12-2022

ANALYSIS FOR AN EFFICIENT OPERATION OF SOLAR POWER PLANTS IN INDIA USING DIFFERENT VARIABLES/PARAMETERS

Sonal Bansi Shinde
California State University - San Bernardino

ANALYSIS FOR AN EFFICIENT OPERATION OF SOLAR POWER PLANTS IN INDIA USING DIFFERENT VARIABLES/PARAMETERS

A Project

Presented to the

Faculty of

California State University,

San Bernardino

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Information Systems and Technology

---

by

Sonal Bansi Shinde

December 2022

ANALYSIS FOR AN EFFICIENT OPERATION OF SOLAR POWER PLANTS IN INDIA USING DIFFERENT VARIABLES/PARAMETERS

A Project

Presented to the

Faculty of

California State University,

San Bernardino

---

by

Sonal Bansi Shinde

December 2022

Approved by:

Dr. Benjamin Becerra, Committee Member, Chair

Dr. Conrad Shayo, Committee Member

Dr. Jay Varzandeh, Committee Member, Dept. Chair, Information & Decision Sciences

ABSTRACT

Vast renewable energy facilities rely heavily on accurate predictions of future solar power output. This study investigated the various factors causing poor, inefficient operation of Solar Plants and different methods to identify underperforming equipment. The main questions are: Q1: How can we predict electricity generation over the next several days so that the plant can run at peak efficiency? Q2: How can we figure out the exact maintenance needs of any power plant? Q3: How do we identify faulty equipment to improve its efficiency to improve overall performance? and Q4: What are the different factors that are causing an inefficient operation of Solar power plant? Data was gathered from Kaggle and iPUMS and then analyzed in PyCharm Community Edition 2021.2.3 to provide answers to the research project questions. Given this observation using PyCharm, important discoveries from this project were: Q1: By comparing the irradiation of both of the plants, both plants' daily irradiation doesn't show much difference surely, but we can say that Plant 1 had the most consistent irradiation throughout a month, Q2: We observed that in comparison with DC power, AC power is a lot lesser than DC power but again since it's a Solar power plant therefore most of the power generation happens during day time.Q3: Figure 4.7 indicates that the 1BY6WEcLGh8j5v7 & bvBOhCH3iADSZry inverters are deficient when compared to others; perhaps these inverters require repair or replacement. Solar power plants are susceptible to several issues that might diminish their electricity generation due to their extended lifespans. Even two

similar solar power plants in different locations may have varying efficiencies. Q4: As the DC_Power /Irradiation decreases there is a significant amount of increase in the model temperature. That excessive increase in heat leads to a decrease in the efficiency of that respective equipment. When the temperature rises, an excessive number of electrons are released from the solar panel, lowering the voltage produced and the panel's overall efficiency. Areas for further study include: (a) comparing the India experience to other growing nations with similar constraints to help create a prediction model that can resist all climatic and environmental changes and (b) conduct additional research on solar power prediction enable solar power plants to function efficiently.

ACKNOWLEDGEMENTS

My deepest gratitude goes out to Dr. Benjamin Becerra, Dr. Conrad Shayo, and everyone else who has been so encouraging and helpful to me over the course of these past several months while I've worked on this study project.

DEDICATION

I would like to dedicate this to my parents, without their support and continuous encouragement I could not have done this. I would also like to thank you, my whole family, and friends, who’ve been supportive throughout this journey. In the end, I would like to thank each and every person who’s been associated directly or indirectly with me.

TABLE OF CONTENTS

ABSTRACT iii

ACKNOWLEDGEMENTS v

LIST OF TABLES vii

LIST OF FIGURES viii

CHAPTER ONE: INTRODUCTION 1

Background 1

Problems Associated with Solar Power Plants 2

Problem Statement 4

Better Grid Management that predicts Solar Power generation 5

Impact of Extreme Weather on a Solar Panel 7

Research Questions 8

CHAPTER TWO: LITERATURE REVIEW 9

Present Situation of Solar Power 9

Advantages of Solar Power Sector in India 14

CHAPTER THREE: RESEARCH METHODOLOGY 17

Aspects Influencing the Solar Output 21

Steps involved in Research Methodology 23

CHAPTER FOUR: DATA ANALYSIS AND FINDINGS 24

Irradiation 24

What does Irradiation mean 24

AC-DC Power 27

Identification of Deficient and Faulty Equipment 29

Other Factors in Forecasting Power Generation 32

CHAPTER FIVE: DISCUSSION, CONCLUSION AND AREAS FOR FURTHER STUDY 37

Discussion and Findings 37

Conclusion 39

Areas for further Study 40

REFERENCES 41

LIST OF TABLES

Table 1. List of Keywords and Articles used for the Study 17

LIST OF FIGURES

Figure 2.0: Renewable Power Capacity Addition by Region, 2004-2006 11

Figure 2.1: Geothermal figures for 2004 and 2003 12

Figure 3.0: Aspects Influencing the Solar output 21

Figure 4.1: Irradiation Status for Plant 1 Weather Sensor 26

Figure 4.2: Irradiation Status for Plant 2 Weather Sensor 26

Figure 4.3: Maximum and Minimum AC-DC Power for Plant 1 and Plant 2........ 27

Figure 4.4: Daily Yield and AC -DC Power during Day hours 28

Figure 4.5: Percentage of DC Power converted into AC Power 29

Figure 4.6: DC Power throughout a day from all the Sources 30

Figure 4.7: DC Power for First 10 and Last 10 Sources 31

Figure 4.8: Correlation Analysis.. 32

Figure 4.9: Correlation Analysis between Ambient Temperature, Module Temperature, and Irradiation 34

Figure 4.10: Evaluation of the efficiency of Inverter 35

Figure 4.11: Module temperature & DC_Power /Irradiation 36

CHAPTER ONE

INTRODUCTION

Background

Kerr (2019) states that traditional power production is not a good technique. The combustion of coal, oil, and gas can be extremely dangerous to the environment. For instance, a part of power production results in excessive CO2 emissions, the mining of fossil fuels from the earth leads to pollution and global warming, and its vast usage of water supply may also create ecological concerns globally. Knowing such considerations, it is acceptable to argue that using renewable energy sources might support the environment. Solar energy generates pure, clean, and renewable energy from the sun, making it an excellent substitute for fossil fuels such as natural gas and coal. It also minimizes the global carbon footprint and greenhouse gas emissions. Finally, after the solar panels are placed, the electricity produced will be emission-free and require only a small bit of water.

According to Kerr (2019), “Solar power is an appealing source of energy since it is both commonly accessible and renewable. The Sun releases enough energy into the Earth every second to fulfill the whole human energy requirement for more than two hours. Nonetheless, solar has still contributed for less than 2% of global energy since 2018. Previously, solar energy collecting was both complicated and expensive. Because the amount of power obtained from solar energy worldwide increased approximately 300-fold from 2000 to 2019, maybe this modest solar usage represents an improvement over the past two decades.

Hence, it is essential to comprehend what are various issues for the lagging pace in solar energy adoption.

Problems Associated with Solar Power Plants

The cost of solar cells, which make it possible to turn sunlight into electricity, has been steadily decreasing over the past two decades. The rising price of solar is analyzed by the National Renewable Energy Laboratory, a government institution in the United States that studies solar cell technology. In their estimation, the hard costs (such as the price of the solar cells themselves) and the soft costs (such as the price of labor or the price of acquiring essential government permits) will be about equivalent (Kerr, 2019).

Kerr (2019) describes that since there are more potential buyers and installation experts for new solar cells, the soft costs have dropped, allowing businesses to produce solar cells in bulk and have them easily installed. Lower material prices and enhanced cell light-capture capabilities are principally responsible for the reduction in hard costs of more than 50% since the year 2000. A deeper dive into the science of solar harvest and innovative engineering are required to produce cheaper, more efficient solar cells.

If a new design were to surpass today's solar cells, it would need to do one of three things: capture more light, convert more of that light into power, or be cheaper to manufacture. Energy producers and consumers are more likely to

`

choose solar power if the electricity it generates is competitive with, or cheaper than, other forms of electricity generation that are often not renewable. Hence, any enhancements to current solar cell designs must result in lower total prices for them to be broadly adopted.

Improving solar cells' ability to convert solar energy into electrical energy is one strategy for improving their overall performance. More photons can be gathered by multi-layer solar cells as opposed to those with a single layer of light-absorbing material. Fourth-layer solar cells performed best in the experiment, absorbing 46% of the available light. Despite their extreme efficiency, these cells are currently too costly and complicated to build for widespread commercial use.

In today's globalized world, a country's social and economic prosperity hinges on the reliability of its energy infrastructure. One of the key reasons that might slow economic development in a developing country is a lack of reliable energy infrastructure (Thelwell, 2019). Constant blackouts and limited access to the grid are wreaking havoc on the citizens of many developing nations right now. The efficiency of renewable energy is often misunderstood and undervalued. The false belief is that renewable energy sources are too costly for all but the most industrialized nations to implement. Investments in renewable energy technology would be more cost-effective than fossil fuels, and their correct implementation in developing nations might lessen their dependency on natural gas and oil. Numerous developing nations are already reaping the benefits of renewable energy (Thelwell, 2019).

Through its appealing economic case, India's solar story leverages lowering renewable technology costs as the route to future energy decarbonization. The government has understood that constructing and running solar plants is far less costly than operating current coal-fired power plants. Renewable energy also has tremendous environmental benefits, making it the single most important driver in assisting us in meeting our carbon emission reduction goals in tackling climate change. With India's increasing economy, energy consumption will only rise, therefore switching to alternative energy sources is the best approach to strike a balance between economic growth and environmental sustainability (Economic Times, 2019).

India's tremendous growth is projected to continue. With 8.8 GW of expected capacity development (a 76% increase over 2016), it is set to overtake Japan as the third-largest PV market in 2017. One of the world's biggest renewable energy programs, India can take a leadership role in driving energy change both nationally and internationally. By 2022, India hopes to have 175 GW of installed renewable energy capacity, comprising 100 GW of solar, 60 GW of wind, 10 GW of biomass, and 5 GW of small hydropower (Editor, 2018).

Problem Statement

Solar power, often known as energy from the sun, may be used to generate either heat or electricity. In terms of environmental impact, solar power is not equal to renewable energy options. Solar technology can capture this

`

energy and use it for a wide range of purposes, such as power generation, illumination, and water heating for residential, commercial, and industrial applications. A lot of challenges remain, however, before solar can fully replace fossil fuels in electricity generation. Many unanticipated difficulties with solar electricity are being discovered by businesses doing business in these underdeveloped countries (Hossain, 2020).

Better Grid Management that predicts Solar Power generation

With seasonal heat waves and power outages, the need for renewable energy sources, especially solar energy, in addressing these problems has become more apparent. It's safe to say that the global epidemic COVID-19 has affected every single country severely. It also highlighted the necessity for stable healthcare and infrastructure to transport lifesaving refrigerated vaccinations in countries like India. In rural areas of India where the epidemic is causing havoc, having access to power might be the difference between life and death for many people. India's plans to gain from solar electricity began long before COVID-19 hit. The nation has set a lofty goal: 100 GW of solar power capacity by 2022. That's great news for its business and industrial users, who utilize 74% of the country's energy, compared to the 13% used by households and government agencies (World Bank Group, 2021).

However, urban load centers need enough transmission to receive power. Intermittent resources like solar can cause higher transmission costs, congestion, and generation limits when not enough transmission capacity is available. Given

`

the possibility of transmission hurdles, solar project developers must weigh the economics of sitting near loads vs where the resource is optimal. Another challenge is photovoltaic efficiency. In the desert, a square meter of solar panel may gather 6 kilowatt-hours each day. (Hossain, 2020) So much energy can't be converted by a solar panel. Solar panel efficiency controls useable electricity. Commercial solar panels are less than 25% efficient (Hossain, 2020). More efficient panels cost more to make.

Furthermore, at the September 2019 Renewable Energy India (REI) Expo 2019 conference, Mercom India chaired a panel discussion, during which one of the speakers eloquently described the challenges of planning and forecasting. Approximately 3 million people were evacuated from the state of Gujarat in advance of a cyclone on June 13, 2019, by the state's administration. There were no warning signs of the impending storm in Gujarat till the 16th of June 2019. On June 18, the storm finally made landfall, although not where it had been predicted to be. It hit around 250 miles to the west.

The percentage of electricity generated by weather-dependent wind and solar energy in the European power mix is increasing. As a result, the power sector is under pressure to be far more adaptable in controlling power demand and supply. The demand for exact estimates of how much power will be supplied into the grid at any given time is growing. Accurate weather forecasts serve as the foundation, but grid operators, electricity dealers, and renewable energy plant

`

operators now rely on a new business that specializes in sector-specific projections.

Under the appropriate circumstances, renewables might account for 80 % or more of Germany's power consumption. On a calm night, the temperature might drop to around zero. This has ramifications for system stability, the location of renewable energy facilities, and power prices. The more accurately you can forecast how much electricity will be generated from renewable sources, the simpler it will be to handle the repercussions. Accurate weather forecasts are required for these forecasts (Wettengel, 2018).

Impact of Extreme Weather on a Solar Panel

Solar panels are made to be long-lasting. PV systems can resist all types of climatic conditions from rain and wind to snowfall and more, thanks to high-quality solar panel installations. You'll be relieved to hear that solar panels are resistant to hail, as discovered by the Department of Energy. They can even withstand hurricanes, as proven by the minimal damage to North Carolina solar systems during Hurricane Florence in 2018. Yet, they are not invincible; in rare instances, they can be damaged by hail, hurricanes, tornadoes, or lightning. However, if you have a decent warranty and/or your panels are protected by homeowners' insurance, you should be able to get broken panels fixed immediately (Sendy, 2019).

Research Questions

From this study we are trying to explore the following questions in India:

1. How can we forecast power generation for the next few days for optimum operation of the Solar power plant?

2. How do we identify the exact requirement of maintenance of the respective Solar power plant?

3. How do we identify faulty equipment to improve its efficiency in order to improve overall performance?

4. What are the different factors that are causing an inefficient operation of Solar power plant?

`

CHAPTER TWO

LITERATURE REVIEW

In this literature study, we will explore the current Solar power situation in India and then go through some of the many potential benefits of solar power in India.

Present Situation of Solar Power

Renewable energy sources and technologies have the opportunity to deliver remedies to developing countries' hard energy concerns. Wind energy, solar energy, geothermal energy, ocean energy, biomass energy, and fuel cell technology can all be employed to help India solve its energy problem. To meet the energy needs of such a rapidly developing economy, India will need a secure supply of 3–4 times the total energy utilized now. Renewable energy is indeed a possibility for meeting this goal. Renewable energy now accounts for around 33% of India's primary energy consumption. India is gradually embracing ethical renewable energy techniques, cutting emissions, cleansing the air, and assuring a more stable environment (Kumar et al. 2010).

India has a demographic of 1.4 billion people and is one of the world's greatest industrialized nations, which will be important for the future of the global energy sector. In recent years, the Indian government has made significant headway in boosting individuals' access to power and efficient cooking methods. It also has effectively executed a variety of energy market reforms and deployed a massive amount of renewable power, particularly solar energy (Kumar et al.

`

2010). In the coming years, the government of India has outlined an ambitious plan to provide citizens with reliable, economical, and energy independence. This comprehensive analysis focuses on assisting the government in attaining its energy policy objectives by outlining a variety of suggestions in each sector, with a potential for energy system reform, global security, and energy pricing. The analysis also emphasizes a number of key insights from India's explosive growth of its energy sector, which could help guide the strategies of other countries all over the world.

However, providing Indian people with access to power and clean cooking fuel has been prominent in the country's government discourse. Between 2000 and 2018, about 700 million individuals in India acquired access to electricity, demonstrating robust and successful policy implementation. The IEA applauds the Government of India for this great achievement and supports its efforts to shift the focus to reaching out to remote areas and guaranteeing shaped electricity distribution stability. The Indian government has also made tremendous headway in lowering the use of biomass fuels in cooking, which is the leading source of indoor air pollution, particularly among women and children. Clean cooking with liquefied natural gas has been promoted and implemented for a long time (IEA, 2020).

`

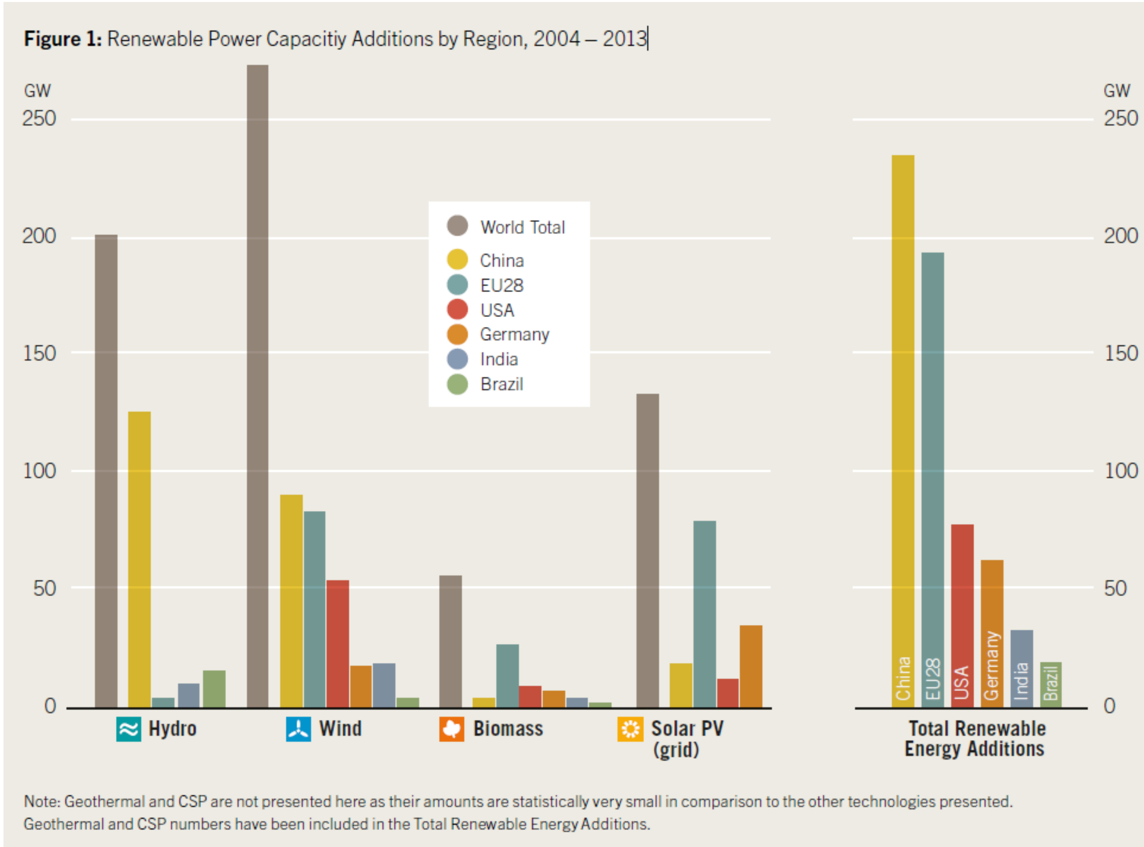

Figure 2.0: Renewable Power Capacity Addition by Region, 2004-2006
Source: REN21_10yr report.

(https://www.ren21.net/Portals/0/documents/activities/Topical%20Reports/REN21_10yr.pdf)

Amidst such positive indicators, the solar PV sector's development to date conveys only a very tiny fraction of the incredibly huge market opportunity; a few countries from high solar radiation regions, such as Africa, the Middle East, Southeast Asia, and Latin America, are on the verge of ramping up their solar implementation. Solar PV is growing into new markets, from Africa and the MENA region to Asia and Latin America, owing to lowering prices. Awareness of

`

this kind of system has been steadily expanded over the last decade, in terms of the quantity and scale of major solar PV installations. Cell and panel producers, on the other hand, struggled as strong competition and drops in pricing and revenue margins spurred industry consolidation, resulting in the closure of several Chinese, European, and American manufacturers.

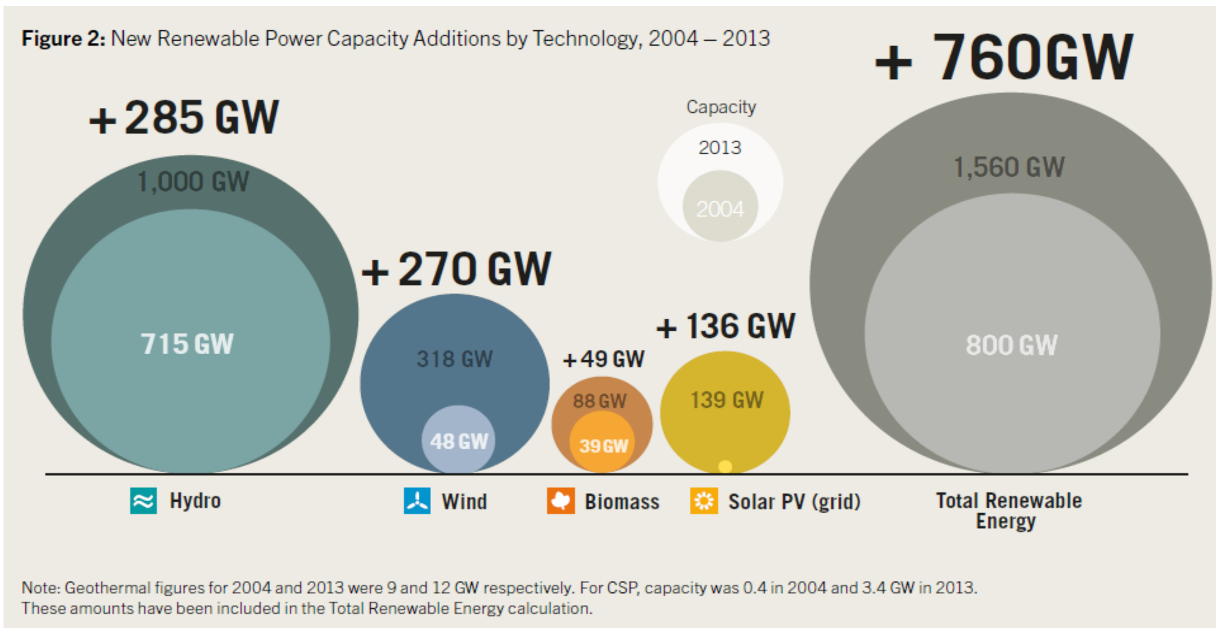

Figure 2.1: Geothermal figures for 2004 and 2003Source: REN21_10yr report. (https://www.ren21.net/Portals/0/documents/activities/Topical%20Reports/REN21_10yr.pdf)

Energy constraints can be addressed by boosting supplies in order to continue economic development and enhance living standards. However, there

`

are two more crucial factors to consider: environmental sustainability and social development. The present economic growth pattern has wreaked havoc on the environment, causing air pollution, generating massive amounts of trash, damaging biological systems, and hastening environmental degradation, with the energy sector bearing a disproportionate portion of this responsibility. At the same time, the effect on inclusive growth must be considered. Many societal issues, such as poverty, illness, unemployment, and unfairness, are exacerbated by a restriction of access to energy services.

IEA (2020) states that India has the administrative system in place to seek further funding to meet its expanding energy requirements. The IEA applauds the government's move to allow private-sector involvement in coal mining as well as to liberalize the country's oil and gas retail markets. The establishment of functional energy markets will assure economic efficiency in the administration of the coal, gas, and power generation sector, which is vital to ensuring energy supplies and bolstering the growth of the economy. This will become further necessary in the future as energy consumption and investment requirements rise in tandem with overall economic growth.

Change in India's power area should be exhaustive to accomplish these objectives. The IEA welcomes the Central Energy Regulatory Commission's (CERC) planned adjustments and the progress made towards working on continuous business sectors. More than anything else, the public infrastructure has to be supported by a robust discount market with a global reach. Building

`

consensus across a wide range of central government institutions, state experts, framework administrators, and utilities on a common vision and transformation roadmap will be crucial to achieving this goal. India must also deal with the difficulty of ensuring the financial health of its power sector, which includes the management of surplus capacity, the reduction in the use of coal and gaseous fuel plants, and the increase in the share of variable, sustainable electricity. The government is making an effort to improve the economic viability of the electricity sector. In the face of the challenge posed by "pushed resources" in the coal and gas-terminated era, it has been implementing a suite of measures to enhance the cost-effectiveness of coal and gas supply for the power age and the availability of funds. Developing the potential of India's age restriction would need the establishment of a robust discount electricity market (IEA, 2020).

<u>Advantages of Solar Power Sector in India</u>

1. <u>Easily Available:</u>

The availability of solar light is the essence of any form of solar power plant. India's topographical reach is between 8°4′ and 37°6′ north latitude and 68°7′ to 97°25' east longitude, and it is the world's seventh biggest country, with a landmass of 2.9 million Km2 and so an extremely rich sun exposure. Data analysis revealed that several locations in India have sun radiation levels in excess of 5 kWh/m2/day, qualifying them as prime locations for solar energy production. India may have 1.89 million km2 of solar hotspots, including the

`

country's Western Ghats, Eastern Ghats, Gangetic plains, Thar deserts, and Gujarat plains (Rathore et al. 2018).

2. Availability of wasteland:

Capital costs and environmental effects need to be taken into account. The volume of sun's energy needed to power a specific amount of farmed land is measured in terms of the land's area. An essential factor if you will. Solar power on a usable scale Energy from power plants uses more land and has a higher energy intensity than power from fossil fuels. It is possible to construct a large-scale solar power plant in India since the country has enough of unused land suitable for the purpose. Scale creation based on use due to the fact that wastelands are unfit for human habitation and agriculture of any type, solar power plants built there do not contribute to environmental stress on food production systems (Rathore et al. 2018).

3. Lesser dependency on external cost:

A further benefit for solar power development companies in establishing a huge solar power plant in India is that the impact of external costs (setup time, fuel delivery risk, water usage, environmental damage, and currency exchange rate) in solar energy systems is minimal when compared to traditional power sources. How many various energy producing methods often set you back, as well as how much some hidden costs can add up to. Solar power delivers more benefits than other forms of energy generation, despite the fact that most forms of power generation have significant external costs to the community and economy (Rathore et al. 2018).

India's fast-growing economy requires energy. The Indian government has improved power and cooking availability. 700 million Indians got power between 2000 and 2018. Solar PV is expanding throughout Africa, MENA, Asia, and Latin America. However, fierce competition and declining price and revenue margins have hurt cell and panel makers. IEA (2020) argues that India has the administrative structure to request more money for its growing energy demands. IEA applauds CERC's planned changes. India also faces the challenge of electricity sector financial health. Solar power plants require sunlight. Developing India's age limitation will require a strong discount power market (IEA, 2020). India has enough vacant land for a huge solar power facility. Solar power plants there do not burden food production systems. Solar energy systems have low external expenses, such as setup time, fuel delivery risk, water use, environmental harm, and currency exchange rate. Moreover, these elements will have a significant impact on shaping the future of the Indian solar business and will undoubtedly entice the global solar sector to engage in the Indian subcontinent.

`

CHAPTER THREE

RESEARCH METHODOLOGY

For this study, I have gone through various research papers, articles, and case studies on Google Scholars, ScienceDirect and OneSeach Databases. Secondary data, existing literature on solar power generation in India, and the most recent solar energy journals were used to gather the data and context for this study. Dataset for this study has been collected through IPUMS, Data.gov, and Kaggle. Two solar power plants in India are included in this dataset, which is used for study from 2020 to 2021. In essence, there are four files: two files pertain to power generation, while the remaining two contain weather sensor data for the appropriate power plants.

Table 1. List of Keywords and Articles used for the Study

Search Engine/ Source	**Keywords**	**# Of Hits**	**# Of relevant Articles used**	**Authors (Year)**
OneSearch CSUSB	Solar Power in India	31,381	There were numerous articles, but 2 articles were relevant.	Hairat & Ghosh, (2017) Sharma, (2011)
ScienceDirect	Solar Irradiation	137,945	There were numerous articles, but 1 article was relevant.	Rajesh Karki, (2017)

`

OneSearch CSUSB	Solar power prediction in India	387	There were comparatively fewer articles but found 4 articles relevant	Mohanty et al., 2017 Suresh Kumar et al., (2022) Prema & Rao, (2015) Rawat & Padmanabh, (1970)
Google Scholar	Solar energy in Developing Countries	1,610,000	There were numerous articles, but 2 articles were relevant.	Shahsavari & Akbari, (2018) Lura, (2013)
Google Scholar	Challenges and opportunities Solar sector in India	279,000	There were numerous articles, and 4 articles were relevant.	Rathore et al., (2017) Thakur et al., (2022) Srilakshmi et al., (2015) Yenneti, (2016)
ScienceDirect	Solar power in Europe	88,241	There were numerous articles, and 2 articles were relevant.	Bett et al., (2022) Burghard et al., (2022)

`

ScienceDirect	Solar power prediction challenges globally	20,742	There were many articles, and 3 articles were relevant.	Goliatt & Yaseen, (2022) Ghimire et al., (2022) Loeper et al., (2020)
Google Scholar	Issues that India facing to expand solar power	70,000	There was good deal of articles, and 3 articles were relevant.	Ansari et al., (2013) Shukla et al., (2017)
Google Scholar	Factors affecting Solar output	836,000	There were numerous articles, and 2 articles were relevant.	Vidyanandan, (2017) Sharshir et al., (2016)
ScienceDirect	Advantages of Solar Power Sector in India	13,115	There were comparatively few articles, but 2 articles were relevant.	World Bank Group, (2021) Thapar & Sharma, (2020)
OneSearch	Factors in Forecasting Power Generation	29,725	There were numerous articles, but 3 articles were relevant.	Bett et al., (2022) Bui et al., (2022) Nikodinoska et al., (2021)

The heart of every solar power plant is the accessibility of solar light. India is the sixth largest country in the world and has a landmass of 2.9 million Km2, giving it unusually rich solar exposure due to its geographical location between 8°4′ and 37°6′ north latitude and 68°7′ and 97°25' east longitude. As can be seen from the data, several locations in India receive more than 5 kWh/m2/day of solar radiation, making them perfect target for solar power generation (Rathore et al.

2018). According to Kannal (2020) when they tried to compare and build forecast model for solar power generation then we can also rule out the possibility that their blackouts are caused by greater temperatures, thus they may merely need to be changed or repaired. PROPHET is significantly easier to use and certainly much faster than SARIMAX.

Module and ambient temperatures were crucial to our analysis, although this information is scarce in other datasets. The primary question we're hoping to answer with this research is, "How can we predict electricity generation over the next several days so that the plant can run at peak efficiency and how can we figure out the exact maintenance needs of any power plant?”. Daily Irradiation, AC to DC power conversion numbers is needed to provide satisfactory responses to these questions. The provided data sets allow us to get precise answers to these questions. Additionally, we were able to do a correlation study, which helped us identify inefficient and malfunctioning equipment in the solar power plant. We were able to learn more about the interplay between irradiation, alternating current (AC) power, ambient temperature, and module temperature thanks to the numbers included in this dataset.

Aspects Influencing the Solar Output

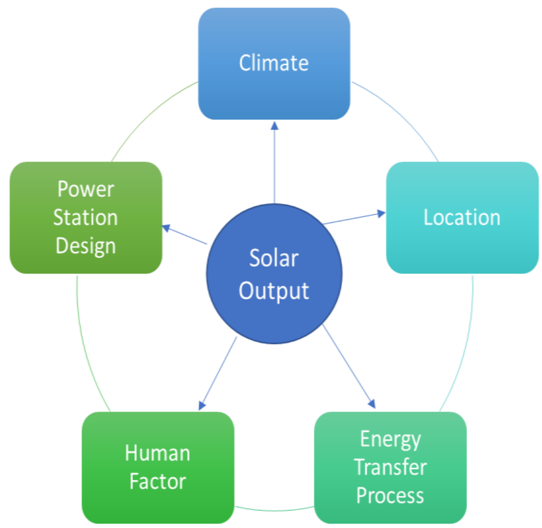

Figure 3.0: Aspects Influencing the Solar output

Climate: According to Sami (2019) "Solar panel output is significantly impacted when exposed to weather conditions that are very severe. Solar cells achieve their maximum efficiency at certain temperatures. It is a common misunderstanding that solar panels operate more effectively when exposed to higher temperatures. On the contrary, doing so might cause damage to your system and possibly degrade its overall performance."

Location: Sunlight is strongest at midday, weakest at dawn and dusk, and in between at other times. Despite the cloud cover, a solar panel's output is highest around midday because the sun's beams are more direct. Seasons impact the sun's position. Summer solar panels

`

generate more power than winter ones since the sun shines directly over them.

Energy Transfer Process: We shouldn't take the sun for granted, as almost all of Earth's energy originates from the massive star at the system's center. Furthermore, we should acknowledge our atmosphere for its role in preventing part of the sun's rays from reaching Earth and for retaining some of the light that does make it here. Excessive exposure to solar radiation is dangerous, but the atmosphere shields humans from the sun's rays through a mechanism called energy transfer (ScienceDaily, 2016). Solar energy must first undergo conduction, convection, and radiation before it can be converted into a usable form of energy. There was a lot of energy lost throughout that procedure, which reduced the overall solar output.

Human Factor: It wasn't until the late 1980s and early 1990s that scientists at ETH Zurich uncovered the first signs that the quantity of sunlight reaching Earth's surface had been progressively diminishing since the 1950s (ETH Zurich, 2021). Initially, it was called "global dimming," which is a very accurate name. In the late 1980s, however, a reversal of this tendency became noticeable. As a result, solar energy reaching the Earth's surface increased, and the sky brightened in numerous places. If or whether these shifts are the consequence of natural changes in the climate system, or whether they are driven by air pollution in the form of aerosols obstructing the sun, is a contentious topic of debate.

Power Station Design: The sun's rays are the most direct and powerful when they are directly overhead. As the sun sinks lower in the sky, the same amount of sunlight illuminates a bigger percentage of the planet. A solar panel collecting light from an ever-increasing area will generate less power as a result. Although the complexity and maintenance of mechanical tracking devices add substantial expense to a solar energy installation, tilting a solar panel to match the sun's angle can somewhat compensate for the diminished intensity. (Papiewski, 2017).

Steps involved in Research Methodology

1. Collect the data of two Solar power plants in India.
2. For the analysis purpose, I will use PyCharm Community Edition. 2021.2.3
3. To read the datasets files, install all the required packages.
4. Given the dataset file’s DateTime Column is not supported by PyCharm, we need to convert that into datetime.
5. Cleanse the dataset and scrape the dataset in order to perform make sense out of the data.

CHAPTER FOUR

DATA ANALYSIS AND FINDINGS

Irradiation

What does Irradiation mean?

For a certain wavelength range, solar irradiance is the amount of energy received from the Sun per unit area (surface power density). The SI unit for solar irradiation is the watts per square meter (W/m2). In order to estimate PV generation for power system sufficiency evaluation, hourly temporal resolution solar irradiation data is typically necessary. Because of the enormous number of variables associated with Earth's atmospheric conditions, accurate modeling of solar radiation at the surface is challenging. Extraterrestrial radiation has an average value of 1367 (W/m2) when stated as the solar constant, meaning it comes from sources outside of Earth's atmosphere (Duffie and Beckman, 1980).

Over time, we have improved our ability to monitor and anticipate climatic phenomena, amassing a wealth of knowledge and data that has aided in our ability to comprehend and predict these events. Most significantly, climatic shifts have far-reaching effects on human societies and their surrounding landscapes. Locational factors such as latitude, elevation, and proximity to bodies of water all have a role. Climate change, pollution, agricultural yield, the food business, and hydrology may all be better understood with a better understanding of solar radiation as one of the key elements. Accurate information on global solar radiation availability at the site of interest is necessary even for the design of a

`

solar energy conversion system. Consequently, the total solar radiation potential will be extremely important in the design and foresight of solar energy systems. (Shrestha et al., 2019).

The ability to accurately anticipate weather calamities like drought, flood, frost, etc. relies heavily on-air temperature, making it an important aspect in many fields like meteorology, agriculture, the military, and others. There have been several attempts to keep tabs on the weather, including the installation of automated weather stations (AWS). Furthermore, dedicated Air Temperature sensors are prohibitively expensive, limiting their potential for widespread use (Sun et al., 2015). To cut down on the expense of AT monitoring, a novel technology called the meteorological wireless sensor network based on a sensing node has been presented. However, external variables might readily affect the sensing node's temperature sensor.

`

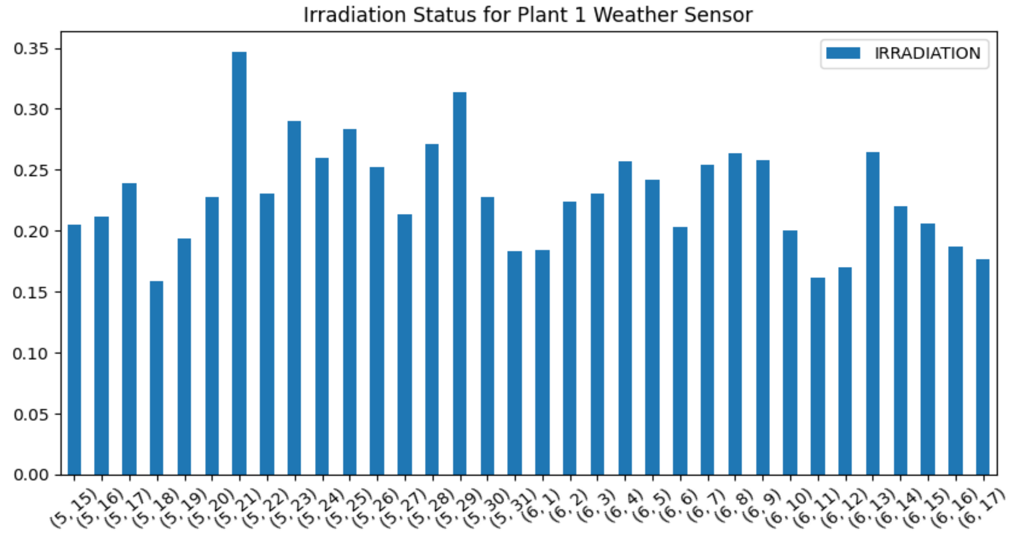

Figure 4.1: Irradiation Status for Plant 1 Weather Sensor

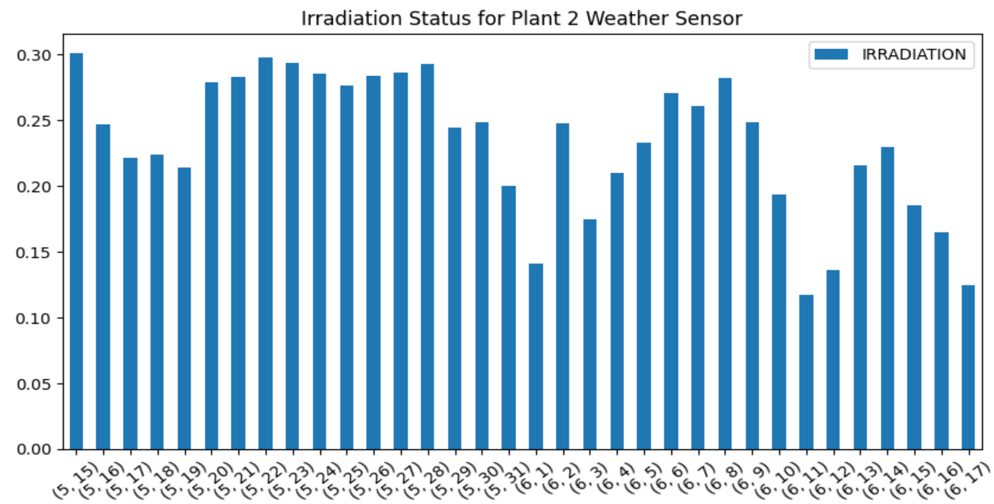

Figure 4.2: Irradiation Status for Plant 2 Weather Sensor

Figure 4.1 and Figure 4.2 show the irradiation status of Plant 1 and Plant 2 respectively. As per both graphical representations, we can state that Plant 1 had

`

maximum irradiation of 0.34 W/m² and plant 2 had minimum irradiation of 0.12 W/m². Though both plants' daily irradiation doesn't show much difference surely we can say that Plant 1 had the most consistent irradiation throughout a month. We can suggest improving Plant 2's irradiation based on this Irradiation status for both of the plants.

AC-DC Power

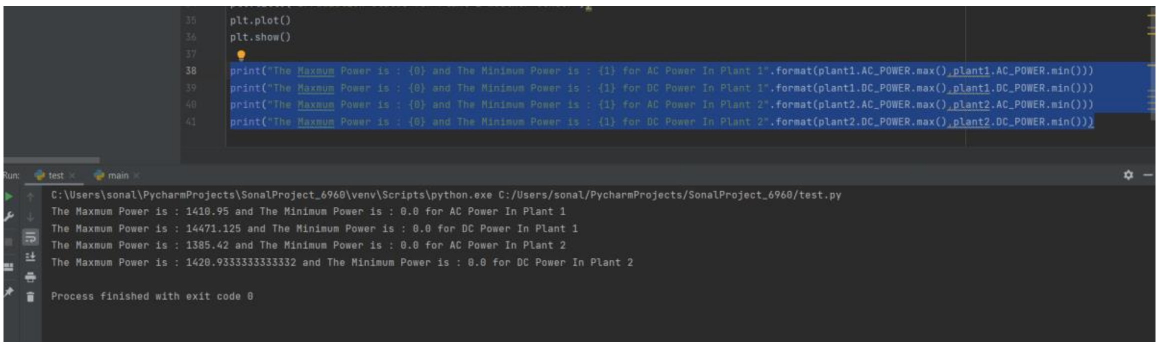

Figure 4.3: Maximum and Minimum AC-DC Power for Plant 1 and Plant 2

Figure 4.3 gives us information about the maximum and minimum AC-DC power of Plant 1 and Plant 2. As per the given output,

The Maximum Power is 1410.95 and The Minimum Power is 0.0 for AC Power In Plant 1.

The Maximum Power is 14471.12 and The Minimum Power is 0.0 for DC Power In Plant 1.

The Maximum Power is 1385.42 and The Minimum Power is 0.0 for AC Power In Plant 2.

`

The Maximum Power is 1420.93 and The Minimum Power is 0.0 for DC Power In Plant 2.

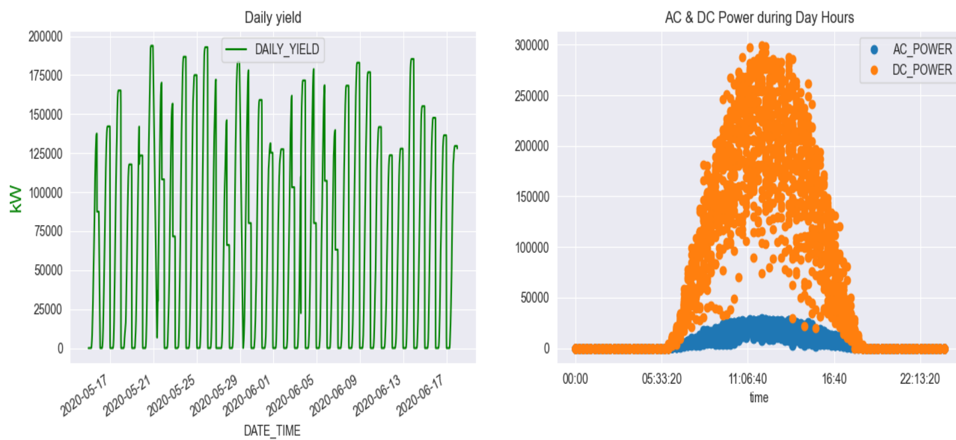

Figure 4.4: Daily Yield and AC -DC Power during Day hours

Figure 4.4 gives us information about daily yield according to the forest of the figure highest daily yield was 195000 kW and the minimum was 120000 kW. The second part of figure 4.4 gives us information about AC and DC Power during day hours. If we observe the AC and DC power hrs closely then we can state that most of the DC power we receive is from 6:33:20 am to 16:40 pm. The maximum DC power we received is 30000 kW at 11:06:40 am. In Comparison with DC power, AC power is a lot lesser than DC power but again since it's a Solar power plant therefore most of the power generation happens during daytime.

`

Since many of today's modern electrical & electronics gadgets favor direct current (DC) electricity due to its seamless functioning and maybe even voltage, we couldn't live without it. Both sorts of power are necessary; neither is "better" than another. In truth, alternating current (AC) leads the electrical market; all power outlets work perfectly with facilities in the form of alternating current (AC), even if the current must be promptly transformed to direct current (DC). This seems to be due to the fact that DC cannot transmit the same larger distances as AC from power plants to buildings. Because of the way generators turn, it is also much easier to generate AC than DC.

Identification of Deficient and Faulty Equipment

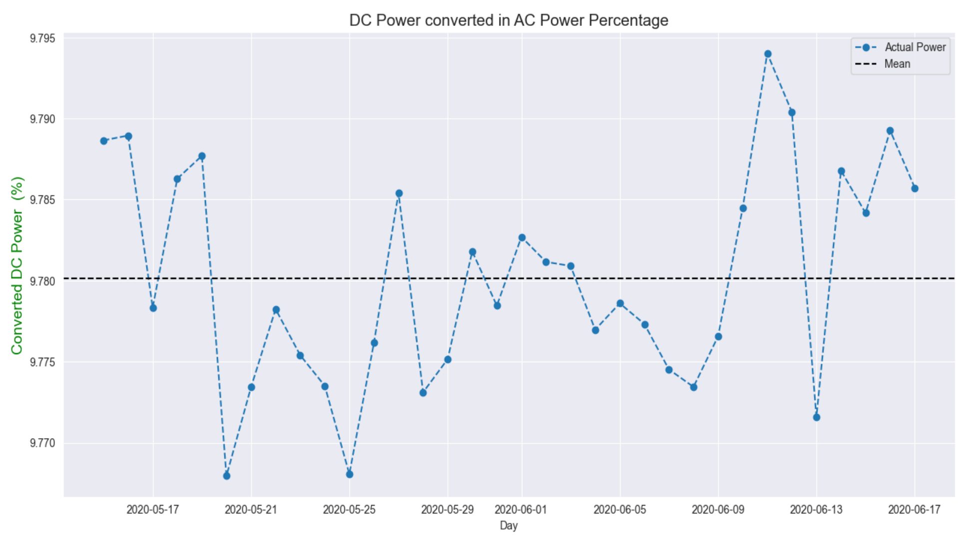

Figure 4.5: Percentage of DC Power converted into AC Power

`

To find deficient or faulty equipment, we need to find actual DC power. Therefore figure 4.5 shows the Percentage of DC Power converted into AC Power. Figure 4.4 indicates the Actual DC power and Mean DC power. The mean power is 9.780 % and the actual power varies from 9.765- to 9.794 %.

Moreover, it still does not give us exact information in order to dig more about decent equipment. We cannot see what is wrong with our power plant, so let us go deeper to examine how different inverters perform during the day. This led us to the next graphical representation which gives information about DC power throughout the day from all the sources.

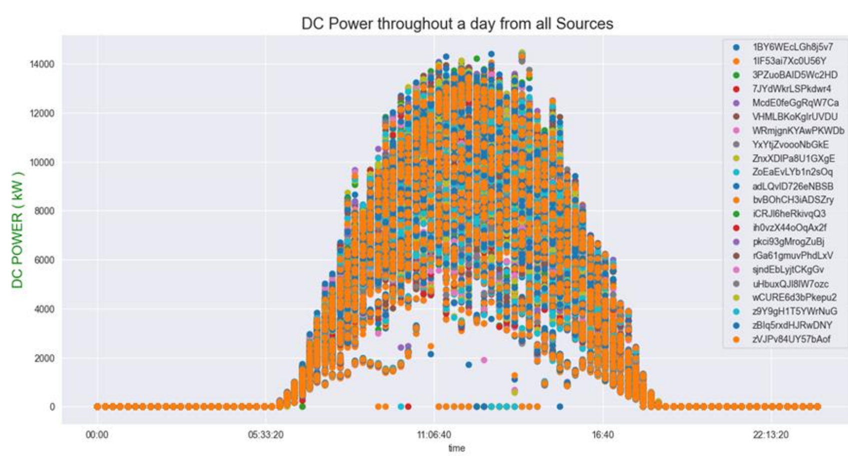

Figure 4.6: DC Power throughout a day from all the Sources

At first glance, this graphical representation looks like a canvas and confuses us more. But there are so many different kinds of sources in both of the plants. In one plant there are approximately 68,778 sources. That is why I

`

narrowed down this question again in the next part. I tried to find out the first and last sources of the plant to see which one was inefficient. If we succeed in finding out the inefficient source, then we can find out the overall efficiency of the plant as well as what other factors are causing the underperforming equipment.

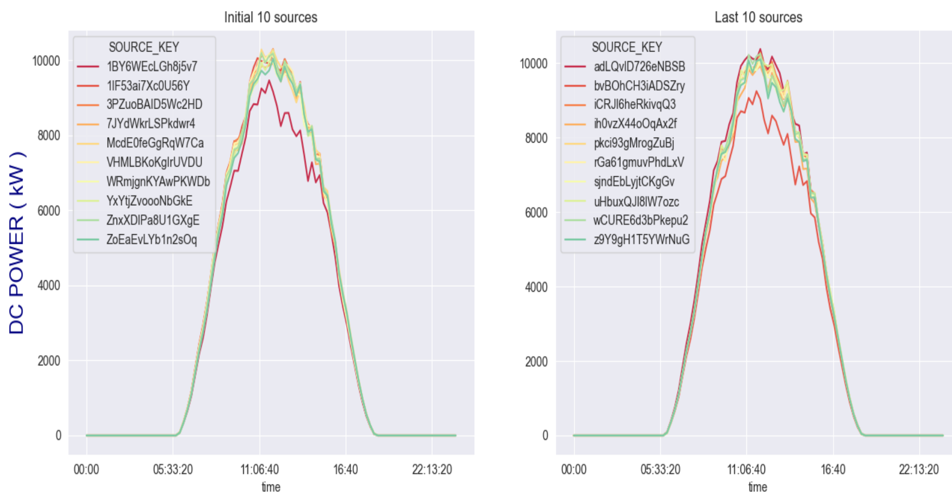

Figure 4.7: DC Power for First 10 and Last 10 Sources

Figure 4.7 indicates the first and the last sources of the plant and we can state that 1BY6WEcLGh8j5v7 & bvBOhCH3iADSZry are lacking when matched to other inverters; perhaps these inverters require repair or replacement. But, as we go into the specifics of inefficient inverters, let us take a look at the overall plant's common issues, so let us look at DC power generation throughout all 34 days.

`

When we look at the daily yield and DC power for both of the plants then we can surely see that there are so many problems with this power plant. In the next part analysis, we are trying to find out how other factors such as Module temperature, Ambient temperature, Irradiation and how that affect power generation.

Other Factors in Forecasting Power Generation

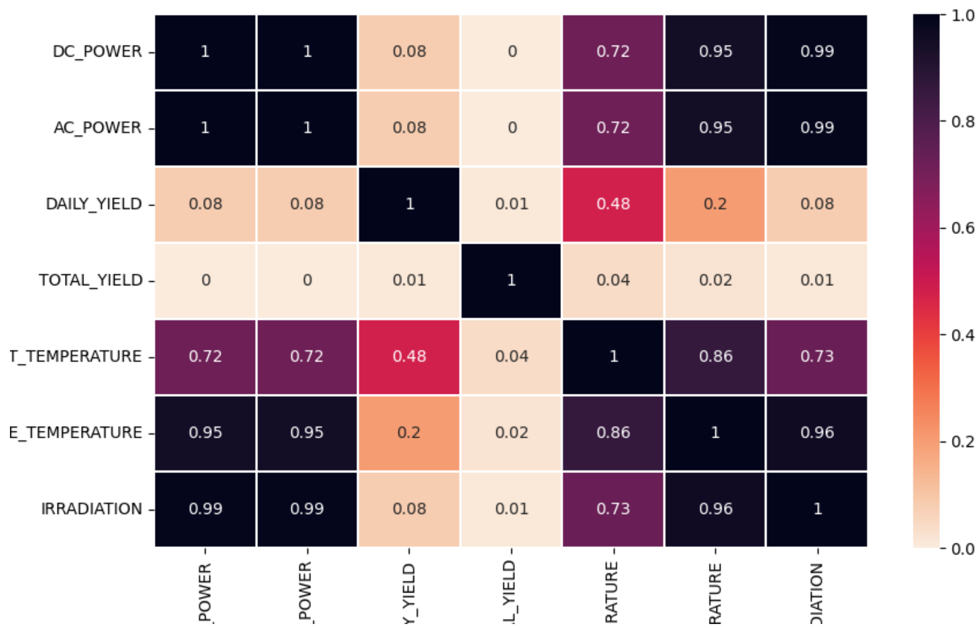

Figure 4.8: Correlation Analysis

Correlation analysis is a statistical tool used in the study in order to determine the strength of a linear correlation between two variables and quantify

`

their correlation. A high correlation indicates a strong association between the two variables, whereas a low correlation indicates a weak relationship.

Figure 4.8 shows the correlation between all the variables. For starters, you can see that the correlation coefficient between AC and DC power is 1 which means we can easily figure out the AC power based on DC power. The correlation between DC power and module temperature is pretty high as well which is 0.95, and 0.99 respectively. The correlation between DC power and total yield is zero.

`

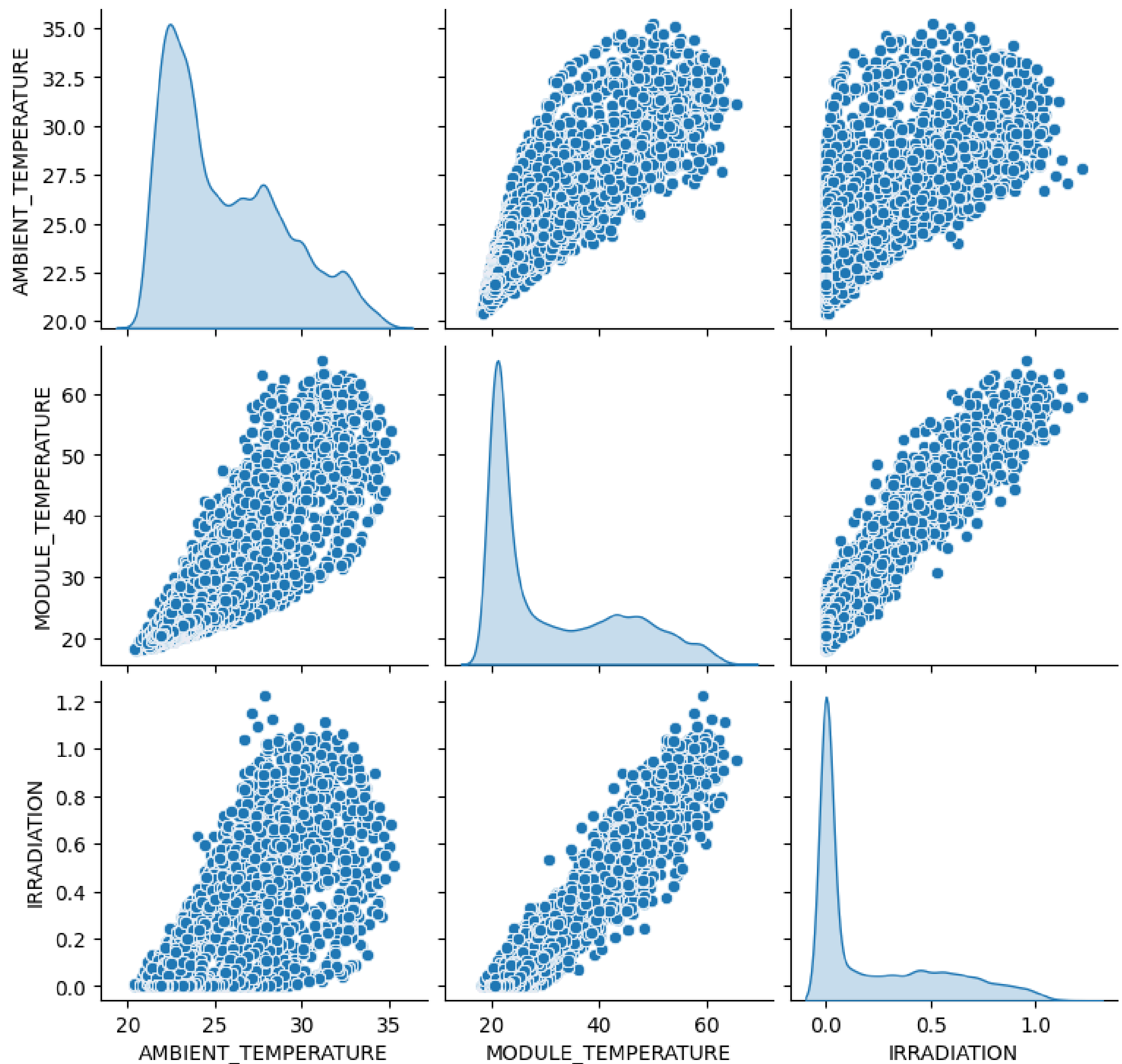

Figure 4.9: Correlation Analysis between Ambient Temperature, Module Temperature, and Irradiation

Figure 4.9 shows another form of correlation analysis between Ambient Temperature, Module Temperature, and Irradiation. Irradiation varies from 0 to 1.0, Module temperature varies from 17 to 65, and Ambient temperature varies from 20 to 35.

`

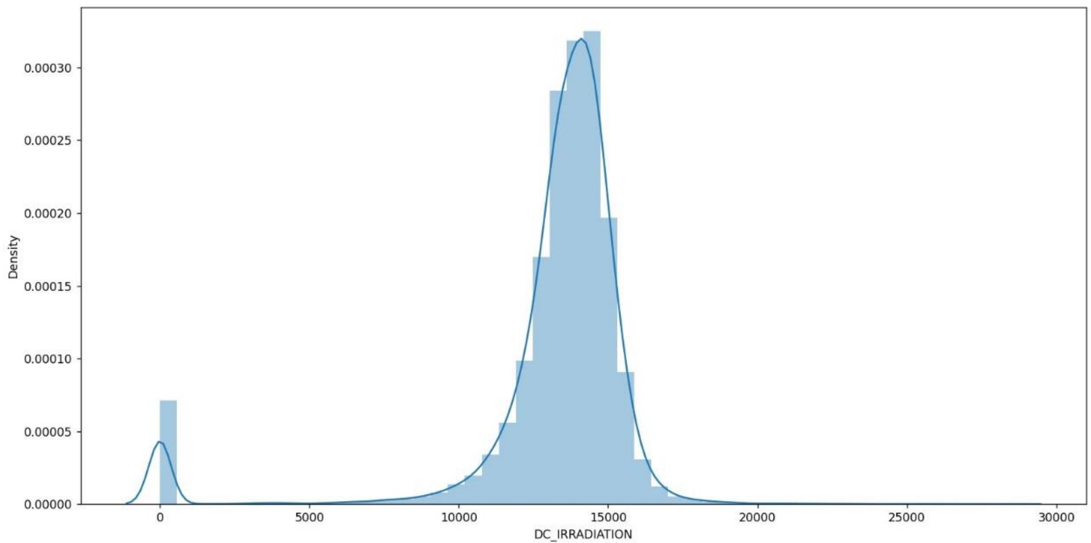

Figure 4.10: Evaluation of the efficiency of Inverter

Figure 4.10 shows us the relationship between DC_IRRADIATION and DC Power in order to find out the most efficient inverter in the plant. As per this graphical representation, we can see that DC_IRRADIATION and DC Power values vary from 5000 to 20000.

`

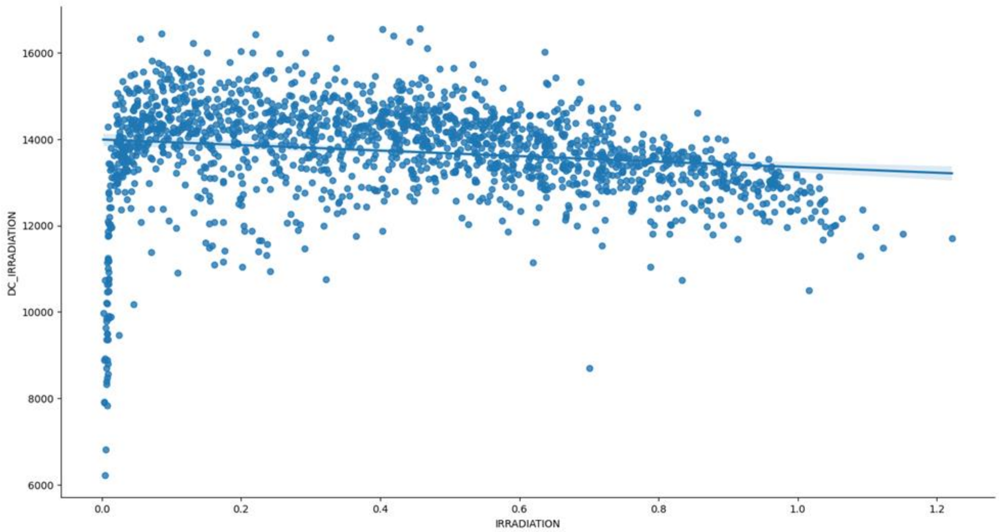

Figure 4.11: Module temperature & DC_Power /Irradiation

Figure 4.11 shows the relationship between DC_Power /Irradiation and module temperature. As per this graphical representation as DC_Power /Irradiation decreases there is a significant amount of increase in the model temperature. That excessive increase in heat leads to a decrease in the efficiency of that respective equipment.

In order to improve the overall performance of the plant, we have to find out all the factors that are causing the inefficient performance of the plant. From this analysis, we can surely say that we have to implement immediate remedies to maintain the temperature of each and every piece of equipment in the plant.

`

CHAPTER FIVE

DISCUSSION, CONCLUSION AND AREAS FOR FURTHER STUDY

Discussion and Findings

Through the course of this study, we have combed through a great deal of scholarly and professional research papers, looking for answers that would be of most immediate use to the functioning of Solar power plants in India which will improve its overall operational efficiency. It has been shown that India's geographical position and market are wholly beneficial to the development and expansion of large-scale solar power developers/investors, both domestically and internationally. With help of this project, we were able to find the main questions of this study are: Q1: How can we predict electricity generation over the next several days so that the plant can run at peak efficiency? Q2: How can we figure out the exact maintenance needs of any power plant? Q3: How do we identify faulty equipment to improve its efficiency to improve overall performance? and Q4: What are the different factors that are causing an inefficient operation of Solar power plant?

This project has shown that by comparing the irradiation of both of the plants, both plants' daily irradiation doesn't show much difference surely, we can say that Plant 1 had the most consistent irradiation throughout a month. Although estimates of monthly average data may usually be acquired, enough hourly sun irradiation data is typically not available for acceptable solar models. Maintaining

`

the link between monthly fluctuations, Graham et al. (1988) provides a time series model to derive daily irradiation estimates. Since the clearness index is independent of latitude and longitude, it is used in place of the irradiation variable. With the help of this analysis, we observed that after calculating AC and DC Power during day hours AC power is a lot lesser than DC power. Karki (2017) states a variety of modern electronic gadgets run on direct current (DC), but they are all made to be plugged into a power outlet that supplies alternating current (AC). Therefore, an inverter is required to transform the DC solar power into the usable AC form. Based on these findings, we were able to anticipate power generation over the following several days for optimal functioning of both solar power plants by identifying their maintenance needs.

Calculating the percentage of DC Power transferred to AC Power is necessary for identifying Deficient and Faulty Equipment; nevertheless, this was not sufficient in revealing the precise answer we were seeking. Figure 4.7 indicates that the 1BY6WEcLGh8j5v7 & bvBOhCH3iADSZry inverters are deficient when compared to others. Solar power plants are susceptible to several issues that might diminish their electricity generation due to their extended lifespans. Even two similar solar power plants in different locations may have varying efficiencies. Weather, seasons, roof orientation, and more determine how much light enters a home. According to Janikas (2019) study, if even a percentage of a solar panel is obscured—by leaves, dirt, or a tree or bush's shadow—the power plant's efficiency is substantially reduced. As the DC_Power

`

/Irradiation decreases there is a significant amount of increase in the model temperature. That excessive increase in heat leads to a decrease in the efficiency of that respective equipment. This process happens within solar panels at an optimum temperature of 25 degrees Celsius, which is why most solar panels are tested at that temperature (Carbonaro, 2022). However, as the panels' internal temperature rises over this threshold, their efficiency begins to decrease regardless of how strong the sunlight is. When the temperature rises, an excessive number of electrons are released from the solar panel, lowering the voltage produced and the panel's overall efficiency. Based on these findings, we identified defective equipment to increase its efficiency and how various factors are influencing solar power plant inefficiency.

Conclusion

To improve plant performance, we must identify additional elements. This research confirms that we must immediately take measures to preserve the plant's equipment temperatures. Traditional power generation's predictability and stability are vital to the system's supply–demand balance and stability. However, solar resource availability is unpredictable, therefore a solar power system's output power varies with time. Limiting control hurts the economy and goes against green electricity. Accurate estimation of solar power system generation might decrease the grid's unpredictability, maintain power quality, and increase the power grid's accommodation capacity with PV integration, making it tough yet

`

important for the research community today and in the future (Hayat et al. 2019). In response to climate change and other environmental problems, India has taken its first steps toward a sustainable future.

Areas for further Study

After gathering data and conducting more research, we can have a better idea of how accurate the results of this study are. The long-term goal is to construct a prediction model that can withstand all climatic and environmental changes by comparing India to other emerging countries with comparable settings of limitations and benefits. More study on solar power prediction may be done, concentrating on specific areas that will aid in the efficient and trouble-free running of Solar Power Plants.

REFERENCES

Ayop, Isa, N. M., and Tan, C. W. (2018). Components sizing of photovoltaic stand-alone system based on loss of power supply probability. Renewable & Sustainable Energy Reviews, 81, 2731–2743. https://doi.org/10.1016/j.rser.2017.06.079

Bett, P. E., Thornton, H. E., Troccoli, A., Felice, M. D., Suckling, E., Dubus, L., Saint-Drenan, Y.-M and Brayshaw D. J. (2022, August 8). A simplified seasonal forecasting strategy, applied to wind and solar power in Europe. Climate Services. Retrieved October 20, 2022, from https://www.sciencedirect.com/science/article/pii/S240588072200036X

Bui, L. D., Nguyen, N. Q., Doan, B. V and Sanseverino, E. R. (2022, August 29). Forecasting energy output of a solar power plant in curtailment condition based on LSTM using p/GHI coefficient and validation in training process, a case study in Vietnam. Electric Power Systems Research. Retrieved October 20, 2022, from https://www.sciencedirect.com/science/article/pii/S0378779622007684

Burghard, U., Dütschke, E., Caldes, N and Oltra, C. (2022, February 25). Cross-border concentrated solar power projects - opportunity or dead end? A study into actor views in Europe. Energy Policy.

`

Retrieved October 20, 2022, from https://www.sciencedirect.com/science/article/pii/S0301421522000581

Carbonaro, G. (2022, July 18). Why record-breaking heatwaves aren't good news for solar power. euronews. Retrieved October 22, 2022, from https://www.euronews.com/next/2022/07/18/solar-panels-feel-the-heat-too-how-higher-temperatures-are-undermining-solar-power#:~:text=The%20heat%20causes%20an%20excessive,generated%20voltage%20and%20its%20efficiency.

Challenges and solutions for ensuring the long-term health of solar power plants. PV Tech. (2021, February 5). Retrieved April 8, 2022, from https://www.pv-tech.org/challenges-and-solutions-for-ensuring-the-long-term-health-of-solar-power-plants/

Chand Malav, Yadav, K. K., Gupta, N., Kumar, S., Sharma, G. K., Krishnan, S., Rezania, S., Kamyab, H., Pham, Q. B., Yadav, S., Bhattacharyya, S., Yadav, V. K., and Bach, Q.-V. (2020). A review on municipal solid waste as a renewable source for waste-to-energy project in India: Current practices, challenges, and future opportunities. Journal of Cleaner Production, 277, 123227–. https://doi.org/10.1016/j.jclepro.2020.123227

`

ETH Zurich. (2021, February 18). Human impact on solar radiation levels for decades. ScienceDaily. Retrieved October 15, 2022, from www.sciencedaily.com/releases/2021/02/210218140126.html

Ghimire, S., Deo, R. C., Casillas-Pérez, D and Salcedo-Sanz, S. (2022, April 19). Boosting solar radiation predictions with global climate models, observational predictors and hybrid deep-machine learning algorithms. Applied Energy. Retrieved October 20, 2022, from https://www.sciencedirect.com/science/article/pii/S0306261922004585

Goliatt, L and Yaseen Z. M. (2022, August 13). Development of a hybrid computational intelligent model for daily global solar radiation prediction. Expert Systems with Applications. Retrieved October 20, 2022, from https://www.sciencedirect.com/science/article/pii/S0957417422014300

Griffin, S. (2021, February 22). Why solar is the way of the future? Build Magazine. Retrieved April 8, 2022, from https://www.build-review.com/why-solar-is-the-way-of-the-future/

Hanawalt, S. (2021, May 4). The challenge of scale. Power Factors. Retrieved April 8, 2022, from https://pfdrive.com/blog/the-challenge-of-scale-article-2-the-top-4-challenges-series/

Hayat, Ali, D., Monyake, K. C., Alagha, L. and Ahmed, N. (2019). Solar energy—A look into power generation, challenges, and a solar-powered future. International Journal of Energy Research, 43(3), 1049–1067. https://doi.org/10.1002/er.4252

Hemani Paliwal, and Vikramaditya Dave. (2021). Green energy sources in India: Current status and future potentials. Annals of Faculty Engineering Hunedoara, 19(4), 45–52.

How India in a short period of time has become the cheapest producer of solar power. The Economic Times. (n.d.). Retrieved April 8, 2022, from https://economictimes.indiatimes.com/small-biz/productline/power-generation/how-india-in-a-short-period-of-time-has-become-the-cheapest-producer-of-solar-power/articleshow/70325301.cms?from=mdr

IEA (2020), India 2020 Energy Policy Review, IEA Energy Policy Reviews, OECD Publishing, Paris, https://doi.org/10.1787/9faa9816-en.

IEA. (2021, December 1). Renewable electricity growth is accelerating faster than ever worldwide, supporting the emergence of the New Global Energy Economy - News. IEA. Retrieved April 8, 2022, from https://www.iea.org/news/renewable-electricity-growth-is-accelerating-faster-than-ever-worldwide-supporting-the-emergence-of-the-new-global-energy-economy

`

Iea. (2022, October 25). India Energy Policy Review 2020 - event. IEA. Retrieved October 18, 2022, from https://www.iea.org/events/india-energy-policy-review-2020

Janickas, R. (2022, October 10). Solar performance and efficiency. Energy.gov. Retrieved October 22, 2022, from https://www.energy.gov/eere/solar/solar-performance-and-efficiency

Kumar, Kumar, K., Kaushik, N., Sharma, S., and Mishra, S. (2010). Renewable energy in India: Current status and future potentials. Renewable & Sustainable Energy Reviews, 14(8), 2434–2442. https://doi.org/10.1016/j.rser.2010.04.003

Kumar. J, and Majid, M. A. (2020). Renewable energy for sustainable development in India: current status, future prospects, challenges, employment, and investment opportunities. Energy, Sustainability and Society, 10(1), 1–36. https://doi.org/10.1186/s13705-019-0232-1

Loeper, F. von, Schaumann, P., Langlard, M. de, Hess, R., Bäsmann, and Rand Schmidt, V. (2020, April 20). Probabilistic prediction of solar power supply to distribution networks, using forecasts of global horizontal irradiation. Solar Energy. Retrieved October 20, 2022, from https://www.sciencedirect.com/science/article/pii/S0038092X20303650

Mittal, Ahmed, W., and Koli, C. S. (2018). Renewable energy in India: Current status and future potentials. Invertis Journal of Renewable Energy, 8(2), 96–. https://doi.org/10.5958/2454-7611.2018.00017.6

Mohanty, Patra, P. K., Sahoo, S. S., and Mohanty, A. (2017). Forecasting of solar energy with application for a growing economy like India: Survey and implication. Renewable & Sustainable Energy Reviews, 78, 539–553. https://doi.org/10.1016/j.rser.2017.04.107

Nikodinoska, D., Käso, and Mand Müsgens, F. (2021, October 18). Solar and wind power generation forecasts using elastic net in time-varying forecast combinations. Applied Energy. Retrieved October 20, 2022, from https://www.sciencedirect.com/science/article/pii/S0306261921012861

Papiewski, J. (2017, November 21). Does the location of the Sun affect the amount of energy solar panels collect? Education. Retrieved October 15, 2022, from https://education.seattlepi.com/location-sun-affect-amount-energy-solar-panels-collect-5021.html

Parikh, A. (2019, November 21). Accurate forecasting of renewable generation a tough task for Solar & Wind Developers. Mercom India. Retrieved October 15, 2022, from

`

https://mercomindia.com/accurate-forecasting-renewable-generation/

Pillai and Banarjee, R. (2009). Renewable energy in India: Status and potential: Energy and its sustainable development for India. Energy (Oxford), 34(8), 970–980.

Prema, V., and Rao, K. U. (2015). Development of statistical time series models for solar power prediction. Renewable Energy, 83, 100–109. https://doi.org/10.1016/j.renene.2015.03.038

Raghuwanshi, and Arya, R. (2019). Renewable energy potential in India and future agenda of research. International Journal of Sustainable Engineering, 12(5), 291–302. https://doi.org/10.1080/19397038.2019.1602174

Rathore, Rathore, S., Pratap Singh, R., and Agnihotri, S. (2018). Solar power utility sector in india: Challenges and opportunities. Renewable & Sustainable Energy Reviews, 81, 2703–2713. https://doi.org/10.1016/j.rser.2017.06.077

Rawat, D. S and Padmanabh, K. (1970, January 1). Prediction of solar power in an IOT-enabled Solar System in an academic campus of India. SpringerLink. Retrieved October 20, 2022, from https://link.springer.com/chapter/10.1007/978-981-16-0730-1_28

Sami. (2022, August 15). 7 factors that impact your solar panel system efficiency. Dynamic SLR. Retrieved October 15, 2022, from https://www.dynamicslr.com/7-factors-that-impact-your-solar-panel-system-efficiency/

ScienceDaily. (2021, February 18). Human impact on solar radiation levels for decades. ScienceDaily. Retrieved October 15, 2022, from https://www.sciencedaily.com/releases/2021/02/210218140126.html

Shahsavari, A and Akbari, M. (2018, April 2). Potential of solar energy in developing countries for reducing energy-related emissions. Renewable and Sustainable Energy Reviews. Retrieved October 20, 2022, from https://www.sciencedirect.com/science/article/pii/S1364032118301527

Shrestha, A. K., Thapa, A and Gautam, H. (2019, December 11). Solar radiation, air temperature, relative humidity, and dew point study: Damak, Jhapa, Nepal. International Journal of Photoenergy. Retrieved October 19, 2022, from https://www.hindawi.com/journals/ijp/2019/8369231/

Solar power - unlimited source of Energy. Fortum. (n.d.). Retrieved April 8, 2022, from https://www.fortum.com/about-us/our-company/our-energy-production/solar-power-unlimited-source-energy

Srilakshmi, G., Venkatesh, V., Thirumalai, N.C and Suresh, N. S. (2015, February 27). Challenges and opportunities for solar tower technology in India. Renewable and Sustainable Energy Reviews. Retrieved October 20, 2022, from https://www.sciencedirect.com/science/article/pii/S1364032115001045

Srivastava and Mallick, S. (2022). Augmenting the potential of ambient energy with special reference to solar energy for bringing a paradigm shift in the Indian Economy. International Journal of Social Ecology and Sustainable Development, 13(1), 1–14. https://doi.org/10.4018/IJSESD.288539

Studies from Department of Mechanical Engineering Reveal New Findings on Renewable Energy (Small hydro power in India: Current status and future perspectives). (2016). In Energy Weekly News (p. 621–). NewsRX LLC.

Sun, X., Yan, S., Wang, B., Xia, L., Liu, Q and Zhang, H. (2015, July 24). Air temperature error correction based on solar radiation in an Economical Meteorological Wireless Sensor Network. Sensors (Basel, Switzerland). Retrieved October 19, 2022, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4570310/

Suresh Kumar, B., Mahilraj, J., Chaurasia, R. K., Dalai, C., Seikh, A. H., Mohammed, S. M. A. K., Subbiah, R., and Diriba, A. (2022). Prediction of photovoltaic power by ANN based on various

`

environmental factors in India. International Journal of Photoenergy, 2022, 1–11. https://doi.org/10.1155/2022/4905980

Thakur, A. K., Singh, R., Gehlot, A., Kaviti, A. K., Aseer, R., Suraparaju, S. K., Natarajan, S. K and Sikarwar, V. S. (2022, April 26). Advancements in solar technologies for sustainable development of agricultural sector in India: A comprehensive review on challenges and opportunities - environmental science and Pollution Research. SpringerLink. Retrieved October 20, 2022, from https://link.springer.com/article/10.1007/s11356-022-20133-0

Thapar, S and Sharma, S. (2020, January 16). Factors impacting wind and solar power sectors in India: A survey-based analysis. Sustainable Production and Consumption. Retrieved October 20, 2022, from https://www.sciencedirect.com/science/article/pii/S235255091930274X

Wei Li, Hui Ren, Ping Chen, Yanyang Wang, and Hailong Qi. (2020). Key Operational Issues on the Integration of Large-Scale Solar Power Generation—A Literature Review. Energies (Basel), 13(5951), 5951–. https://doi.org/10.3390/en13225951

Wettengel, J. (2018, November 26). Volatile but predictable: Forecasting renewable power generation. Clean Energy Wire. Retrieved November 29, 2022, from https://www.cleanenergywire.org/factsheets/volatile-predictable-forecasting-renewable-power-generation

World Bank Group. (2021, August 30). India's Solar Learning Curve inspires action across the world. World Bank. Retrieved October 15, 2022, from https://www.worldbank.org/en/news/feature/2021/07/09/india-s-solar-learning-curve-inspires-action-across-the-world

Yenneti. (2016). The grid-connected solar energy in India: Structures and challenges. Energy Strategy Reviews, 11-12, 41–51. https://doi.org/10.1016/j.esr.2016.06.002

`