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GAPS OF INDIAN ELECTRICAL ENERGY SECTOR AND ITS OPTIMAL MITIGATION BY USING OPTIMAL UTILIZATION OF INDIAN RENEWABLE ENERGY POLICY WITH THE HELP OF THE P&O MPPT TECHNIQUE

G. Suresh[1], Dr.D. Lenine[2]

[1]*Research Scholar, Department of EEE, JNTU Anantapur, Nandyal, India.*
e-mail: gsuresh248@gmail.com, orcid: https://orcid.org/0009-0008-5666-9658
[2]*Professor, Department of EEE, RGM College of Engineering &Technology (Autonomous), Affiliated to JNTU Anantapur, Nandyal, India.*
e-mail: lenine.eee@gmail.com, orcid: https://orcid.org/0000-0001-8816-163

SUMMARY

Developing countries, especially, India, depend importantly on energy sources to perform their country's industrial and economic activities. Mainly the two factors continuous population growth of the country and the rapid growth rate of industrialization of the country, the gap between electrical energy supply and demand for electrical energy is slowly and consistently increasing. To resolve this unevenness, there is a jointly planned attempt is required to enhance the contribution of renewable energy in the all over mix of energy. Despite these attempts, unexpected surges caused by the sector of domestic energy consumption could lead to important shortfalls between energy requirements at peak demand and available supply in India. As a solution to this challenge, the Union government of India has launched a new policy, named PM SURYA GHAR: MUFT BIJLI YOJANA, targeted to handle this crucial problem head-on. This initiative requires addressing the increasing energy demand by promoting the utilization of solar power in households throughout the length and breadth of the country. With the implementation techniques of Photo voltaic optimization, this analysis explores how such types of strategies can play a significant role in filling the gap between the energy supply-demand in the Indian context. Employing the solar energy potential and optimizing and utilization of solar energy, creates a path to not only meet the enhancing energy requirements but also creates the path for a more environmentally friendly and sustainable energy in India. By integration of innovative technologies and solutions of renewable energy holds the key to ensuring a balanced, sustainable, stable energy supply for the future of India and country's growth and development.

Key words: *energy gap, maximum power point tracking, economic growth, muftbijli, solar energy.*

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INTRODUCTION

Developing nations are witnessing a notable rise in electricity demand due to their Industrialization activities, creating huge pressure on the present infrastructure power systems, as certain industries require more power, such as mining and manufacturing industries. This rise in demand has exceeded the growth of power generation capacity in many countries, resulting in shortages and outages. The lack of maintenance, inadequate infrastructure, and upgrades, have created very frequent power shortages, which results in economic stagnation [21].

The country's natural resources, like water and fossil fuels, are excessively consumed for the generation of electric power, which in turn causes various environmental issues. Lack of regulations and inefficient technologies further worsen these issues. Developing countries have to face this type of challenge and design prominent steps for the sustainability of the country's electrical energy sector.

It is anticipated that there will be a significant rise in population of India's; it is projected to create a remarkable rise in the electricity demand, thereby creating more pressure on the electrical power infrastructure, which already exists. By 2030, it is expected that Indian population will rise to 1.77 billion. this growth in population might create a large electrical demand, which may anticipate at over 2000 billion units. This surge in demand requires a significant improvement in the generation capacity of electric power, not only generation but also enhancing the power handling capacity of transmission and distribution infrastructure. Even though, the present India's power infrastructure is struggling to meet the current demand, which causes power outages very frequently. The growth of the Indian population is poised to intensify the current problem, unless significant efforts are devised towards expanding and upgrading the existing power infrastructure of the country.

INDIAN ENERGY SECTOR IN A GLANCE

Installed Capacity of Fossil fuels in India

Table 1[1], presented as follows displays the installed generation capacity of various energy sources in megawatts (MW). From the data on the power generation of coal, It is evident that the coal-based power plants will hold the highest installed generation capacity at 205,235MW, signifying coal consumption will play a substantial role in the sector of electrical energy generation. Lignite, a variation of coal, named lignite and characterized by its lower carbon content, exhibits a remarkably lower installed capacity of 6,620 MW in comparison to coal. Natural Gas emerges as the third most prominent energy source of power generation in India, with an installed capacity of 24,824 MW, highlighting the significance of Natural gas in India's energy portfolio. Diesel, frequently used as a pinch or emergency power supply, has a generation capacity of 589MW, which is recorded as the lowest capacity of fossil fuel generation. The data from the table, for the most part, furnishes helpful discernment into the distribution of installed capacity of fossil fuel generation in India.

Table 1. Data pertaining to installed capacity of generation from fossil fuels

S.NO	Category of Fuel	Installed Capacity (Mega Watts)
1	Coal	2,05,235
2	Lignite	6,620
3	Gas	24,824
4	Diesel	589

As per data availability of various fuel sources by the end of May 2023[1], the installed capacity of generations represented in the table. The data has been categorized according to the percentage share of each fuel category in the entire installed power generation capacity and it is represented by a pie diagram shown in Figure 1.

The highest share, approximately half of the total installed fossil fuel capacity of India, 49.10%, is associated with coal, which shows a remarkable contribution by power plants that are coal-fired based. Lignite, a type of coal distinguished by less percentage of carbon content, represents only 1.60% of the total capacity. The power plants that fire natural gas contribute 6.00% to the total capacity, highlighting the importance of natural gas as one of the prime fuel sources for generating electric power. Diesel, typically utilized as an emergency or peaking fuel, contributes for the lowest portion of total installed capacity, only0.1%. This distribution of the capacity of electrical power generation by the category of fuel type offers insights into the mix of energy and electricity sources produced during this particular period.

The potential values of data hold for policymakers, stakeholders of various industries, and researchers seeking to make sense of the contemporary energy environment and strategize energy transitions of the future [1].

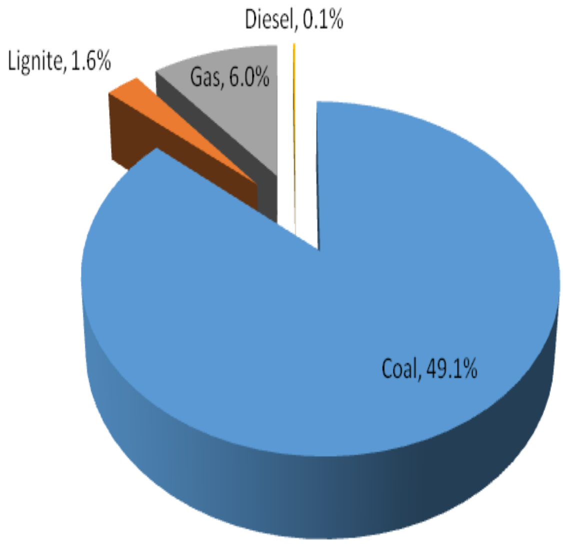

Figure 1. Share of each category fossil fuel

Installed Capacity of Non-Fossil fuels

Within reference to following Table 2[1], the various categories of non-fossil fuel sources and their corresponding capacities are delineated. The data illustrates the Megawatt (MW) capacity attributed to each category of non-fossil fuel source. The categories encompassed in the table consist of Hydro, Wind, Solar, BM Power/Cogen, Waste to Energy, and Small Hydro Power. The capacity allocation for each category of non-fossil fuel source is as follows: Hydro is endowed with a capacity of 46,850MW, Wind possesses a capacity of 42,868 MW, Solar exhibits a capacity of 67,078 MW, BM Power/Cogen maintains a capacity of10,248 MW, Waste to Energy holds a capacity of 554MW, and Small Hydro Power retains a capacity of 4,944 MW. These figures indicate the potential energy generation capacity associated with each category of non-fossil fuel source, highlighting the important contribution of renewable energy sources to the wider energy framework. The data available from the table can be used to examine the organization of non-fossil fuel sources and their potential impact on the domain of electrical energy, furnishing valuable guidance for policymakers, researchers, and industry stakeholders.

Table 2. Data pertaining to installed capacity of generation from non-fossil fuels

S.NO	Category of Fuel	Installed Capacity (Mega Watts)
1	Hydro	46,850
2	Wind	42,868
3	Solar	67,078
4	Biomass/Others	10,248
5	Waste to Energy	554
6	Small Hydro Power	4,344

The above entire analysis represented in the criteria of percentage of share. The same represent with help of pie diagram shown in the following Figure 2. Share of each category non-fossil fuelFigure 2[1]. It will represent the relation between the total installed capacities of various categories of the fuels.

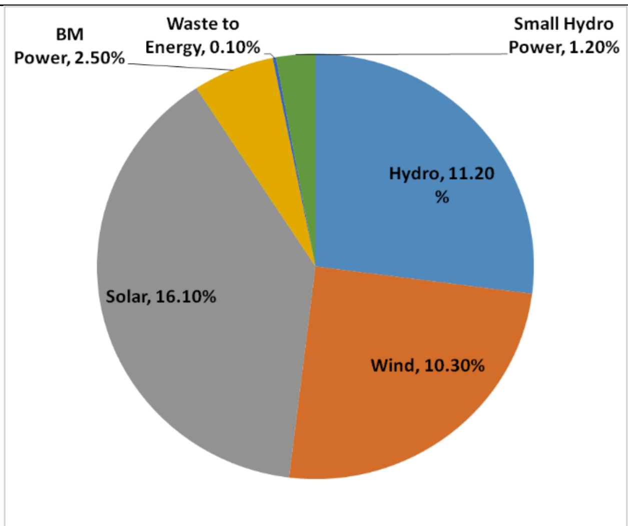

Figure 2. Share of each category non-fossil fuel

Total Installed Capacity of India in Various Categories

Table 3 presented here in displays the installed capacity of various fuel source categories utilized for power generation. The initial category, referred to as Fossil Fuel, exhibits an installed capacity of 2,37,269 Mega Watts. Fossil fuels encompass coal, oil, and natural gas, serving as non-renewable energy sources. The subsequent category, denoted as Hydro, showcases an installed capacity of 1, 78,563 Mega Watts. Hydro electric power derives from the kinetic energy of flowing water, rendering it a renewable energy source. The third category, identified as Nuclear, demonstrates an installed capacity of 6,780 Mega Watts. Nuclear power production involves nuclear reactions, yielding a substantial power output while maintaining low greenhouse gas emissions. The final category, labeled as Renewable, features an installed capacity of 1,20,294 Mega Watts. Renewable energy sources like wind, solar, and biomass offer sustainable and eco-friendly alternatives for power generation.

This data from the table signifies the array of fuel sources used in the generation of electrical power and demonstrates an amalgamation of choices of non-renewable and renewable choices within the sector of energy.

Table 3. Data pertaining to the installed capacity of generation from all major categories of fuels

S.NO	Category of Fuel	Installed Capacity (Mega Watts)
1	Fossil Fuel	2,37,269
2	Hydro	1,78,563
3	Nuclear	6,780
4	Renewable	1,20,294

From the data in Table 3[1], it is evident that fossil fuels contribute the largest installed capacity, accounting for 2,37,269 MW. This contributes around 56.80% of the overall capacity Fossil fuels encompass coal, oil, and natural gas, which are conventional energy sources known for their carbon emissions that raise environmental concerns. Hydro electric power, derived from water sources, exhibits an installed capacity of 1,78,563 MW, representing 11.40% of the total capacity. Nuclear power, produced through nuclear reactions, demonstrates a significantly lower installed capacity of 6,780 MW, contributing merely 1.60% to the total capacity. Renewable energy sources, including solar, wind, and biomass, collectively possess an installed capacity of 1,20,294 MW, accounting for 30.20% of the total capacity. The entire percentage of share represented by Figure 3. Renewable energy sources are recognized as cleaner and sustainable substitutes for fossil fuels, and their expanding capacity signals an intercontinental shift towards more eco-friendly energy sources. This data set offers significant insights into the current energy scenario and highlights the increasing importance of renewable energy sources within the wider energy portfolio.

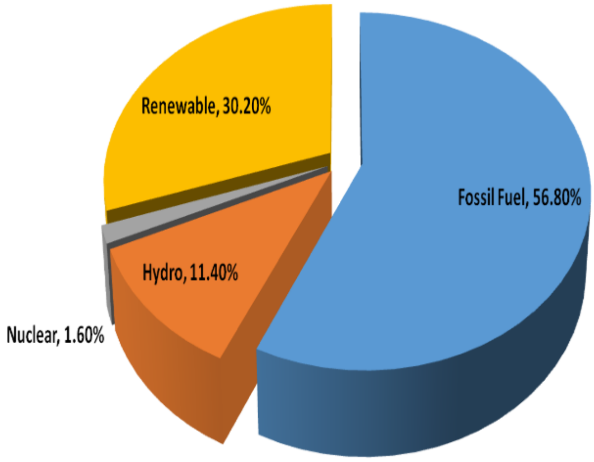

Figure 3. Share of all major categories of fuels

The Gap between Energy Requirement & Availability

Table 4. Data related to energy requirement and availability for past quattuordecennial

	YEAR	Energy Requirement (BU)	Energy Availability (BU)
1	**2009-10**	830.594	746.644
2	**2010-11**	861.591	788.355
3	**2011-12**	937.199	857.886
4	**2012-13**	995.557	908.652
5	**2013-14**	1002.257	959.829
6	**2014-15**	1068.923	1,030.785
7	**2015-16**	1114.408	1,090.850
8	**2016-17**	1142.929	1,135.334
9	**2017-18**	1213.326	1,204.697
10	**2018-19**	1274.595	1,267.526
11	**2019-20**	1291.010	1,284.444
12	**2020-21**	1275.534	1,270.663
13	**2021-22**	1379.812	1,374.024
14	**2022-23**	1511.847	1,504.264

Table 4[1], Represents Energy requirements (demand) and energy availability (supply) in billion units (BU) in the long run of fourteen years, from 2009-10 to 2022-23. The demand for energy indicates the quantity required, while the energy supply showcases the actual amount obtained during each respective year. In 2009-10, the energy demand accounted for 830.594 BU, with an energy supply of 746.644BU. There has been an overall increase in energy demand and supply, although with scattered fluctuations. For example, in 2014-15, the energy demand reached to the highest point at 1068.923BU, while the energy supply stood at 1030.785BU. This improving trend persisted, reaching a pinnacle in a peak in 2022-23 with a requirement of energy of 1511.847 BU and availability of energy of 1504.264 BU.

Figure 4 represents the bar chart diagram of energy availability and supply, this dataset showcases significant insights into the landscape of energy, emphasizing the increasing demand for energy and the endeavors undertaken to fulfill these essential requirements. The disparities between energy requirement (demand) and availability (supply) in certain years may significantly indicate potential hurdles in ensuring a compatible and sustainable energy delivery for future energy requirements. This data is vitally important for researchers, policymakers, and stakeholders of the energy domain to write out well-informed resolutions and fabricate strategies to address the needs of energy in an effective manner.

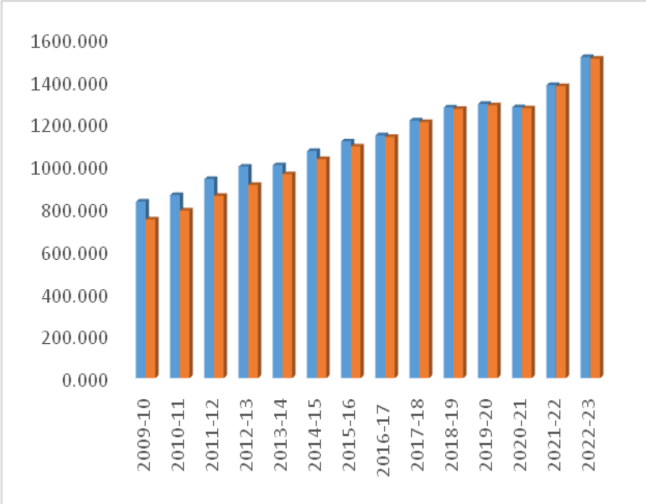

Figure 4. Scenario in the form of bar chart to energy availability (supply) and energy requirement (demand) for past quattuordecennial

For the year 2023-24, till the end of the May, 2023, the Data of the requirement of energy (demand) is 266.51BU and the data of availability of energy (supply) is 266.360BU

Table 5. Data related to the difference in between energy requirement to availability and percentage of gap for past quattuordecennial [1]

S.NO	Year	Energy Surplus(+)/Deficts(-)	
		(BU)	(%)
1	**2009-10**	-83.950	-10.1
2	**2010-11**	-73.236	-8.5
3	**2011-12**	-79.313	-8.5
4	**2012-13**	-86.905	-8.7
5	**2013-14**	-42.428	-4.2
6	**2014-15**	-38.138	-3.6
7	**2015-16**	-23.558	-2.1
8	**2016-17**	-7.595	-0.7
9	**2017-18**	-8.629	-0.7
10	**2018-19**	-7.070	-0.6
11	**2019-20**	-6.566	-0.5
12	**2020-21**	-4.871	-0.4
13	**2021-22**	-5.787	-0.4
14	**2022-23**	-7.583	-0.5

Table 5 represents the data of Energy surplus(+)/Deficit(-), From Year 2009-10 to Year 2012-13, significant deficits were observed, ranging from -83.950 BU to - 86.905 BU, corresponding to -10.1% to -8.7% of the total energy. However, in the subsequent years, there was a gradual decrease in deficits, with the lowest deficit being recorded in 2020-21 at -4.871 BU (-0.4%). This down ward trend persisted until 2022-23, where the deficit experienced a slight increase to -7.583 BU (-0.5%).

The reduction in deficits over the years indicates improvements in energy management and efficiency, resulting in a more balanced energy supply and demand scenario. These findings may suggest successful energy conservation measures or advancements in renewable energy sources, contributing to a more sustainable energy future.

The above entire analysis in a pictorial form represented in bar char as explained through the Figure 5, it will represent relation to Difference in between Energy Requirement to Availability and percentage of gap for past fourteen years.

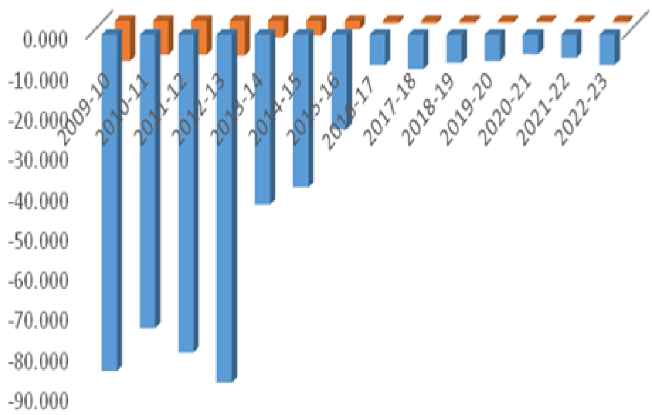

Figure 5. Bar chart related to the difference in between energy requirement to availability and percentage of gap for past quattuordecennial

For the year 2023-24, up to May, the difference in energy requirement data to energy availability data is 591MU, and Deficits are -0.2%, respectively.

The Gap Between Peak Demand & Peak Met

Table 6. Data related to peak demand and peak met for past quattuordecennial

	YEAR	Peak Demand (GW)	Peak Met (GW)
1	2009-10	119.166	104.009
2	2010-11	122.287	110.256
3	2011-12	130.006	116.191
4	2012-13	135.453	123.294
5	2013-14	135.918	129.815
6	2014-15	148.166	141.160
7	2015-16	153.366	148.463
8	2016-17	159.542	156.934
9	2017-18	164.066	160.752
10	2018-19	177.022	175.528
11	2019-20	183.804	182.533
12	2020-21	190.198	189.395
13	2021-22	203.014	200.539
14	2022-23	215.888	207.231

The data on peak electricity demand (in Gigawatts, GW) and peak electricity met for the years 2009-10 to 2022-23 is presented in the Table 6. The peak demand, which signifies the maximum electricity required at any given time, and the peak met, indicating the maximum electricity supplied to meet the demand, are included in the analysis. A noticeable trend of escalating peak demand is observed, commencing at 119.166 GW in 2009-10 and culminating at 215.888 GW in 2022-23. Similarly, a consistent rise is noted in the peak met figures, progressing from 104.009 GW in 2009-10 to 207.231 GW in 2022-23.

The disparity between peak demand and peak met serves as an indicator of the safety margin or reserve capacity within the electricity system. The data implies that the electricity supply has effectively matched the escalating demand throughout the years, with the peak met consistently surpassing the peak demand. This data holds significant importance for policymakers and energy strategists in ensuring a dependable and sustainable electricity supply to cater to the requirements of the population and industries.

The above entire analysis in a pictorial form represented in bar chart as shown in Figure 6. Bar chart related to peak demand and peak met for past quattuordecennialFigure 6 its Peak Demand and Peak Met for past fourteen years.

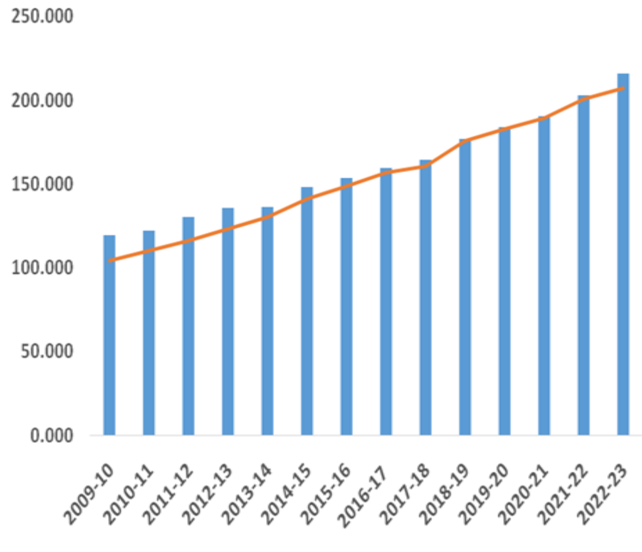

Figure 6. Bar chart related to peak demand and peak met for past quattuordecennial

Table 7. Data related to the difference peak demand to peak met and percentage of surplus/deficit gap for past quattuordecennial

S.NO	Year	Peak Surplus(+)/Defícts(-)	
		(GW)	(%)
1	**2009-10**	-15.157	-12.7
2	**2010-11**	-12.031	-9.8
3	**2011-12**	-13.815	-10.6
4	**2012-13**	-12.159	-9
5	**2013-14**	-6.103	-4.5
6	**2014-15**	-7.006	-4.7
7	**2015-16**	-4.903	-3.2
8	**2016-17**	-2.608	-1.6
9	**2017-18**	-3.314	-2
10	**2018-19**	-1.494	-0.8
11	**2019-20**	-1.271	-0.7
12	**2020-21**	-0.803	-0.4
13	**2021-22**	-2.475	-1.2
14	**2022-23**	-8.657	-4

The Table 7 shows peak surplus or deficits in Giga watts (GW), and percentage for each year. Deficits in power generation are indicated by Negative ('-') values; similarly, a surplus of power generation is indicated by positive ('+') values. In 2009-10, a deficit of 15.157GW was noticed, accounting for 12.70% of the total electrical power generation. The deficits experienced a step-by-step decrease, attaining a minimum of 0.803 GW in 2020-21, be evidence of a deficit of 0.4%. Anyway, in 2022-23, a remarkable rise in the deficit to 8.657GW was registered, approximately a deficit of 4%.

This data plays a crucial and complex role in puzzling out the trends in electrical power generation and consumption over the years, emphasizing the importance of effective strategies of energy management strategies to drive deficits and safeguard an unfluctuating supply of power. The fluctuations of deficits or fluctuations of the surplus can be attributed to a variety of factors, which include energy demand alterations, availability of resources, and efficient operation of the power generation system. Further in-depth analysis of this data could offer significant inputs for planners of energy and policymakers to devise knowledgeable decisions regarding sustainable energy and infrastructure of energy.

The above entire analysis in a pictorial form represented in the following bar diagram, as shown in Figure 7, it relates the Difference in between Peak Demand to Peak Met and the percentage of surplus/deficit gap past fourteen years.

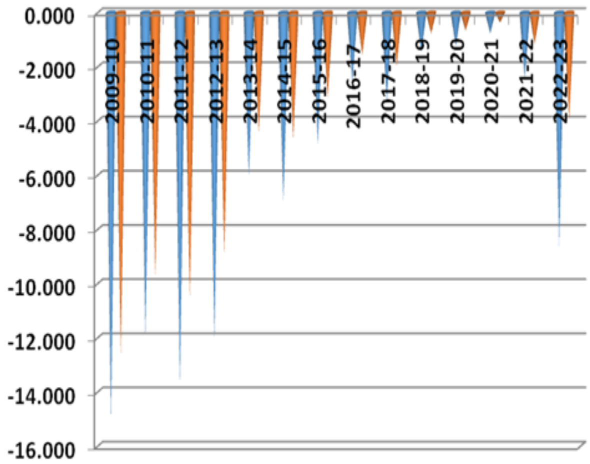

Figure 7. Cone chart related to the difference in between peak demand to peak met and the percentage of surplus/deficit gap for past quattuordecennial

LITERATURE SURVEY

In India, various policies of renewable energy have been actively promoted to address the increasing energy requirements and decrease dependency on fossil fuel-based generation [2][3]. The country is pursuing the goal of achieving zero carbon emissions by 2050 through the advancement and application of solar and other sustainable sources of energy [2].

India has set ambitious goals, including the target of 500 GW of green energy capacity by 2030, specifically focusing on increasing energy security and contributing to the growth of the economy [4].

The renewable energy sector of India has showcased remarkable growth, boasting a compound annual rate of growth of 15.51% over the past five years, specifically in wind and solar energy.

Anyway, the wind energy sector has faced various hurdles, such as obstacles in land acquisition, incentives removal, and changes to bidding processes.

To resolve these issues, solutions like offering tax incentives for re-power in gold wind farms and are much required to refresh the sector [5].

In the realm of policy of climate finance, the Renewable Energy Certificate (REC) mechanism in India has come across remarkable obstacles in the form of deficiencies and challenges, as a focus in the study by Baranidharan. The purpose objective of the mechanism of REC, which is to provide encouragement aspects for the generation of renewable energy and promotion of their sustainability, has not produced the desired results, leading to concerns regarding its efficacy in facilitating the shift towards cleaner energy sources [6].

In a relative analysis, the policies of renewable energy in the countries of Iran and India have been analyzed and examined carefully by Zuhaib, Mehrdad, and Behrooz in their research. The research decodes the contrasting strategies of the two nations to employ in the development of renewable energy and their renewable energy sector's advancement, showcasing the importance of the consistency of their policy and productiveness in promoting transitions to sustainable energy. By checking the difficulty of the landscapes of policy in each country, important remarks can be obtained to take control of upcoming policy-making decisions and encourage working together in the sector of renewable energy [7].

Moreover, the solar energy policy of India and its comprehensive analysis are showcased in this research report, focusing on India's endeavors to effectively utilization solar power as a fundamental element of its energy portfolio. The importance of robust frameworks of policy in directing solar energy's deployment is focused, emphasizing the requirement for current investment and innovation in this critical sector. Moreover, the latest research has shed light on scrutinizing the law of energy in India within the view of the low-carbon transition, signifying the evolving legal landscape and the crucial alignment of regulatory frame works with climate objectives [8][9].

Aparna emphasizes the pivotal role of climate policy and renewable energy in India in advancing a circular economy and sustainable development. The study research gives prominence to the interrelated behavior of economic, environmental, and social factors in influencing outcomes of policy, emphasizing the importance of integrated approaches to tackle complex sustainability challenges.

India can propel its transition towards a more sustainable and resilient energy future by promoting synergies among climate policy, renewable energy initiatives, and circular economy principles [10].

India's energy sector is confronted with various challenges that arise from a blend of economic, social, and political factors. Security of Energy concerns and issues of the environment are worsened by India's considerable dependence on conventional sources of energy, such as crucial imports of oil, gas, and high-grade coal [12].

India continues to struggle with inadequate energy reserves to meet the rapid increase in demand, particularly in the oil sector [15].

Unresolved matters persist, including the establishment of politicized tariff, instabilities of supply in the industries of natural gas, and the requirement for creative approaches to increasing the energy efficiency [11][13].

Various factors represent the complexity of India's energy landscape post-independence [14]. Addressing these challenges necessitates a comprehensive method for balancing energy security, ensuring the sustainability of the environment, and increasing economic development.

The Perturb and Observe method (P&O) Is simply implemented optimization strategy in the kingdom of renewable energy systems, particularly, with in the field of photovoltaic (PV) systems and wind turbines. [16] [17][19].

While the P&O MPPT technique is well known for its simplicity in implementation and cost efficiency, obstacles are nullified inaccurately obtaining the maximum power point (MPP), when it is subjected to changing conditions, such as partial shading conditions in PV systems or variation of in wind speed [16][19].

To control of these constraints which are, adaptations of the Perturb and Observe (P&O) technique are being devised by researchers, such as the Modified Perturb and Observe Method, with the objective of improving the differentiation between the GMPP (global maximum power point) and LMPPs (local maximum power points) in a more competent method, thereby make greater the extraction of energy and efficiency in solar or wind systems or both [19].

These improvements in P&O algorithms are significant because they can optimize the performance of renewable energy systems when they are subjected to environmental conditions, such as varying wind conditions, partial shading conditions, or both.

INDIAN POLICIES TOWARDS RENEWABLE- ENERGY SOURCES

National Renewable Energy Policy

The NREP (National Renewable Energy Program) has pioneering goals for the distribution of renewable energy, besides adding 10,000 MW of new capacity of generation and executing various biogas and solar projects.

To grab huge investments, the program offers various incentives offered by this program, such as subsidies, financing options, and tax credits, while also setting up a structure with the nodal agencies and green energy funds to support project expansion and guarantee financial portability. Besides, the policy includes steps such as preferential tariffs, quotas, and pricing guidelines to decrease financial risks and make projects of renewable energy more attractive to stakeholder or venture capitalists, with a more emphasis on promoting skills development and local manufacturing in the sector.

Off-Shore Wind Energy Policy

The government is adopting the plans of a production-linked incentive strategy for wind turbines that are offshore manufacturing-based, including the possibility of providing viability gap funding for setting tariffs. The MNRE (Ministry of New and Renewable Energy) takes care of offshore wind projects in India which has introduced three models and tendering processes in its revised strategy to meet target capacity by 2030.

This proposal is made within a policy that aims at obtaining net-zero emissions by 2070 through the focus on offshore wind energy, among other things as it has been mentioned above that there will be a need to boost offshore wind turbine manufacturing through PLI (Production-Linked Incentive) PLI Scheme while offering VGF (Viability Gap Funding) for power tariff achievement projects.

The necessity for establishing a strong supply chain, encompassing ports and logistics, to bolster the expansion of the offshore wind sector is acknowledged by the policy

Challenges are recognized by the policy in the off-shore wind industry, encompassing the effects of the COVID-19 pandemic, regulatory obstacles, and the necessity for a conducive environment.

Opportunities are emphasized by the policy in off shore wind energy, such as the possibility of competitive tariffs, decreased emissions, and the generation of employment.

Wind Solar Hybrid Policy

India's objective is to achieve an installed capacity of175 GW from renewable energy sources by 2022, with 100GW coming from solar power and 60GW from wind power. The main goal of the policy is to establish a structure that promotes the use of large grid-connected wind-solar PV hybrid systems to maximize the efficiency of transmission infrastructure and land use, decrease the fluctuations in renewable power generation, and enhance grid stability.

Fiscal and financial incentives that are accessible to wind and solar power projects will be extended to hybrid projects as well. In the realm of wind-solar hybrid systems, technology development projects will receive government backing, along with assistance in establishing standards for hybrid systems.

The development of wind-solar hybrid projects in India is overseen by the Ministry of New and Renewable Energy (MNRE), which serves as the nodal agency.

The MNRE has issued bidding guidelines for wind-solar hybrid projects, and the Solar Energy Corporation of India Ltd. (SECI) has released tenders for hybrid/RTC/peak power capacity.

By November2021, tendersfor10, 100MW of hybrid/RTC/peak power capacity have been issued by SECI, with 5350 MW already being awarded.

The policy is designed to minimize the fluctuations in renewable power generation and enhance grid stability through the integration of wind and solar power at a common grid connection point. Battery storage integration is permitted in wind-solar hybrid projects under the policy to enhance the consistency of power output.

Hybridization of Existing Plants: The hybridization of existing wind and solar plants is encouraged by the policy in order to optimize the utilization of infrastructure, encompassing land and transmission systems.

New Technologies and Methods: The policy is oriented towards the promotion of novel technologies, methodologies, and approaches for facilitating the combined operation of wind and solar PV plants.

The mitigation of renewable energy droughts can be achieved through wind-solar hybrid projects, which offer a more stable power output profile.

In India, solar and wind resources exhibit complementarities, rendering hybridization advantageous for diminishing variability and enhancing infrastructure utilization.

Aatma Nirbhar Bharat with a PLIscheme

A total capacity of 48,337 MW for domestic Solar PV module manufacturing has been allocated by the government under the PLI Scheme, with cumulative support exceeding Rs. 18,500Crore.

It is anticipated that the Tranche-II of the PLI Scheme will result in the creation of a total of 1,01,487 jobs, with 35,010 individuals obtaining direct employment and 66,477 being employed indirectly.

An investment amounting to Rs.93,041crore is projected to be attracted by the Tranche-II.

The Production Linked Incentive (PLI) Scheme is designed to offer incentives to chosen manufacturers of solar PV modules for a period of five years following commissioning, contingent upon the production and distribution of High Efficiency Solar PV modules.

The total amount of money kept in reserve for the PLI (Production Linked Incentive) scheme by the government of India is Rs. 240 billion, out of which Rs. 4.5 billion is portioned out to Tranche-I and Rs.19.5 billion has been kept aside for Tranche-II respectively.

The scheme of PLI is implemented by the MNRE (Ministry of New and Renewable Energy) as a nodal agency. There are two tranches that the plan has been divided into, tranche I having already received its award, while tranche II is currently ongoing. To improve market quality and ensure only authorized models and manufacturers qualify for the PLI Scheme, the Government has introduced an Approved List of Models & Manufacturers (ALMM).

To boost domestic manufacturing competitiveness and cut imports, the Indian government has imposed Basic Custom Duty (BCD). Setting up an integrated solar PV manufacturing ecosystem that serves both domestic and international needs with a view to enhancing India's standing in the renewable energy sector is the objective of this policy. Coming with globally competitive products will be the center of this strategy so that India becomes attractive to markets seeking supply chain diversification opportunities.

The Policy aims at supply chain diversification, intending to reduce dependence on imports, especially from China, and promote local production to address supply chain weaknesses.

PM Surya Ghar: Muft Bijli Yojana

The policy's objective is to achieve the solarization of one crore (10 million) households by the year 2027. It is intended that households consuming up to 300 units of electricity per month will receive free or low-cost electricity through this initiative.

The government provides Central Financial Assistance (CFA) to residential solar consumers, which is subsequently transferred to their bank accounts upon the completion of the installation process. A25% increase has been implemented in the subsidy amount for residential installations, with a benchmark cost of INR 50,000 per kilowatt (kW) for the initial 2 kW of roof top solar (RTS) capacity, and INR 45,000 for each additional kilowatt. Consumers residing in specific states, such as Uttar Pradesh and Pondicherry, are entitled to additional subsidies ranging from INR 15,000 per kilowatt to IN R9,000 per kilowatt.

The implementation of the policy is overseen by the Ministry of New and Renewable Energy (MNRE), which serves as the nodal agency.

A unified platform for consumers throughout India to submit their applications and monitor the entire installation process is the National Portal for Roof top Solar(https://pmsuryaghar.gov.in/).

Physical inspections, signing necessary agreements with beneficiaries, and approving the DISCOM report are responsibilities carried out by distribution companies (DISCOMS).

Solar modules utilized in the installation must originate from domestically produced cells to meet the Domestic Content Requirements and qualify forth eCFA.

The net metering process has been streamlined by the policy, enhancing its efficiency and decreasing the necessary documentation.

Solar Panel Prices: A 30% decrease in solar panel prices has been observed over the last six months, leading to increased affordability of roof top solar installations.

Domestic Manufacturing: The policy's objective is to promote domestic manufacturing of solar panels, which as seen significant expansion in recent years.

Some consumers have reported implementation challenges in obtaining feasibility approvals from DISCOMS, and there are reservations regarding the practical efficacy of the policy.

Opportunities are presented by the policy or households to lower their electricity expenses and support India's renewable energy objectives.

WORKING OF PHOTO-VOLTAIC CELL

A semiconductor diode with a p-n junction exposed to light is known as a photovoltaic cell. Various semiconductors, such as mono-crystalline and poly- crystalline silicon, are utilized to produce different types of photovoltaic cells.

Charges are generated within the PV cell upon exposure to light, leading to the production of current. The quantity of current generated is contingent upon the energy level of the photons present in the incident light [18],[20]. The same explained through the Figure 8

Photo Voltaic Modeling

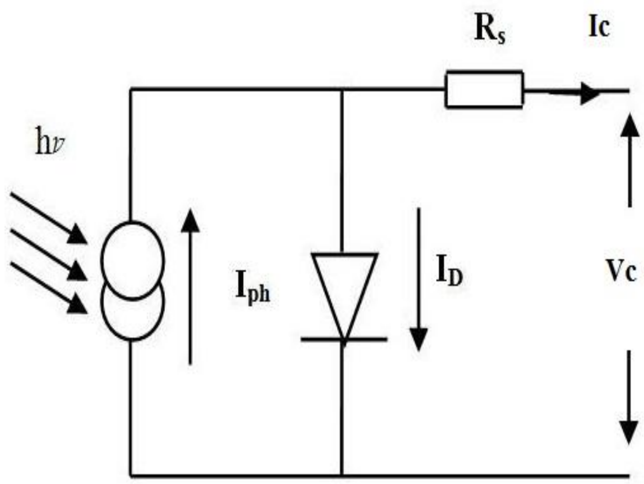

Figure 8. Equivalent circuit of PV cell

The following equations will represent the basic current equations of the PV cell [20].

$$I_{pv} = I_{ph} - I_D \qquad \textbf{(1)}$$

$$I_D = I_0 \left[e^{\left\{\frac{qV_D}{nKT}\right\}} - 1 \right] \qquad \textbf{(2)}$$

the current generated by theincident light (it is directly proportional to the Sun irradiation) denoted by $\boldsymbol{I_{ph}}$

The current equation of Shockley diode equation represented by $\boldsymbol{I_D}$

The reverse saturation or leakage current of the diode denoted by $\boldsymbol{I_0}$

The charge of an electron ($1.60217646\times 10^{-19}$ C) represented by ***q***

The Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K) represented by ***k***

The temperature (in Kelvin) of the *p–n* junction represented by ***T***

The diode ideality factor denoted by ***n***

The output current of PV cell (in amperes) represented by $\boldsymbol{I_{pv}}$

The photocurrent, which depends up on level of irradiation &temperature of junction (5.00 amperes) Indicated by $\boldsymbol{I_{ph}}$

The diode's reverse saturation current (200 μA) Indicated by $\boldsymbol{I_0}$

The series resistance of cell (1000 μΩ) Indicated by $\boldsymbol{R_s}$

The operating temperature of PV cell for reference (20°C) represented by $\boldsymbol{T_c}$

The determination of the net effective current (I_{pv}) of a photovoltaic (PV) cell is based on Equation (1), which includes the components of I_{ph} (current generated by light) and I0 (diode current). In order to enhance the current output, PV cells are recommended to be connected in parallel, whereas for increased voltage output, they should be connected in series.

The intensity of sunlight depends on various factors, including atmospheric conditions, variations in seasons, PV cells' geographical location, and The Earth's latitude and longitude, impacting solar irradiation reaching the surface and affecting voltage and current levels. The variations of temperature influenced primarily by season, climate, time of day, and geographic location can also affect PV cell's voltage and current outputs, with the higher temperatures typically resulting in upward movement of voltage levels while current levels remain stable.

The Control System for Maximum Power Point Tracking in PV Systems

To optimize the operation of a PV array around its maximum power point (V_{mp}, I_{mp}), it is essential to employ Maximum Power Point Tracking, the maximum power point of a photovoltaic cell or group of cells, which tracks with the help of an algorithm. By amalgamating an MPPT device with the PV array, the system can be directed to operate near the maximum power point, as shown in Figure 9, based on the PV curve of the specific configuration or device [18].

$$\frac{\Delta P}{\Delta V} = 0 \; for \; V = V_{mp} \qquad \textbf{(3)}$$

$$\frac{\Delta P}{\Delta V} > 0 \; for \; V < V_{mp} \qquad \textbf{(4)}$$

$$\frac{\Delta P}{\Delta V} < 0 \; for \; V > V_{mp} \qquad \textbf{(5)}$$

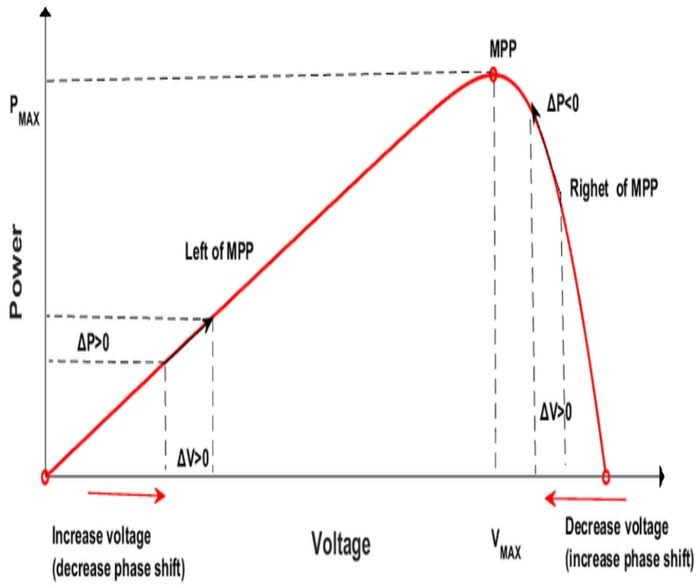

Figure 9. P-V Characteristics of a module to trace maximum power point

P and O (Perturb and Observe) Control Technique

Due to the advantage of the simple structure of P&O MPPT, as shown in Figure 10. This technique is generally used in most of the Maximum Power Point (MPP) algorithms because of its simple structure, which requires only a few parameters for effective control of Photovoltaic (PV)arrays [18],[20].

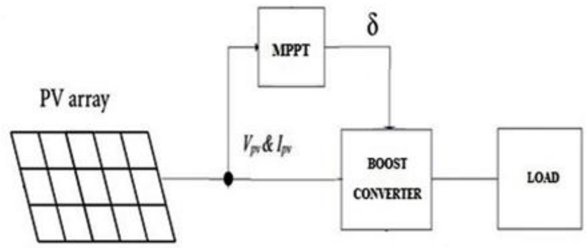

Figure 10. Setup for perturb and observe MPPT (P&O)

This strategy centers on the change of the terminal voltage of PV arrays periodically, through a duty cycle to keep them operating at their Maximum Power Point in a straight forward and flexible way. To increase comprehension of this method, with 'k' indicating the present moment and 'k-1' representing the preceding or previous moment.

The management of the switching operation of the DC-DC converter is achieved through the utilization of a clock signal. Activation of the converter's switch is initiated by a gate signal when the current level aligns with the reference value. In cases where the current surpasses or drops below the reference level, the same switch is deactivated by the clock signal. This method enables gradual adjustments to the reference current within each switching cycle, following a perturb and observe methodology. Essentially, the refresh rate, or perturbation cycle, is synchronized with the switching cycle.

Individuals can examine the connection between the PV array and the voltage control-based boost converter. The current passing through both the inductor and the load will have an identical magnitude. This current is utilized in creating feedback for the PV array. By comparing the saw tooth wave with the filter output, a Pulse Width Modulation (PWM) signal can be produced. This PWM signal can then serve as the gate signal for the converter switch. The boost converter's duty ratio is determined by comparing the terminal voltage and power of the PV system at that moment with the reference terminal voltage and power of the PV array.

The primary focus of the MPPT control algorithm discussed is the regulation of peak current. The management of the switching operation of the DC- DC converter is achieved through the utilization of a clock signal.

Activation of the converter's switch is initiated by a gate signal when the current level aligns with the reference value. In cases where the current surpasses or drops below the reference level, the same switch is deactivated by the clock signal. This method enables gradual adjustments to the reference current within each switching cycle, following a perturb and observes methodology. Essentially, the refresh rate, or perturbation cycle, is synchronized with the switching cycle.

In order to ensure precise tracking of the Maximum The comparison of the saw tooth wave with the filter output triggers the generation of a PWM (Pulse Width Modulation) signal to the converter switch, which can act as a gate signal for it. The Duty ratio of the boost converter is established by evaluating the PV system's terminal voltage and power against the PV array's reference values. To get accurate Maximum PowerPoint Tracking, various, such as temperature and solar irradiation under atmospheric conditions, must be taken into account.

The issue of load matching in MPPT can be resolved by modifying the input resistance of the PV panel to align with the load resistance through alterations in the duty cycle. This modification necessitates a DC-to-DC converter, such as a boost converter. A schematic representation of a boost converter is depicted in the Figure 11.

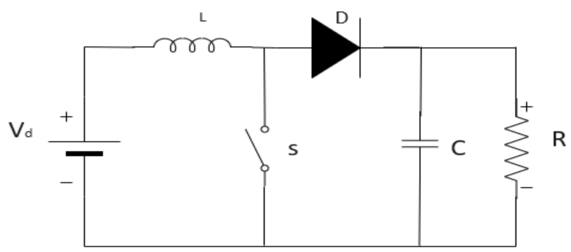

Figure 11. Boost converter's topology

$$V_{in}*t_{on} - (V_o-V_{in})\ t_{off} = 0 \qquad \textbf{(6)}$$

Therefore

$$V_{in}*\ \delta\ *T = (V_o - V_{in})\ (1- \delta)\ T \qquad \textbf{(7)}$$

$$V_o\ /\ V_{in} = 1/\ (1- \delta) \qquad \textbf{(8)}$$

The voltage level on the output side can be increased by the regulator. This improved performance is due to the presence of a single switch. According to Equation (8), variations in the duty cycle have a notable effect on the output voltage of the DC-DC converter, and the current remains continuous only when the boost converter operates in continuous conduction mode (CCM).

The calculation of the inductance value can be done by using the given equation [18].

$$L_{min}= ((1-\delta)^2\delta R)/2f \qquad \textbf{(9)}$$

The output voltage ripples generated by the photovoltaic system are mitigated by a substantial RC filter situated on the output side. This filter is operated with a discontinuous supply of current.

When the diode (D) is in the off state, the filter capacitor supplies DC current to the load. Equation number 10 can be utilized for calculating the necessary capacitance of the filter under conditions of voltage ripple [18].

$$C_{min}= \delta\ /\ (R*f*V_r) \qquad \textbf{(10)}$$

SIMULATION RESULTS AND DISCUSSION

The overall setup had been implemented in the Matlab-SIMULINK enivironment the schematic diagram as shown in the Figure 12.

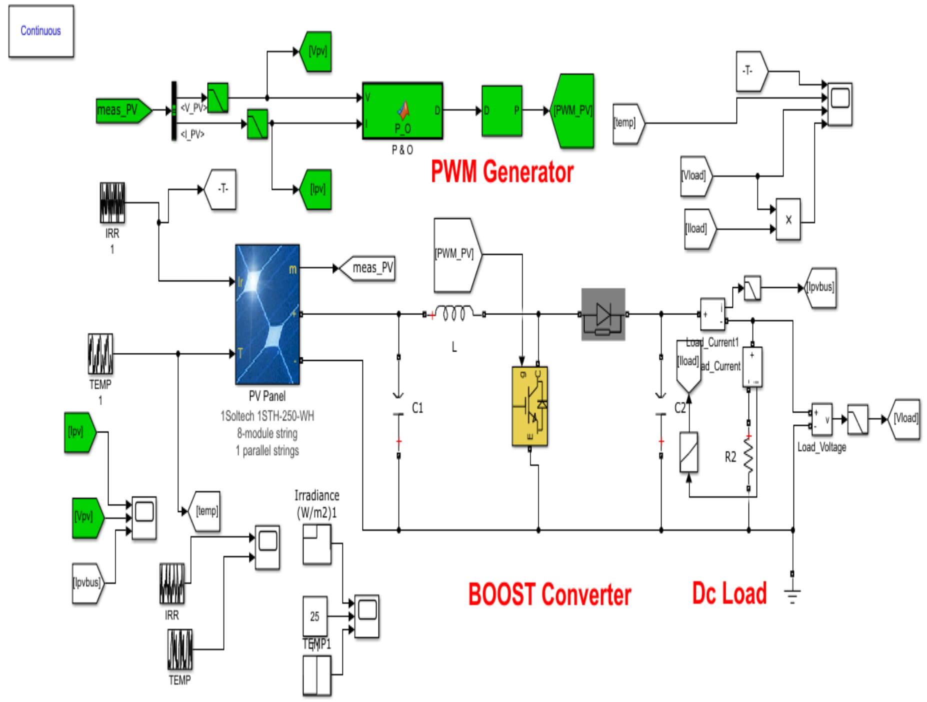

Figure 12. The matlab simulink diagram illustrates a photovoltaic (PV) array being powered by the perturb and observe (P&O) algorithm while experiencing varying irradiance and temperature conditions

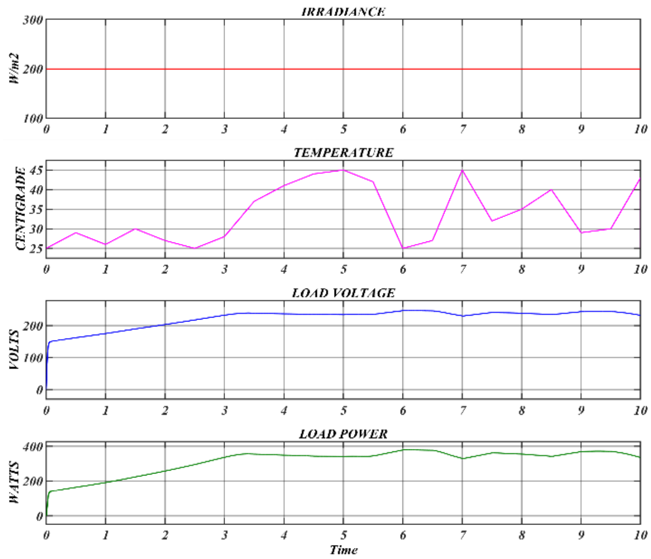

Figure 13. The behavior of voltage and power levels from photovoltaic (PV) array w.r.t to load under constant irradiance of 200 W/m2and fluctuating temperature conditions when the perturb and observe (P&O) maximum power point tracking (MPPT) method is employed

According to Figure 13, the photovoltaic (PV) system experiences a constant irradiation of 200 W/m^2 with temperatures ranging from 25°C to 55°C. Despite the temperature fluctuations, the load voltage remains stable. This suggests that the PV system functions under varying temperature conditions while sustaining a consistent load voltage. However, the system's power generation capacity is constrained to 150V during extremely low irradiance levels.

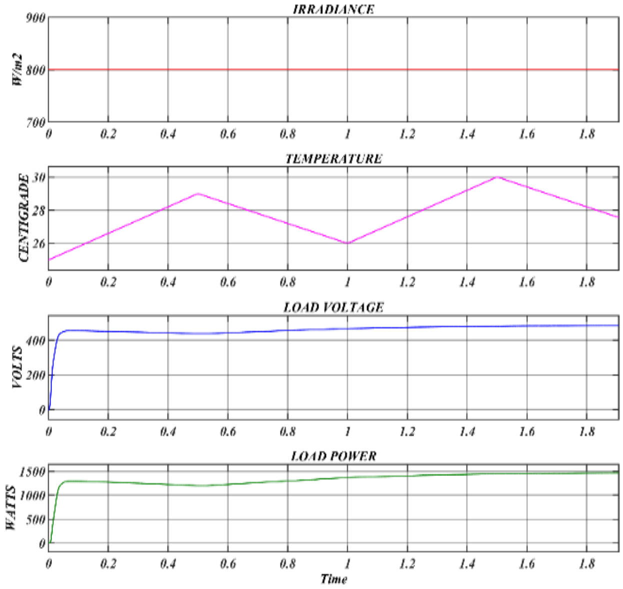

Figure 14. Voltage and power behavior from the system of photovoltaic (PV) array w.r.t to load under constant irradiance of 800 W/m2 and fluctuating temperature conditions when the perturb and observe (P&O) tracking of maximum power point (MPP) method is employed

By considering wave form from Figure 14, the PV (photovoltaic) system is subjected to a constant level of irradiation, 800 W/m2. Meanwhile, the same system experiences fluctuating temperatures ranging in between 25°C to 30°C. Despite this, the stability of the load voltage is maintained. This indicates that the PV system can operate under fluctuating temperature conditions while keeping the load voltage nearly constant.

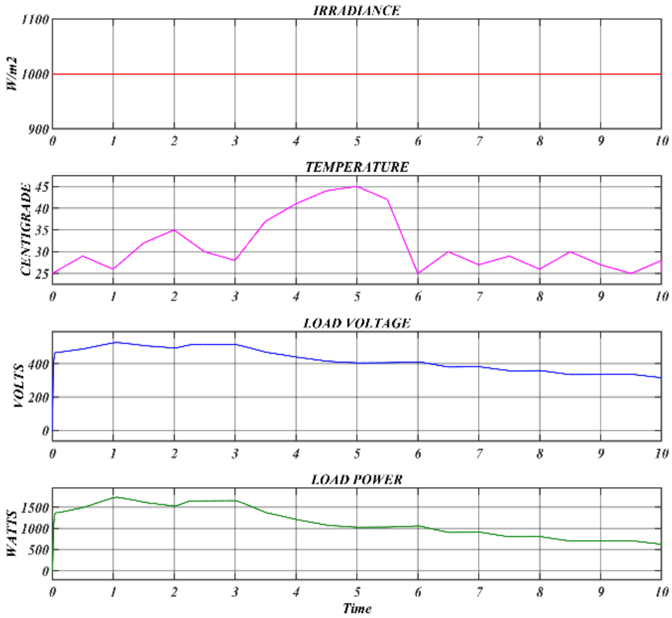

Figure 15. power and voltage levels of PV array w.r.t to load under constant irradiance of 1000 W/m2 and their under fluctuating temperature conditions when the perturb and observe (P&O) maximum power point tracking (MPPT) method is employed

With reference to Figure 15, we can interpret that, despite variations in temperature, the photovoltaic system shows its ability to maintain a stable load voltage under consistent irradiance conditions.

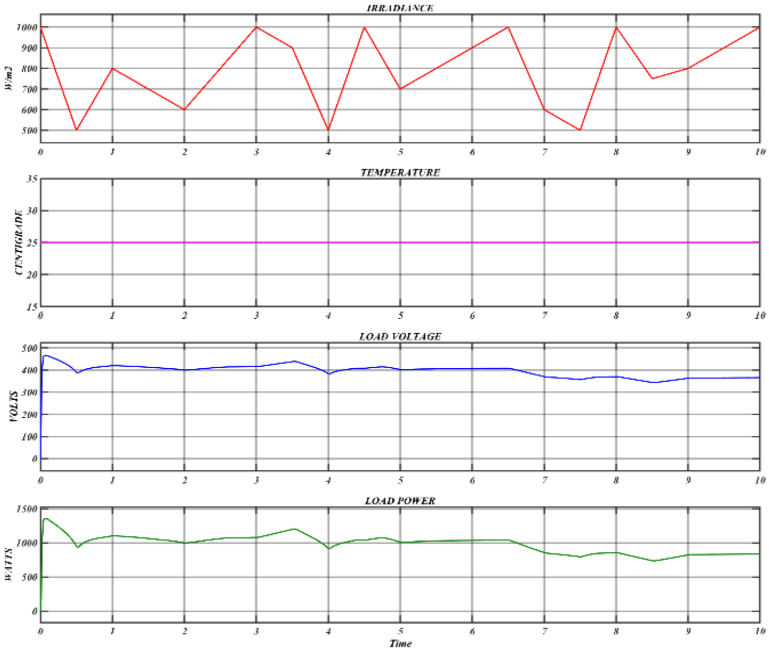

Figure 16. The effect of varying intensity of sunlight levels and at a constant temperature of 25°C on the performance of load parameters, VL and PL in a photovoltaic (PV) array, utilizing the Perturb and observe (P&O) maximum power point tracking (MPPT) technique

With reference to Figure 16, it is ensure that the voltage at the load of the PV system remains stable within the range under constant temperature of 25°C and under fluctuating conditions of irradiation, showcasing the ability of system to maintain voltage stability enclosed by consistent temperature and variable irradiance conditions.

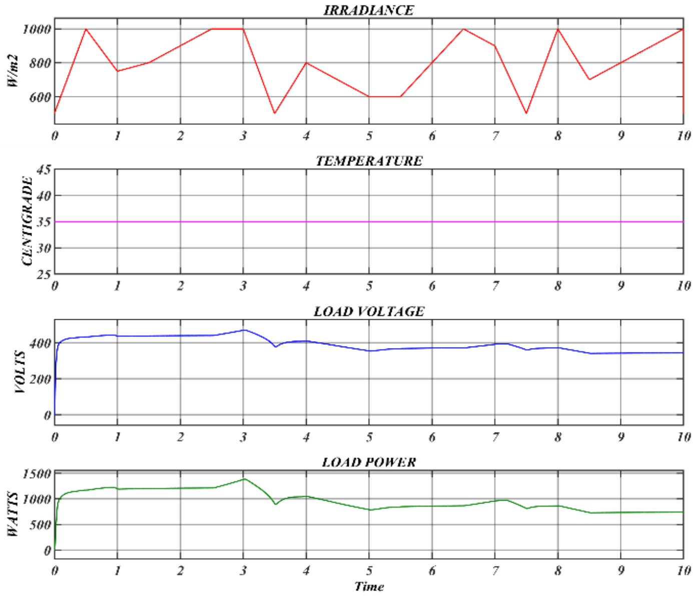

Figure 17. The influence of fluctuating levels of sunlight and a steady temperature of 35°C on the performance load parameters of VL and PL in a photovoltaic (PV) array, utilizing the perturb and observe (P&O) maximum power point tracking (MPPT) technique

With the help of Figure 17, we can interpret that, the solar PV system operates at a steady temperature of 35°C and subjected to Fluctuating levels of sunlight yet it is able to maintain a consistent voltage supply to load, demonstrating its capacity to withstand consistent performance despite variations of sunlight intensity.

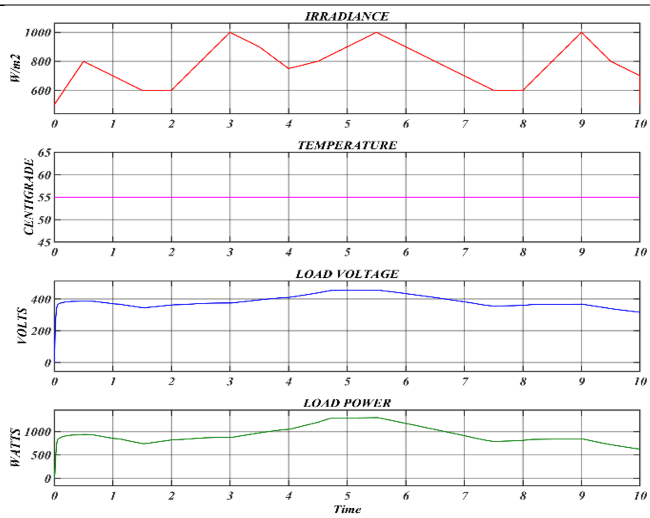

Figure 18. The effect of fluctuating intensity levels of sunlight and a uniform temperature of 55°C on the performance of the load constraints VL and PL in a photovoltaic (PV) array, utilizing the perturb and observe (P&O) maximum power point tracking (MPPT) technique

With reference to the above Figure 18, the mppt technique able to maintains a stable load voltage within a certain range, even if presence of variation in intensity of sunlight and uniform conditions of temperature, this scenario will indicate, the PV system ability to sustain persistent performance, when it subjected to fluctuating factors of environmental.

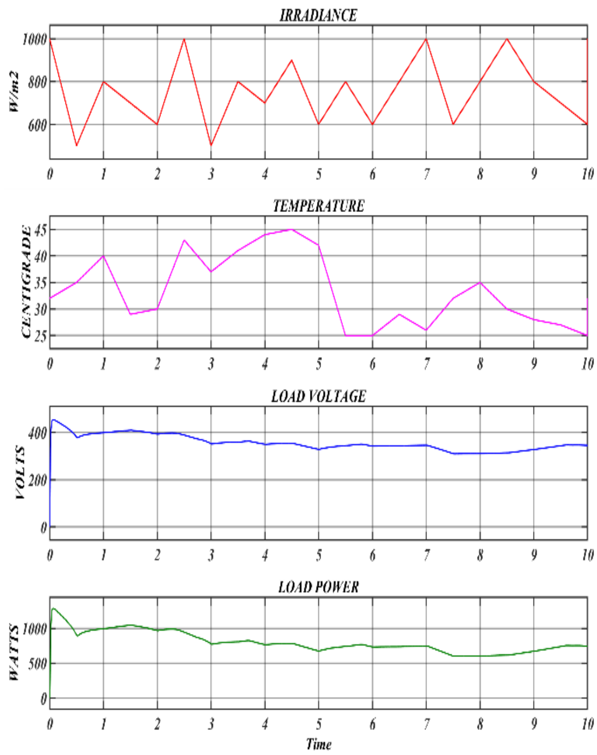

Figure 19. The performance of VL and PL is impacted by varying levels of sunlight and temperature within a PV array when employing the perturb and observe (P&O) technique for maximum power point tracking (MPPT)

According to Figure 19, the photovoltaic (PV) system experiences fluctuations in temperature within the range of 30°C to 45°C and varying irradiation levels spanning from 600 W/m^2 to 900 W/m^2, while always remaining below 1000 W/m^2. It is observed that despite these changes, the consistency of the load voltage is maintained. This observation suggests that the load voltage remains relatively stable even when subjected to fluctuating irradiance levels under constant temperature conditions.

From the above result analysis, shown in Fig 19 we can interpret that, The PV system subjected constant temperature conditions at variable irradiance level, that is low irradiation levels and high irradiation levels, the load voltage is almost maintained constant within a certain range.

CONCLUSION

In this study, key parameters focusing on the gap between energy demand and supply were analyzed using specific statistical data. The initiatives undertaken by the Union Government of India in the realm of renewable energy sources were also examined. The MPPT (P&O) Technique-based PV array was found to maintain a nearly constant voltage range, particularly under varying irradiance (W/m^2) and temperature (°C) conditions. The implementation of MPPT-controlled PV techniques through policy measures can facilitate the deployment of PV systems, offering significant advantages to emerging economies such as India, China, and South Africa, while also enhancing energy security. Notably, the power sector in India is predominantly reliant on fossil fuel power plants. The integration of MPPT technology has the potential to enhance power generation from PV arrays, thereby reducing the Plant Load Factor of fossil fuel-based plants and ensuring adequate peak energy supply to meet demand.

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