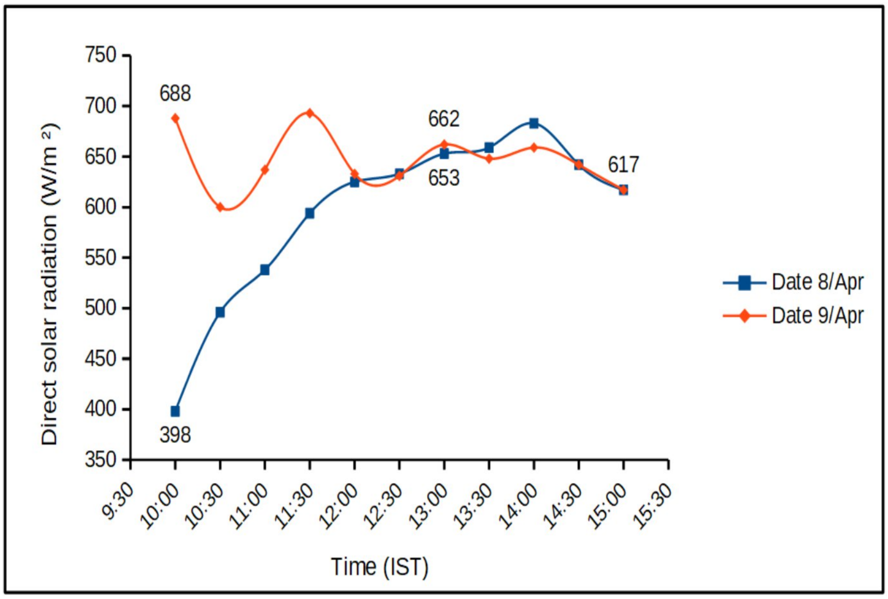

Figure 2.4: Direct Solar Radiation 2 (W/m^2)

III. SIMULATION RESULTS

To examine the precision and efficacy of the suggested approach, a PV system comprises PV modules, a DC-DC boost converter, a resistive load, and a control system. These components are then taken into account and modelled using MATLAB/SIMULINK software. To compare the performance of the suggested enhanced DP P&O MPPT technique with that of the DP P&O MPPT method, simulation models have been run and examined.

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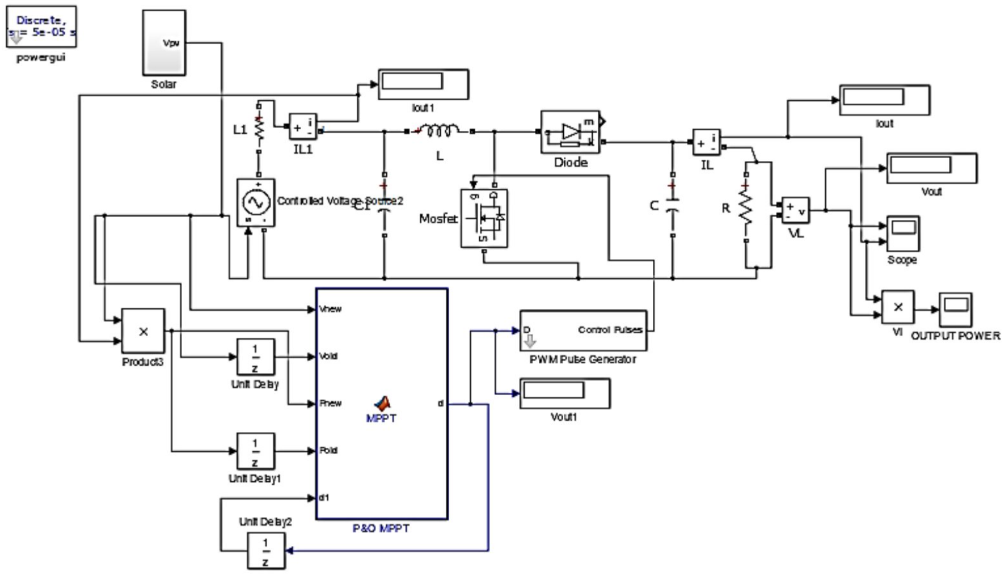

Figure 3.1: Simulink model of DP P&O method

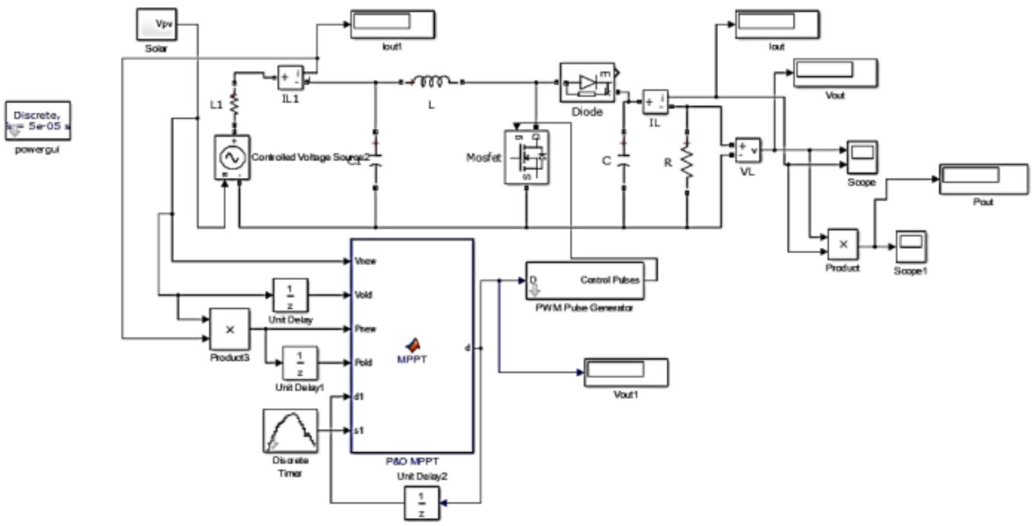

Figure 3.2 Simulink model of improved DP P&O method

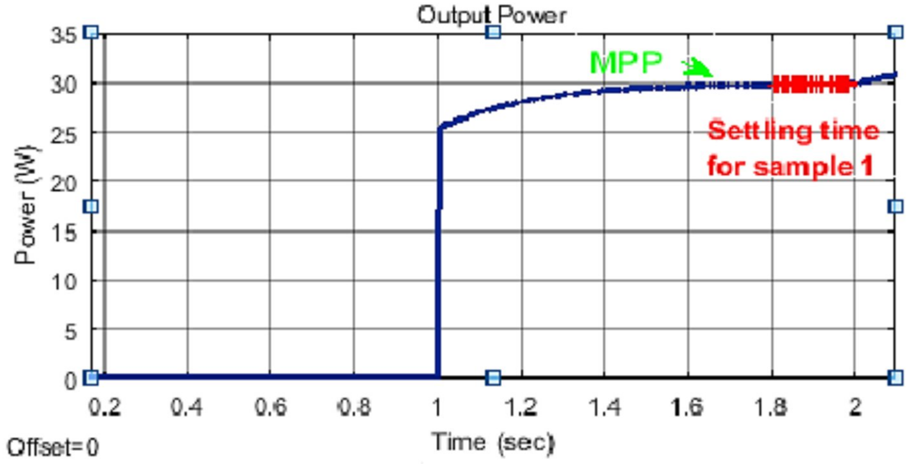

Figure 3.3 Tracking trajectories of DP P&O

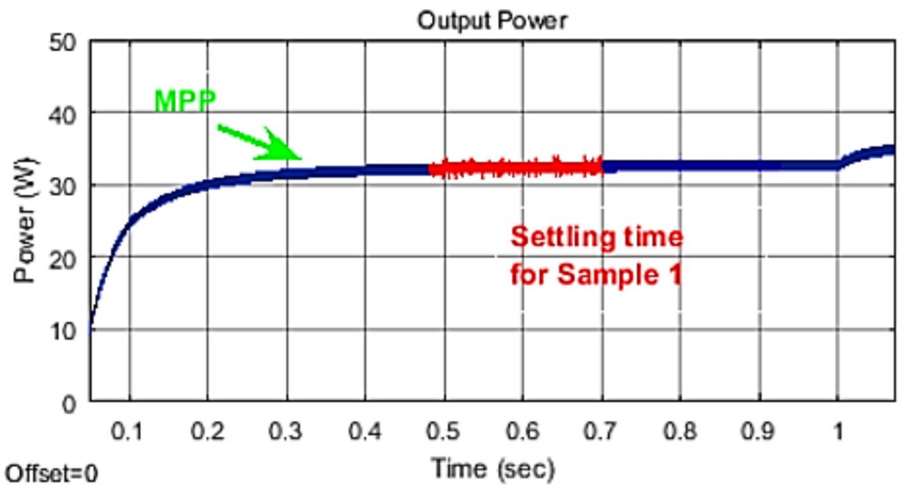

Figure 3.4 Tracking trajectories of Improved DP P&O method

This chapter provides an explanation of the suggested enhanced DP P&O MPPT approach. A detailed discussion is held on the sun irradiation and forecast analytical model. MATLAB is used to simulate both the current DP P&O and enhanced DP P&O MPPT methods. Analysis is done on how the solar PV system's current and suggested MPPT regulation techniques respond. It can be deduced from the simulation results that the suggested enhanced DP P&O MPPT approach outperforms the current MPPT technique in terms of speed.The system and test setup were created with particular goals in mind: system characterisation, performance equation creation, study of thermal losses, improvements in thermal efficiency, and investigation of wind impacts. This research project was carried out to examine many facets of the Scheffler system. A particular research approach and set of applications were needed for each of these investigations. Therefore, each component of the research had its own approach, technique, and independent outcomes and findings, even if the ultimate goal was to investigate the Scheffler system. To make it easier to relate these findings to their particular technique, data, and analysis, they have been given and discussed at the conclusion of each section or chapter [119]. The overall findings are emphasized, analyzed, and contrasted with findings from related published publications in this chapter.

The design and selection of the Scheffler system for the experimental work reflect a few features that set the research project apart from other studies on Scheffler systems in terms of its goals and approach. A 9.7 m2 Scheffler size was used instead of an existing standard system since the purpose of this work was to assess a Scheffler system with a 4 kg/h steam producing capacity [120]. An extra Scheffler system size (2.7m2) was chosen in order to investigate the impact of various concentration ratios on thermal efficiency. Cylindrical receivers are used in normal Scheffler systems; however, in order to experiment with receiver geometries, two geometries—cylindrical and conical receivers—were examined.

IV. CONCLUSIONS

Adaptive control techniques may react to unforeseen changes in inputs or system dynamics, they are widely used in time-varying or nonlinear systems. Furthermore, adaptive controllers often demand less computational time and previous system information. The model reference adaptive controller is used in this article to tune the PV output voltage to the MPP under rapidly changing temperature and radiation conditions. The results demonstrate the great efficiency of the suggested MRAC approach. The effectiveness of the novel MPPT approach falls between 99.20% and 99.94%, whereas P&O and INC fall between 97.90% and 97.93% and 97.90% and 98.10%, respectively. When compared to the alternatives, the suggested MPPT approach produces the lowest MPP oscillation rate, faster convergence time, greater efficiency, insignificant ripple, and reduced error rate. The technique rises to the top of the efficiency rankings as a result. Furthermore, MPP is captured in just 3.6 ms, which is almost ten times quicker than INC and twelve times faster than the P&O method. The design of MRAC-based MPPT for partial shade situations will be the main emphasis of this effort in the future.

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