IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received January 26, 2021, accepted February 5, 2021, date of publication February 12, 2021, date of current version February 25, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3059297

Feasibility Analysis of Solar Technology Implementation in Restructured Power Sector With Reduced Carbon Footprints

IRAM AKHTAR[1], SHEERAZ KIRMANI[1,2], MOHAMMED JAMEEL[3], AND FARAZ ALAM[4]

[1]Department of Electrical Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia (A Central University), New Delhi 110025, India
[2]Department of Electrical Engineering, Faculty of Engineering and Technology, Aligarh Muslim University, Aligarh 202002, India
[3]Department of Civil Engineering, College of Engineering, King Khalid University, Abha 62529, Saudi Arabia
[4]Research and Policy (Energy and Power Sector), Vasudha Foundation, New Delhi 110014, India

Corresponding authors: Iram Akhtar (iram1208@gmail.com; akhtariram12@gmail.com), Sheeraz Kirmani (sheerazkirmani@gmail.com), and Mohammed Jameel (jamoali@kku.edu.sa; jameeliitd@gmail.com)

This work was supported by the Deanship of Scientific Research at King Khalid University through the General Research Project under Grant G.R.P-177-41.

ABSTRACT Solar energy technology has gained significant attention in recent years. It has strongly emerged as an alternative to the conventional mode of electricity generation for developing countries like India for their rising energy needs. Solar energy based electricity generation not only addresses environmental concerns but also increases the energy security and reduces the carbon footprints generated by the coal-based power plant. To boost the share of Renewable energy in the energy mix, the renewable energy policy introduced by the government has acted as a catalyst for large scale deployment of solar energy system to push it as the major energy alternative for India. The normal intensity of solar radiation in India is 220 MW per km square with around 300 sunny days in a year, whereas the coal-based plant generates a huge amount of carbon footprints. Therefore, solar based power generation has the potential of not only reducing the emissions and but also it can cater the rising energy demand. Thus solar photovoltaic plants has become a major alternative energy option in India with the ability to give an improved power supply, reduced global warming and enhance the security of energy supply. In this paper, efforts have been made to look into the overall perspective of solar energy and coal based generation by studying and analyzing the present status, technologies use, accessibility, policies interventions, major contributions, future potentials and trends of solar energy and fossil fuels in the Indian power sector. A feasibility analysis of solar technology implementation with the replacement of coal based plant pant is carried out for Singrauli, India. Results of the proposed study shows that the coal-based power plant generates a huge amount of carbon footprints and it can be reduced by replacing the coal based power plants with solar energy based power generation system. Consequently solar energy based power generation system is a key alternative for developing countries like India having metrological parameters similar to the case study done in this paper with the capacity to provide an improved supply, decreased global warming in addition to improving the energy security.

INDEX TERMS Solar energy system, Indian solar market, solar energy policy, carbon footprints.

I. INTRODUCTION

Power sector is the major contributing sector in a country's economy. In the last decades, various utilities across the world have focussed on the changing their operational ways in power sector. Whereas the vast use of fossil fuels reserves has caused noticeable damage to the environment, hence renewable energy systems are being developed rapidly [1]–[3]. Indian solar industry has gained major attention and has been developing since the announcement of National Solar Mission (NSM) by the Ministry of New & Renewable Energy (MNRE), Government of India, an improved policy structure for better diffusion of solar power i.e. 100 GW capacity by the year 2022. The main mission of the proposed plan is to reduce the solar power generation cost in the long term, deployment in large scale and subsequently reducing global warming.

The associate editor coordinating the review of this manuscript and approving it for publication was Dwarkadas Pralhaddas Kothari.

The Renewable energy policy in India aims to promote the companies to follow the chance based path and technology organization to follow the capability-based path [4]. By adding the renewable energy sources, the generated units taken from the coal based thermal power plant is reduced, eventually it decreases the carbon footprints [5]. The solar technologies can be used to empower the vehicle industry also which gives the support to voltage profile [6]. Further, it is very hard to know the exact behavior of the renewable energy based system because of its changeability. Therefore, reliable operation and proper implementation of the solar energy system is the main concern [7]. The solar energy system is connected to the main grid via the net metering scheme, hence proper scheduling and feasibility of emerging the grid-based solar energy system is also improtant [8].

If India wants grow at a good economic growth then it is necessary to have large scale deployment of solar based electricity in various sectors, to cater rising energy demand [9], [10]. There are many advancement in the technologies that has taken place recently in the solar energy system, which can be helpful to enter a phase of additional growth in India. It is very important to update the predictive equipment linked with the recent technology for better utilization of solar energy [11]–[13]. The energy security is another major focus part for India to reduce its dependency on import of coal which can be increased by the development of the renewable energy system. This includes the economics of power sector with low dependency on the coal imports. Hence there is a need for a proper provision to supply the energy from the alternative energy sources at a viable and affordable cost. Government of India is promoting solar energy based electricity generation by giving subsidies which has significantly reduced per unit cost to encourage the solar technology utilization. Solar based generation system for home has a major potential for the government to decrease the carbon emissions in addition to decrease in the need of other energy sources [14]. There are few technology constraint which still persists with solar based electricity generation. The solar irradiation tends to change mostly all over the day, the difference can be noticed between the early sunshine hours and during peak hours. However, it is preferable to give constant power to the load and grids for better reliability. Hence different techniques have been proposed to reduce the changes in the solar power generation [15], [16]. For large scale power production from the solar system, the solar panels are interconnected to form the array. In this system, the partial shade can result in the lower power output and give different power peaks throughout the day. As a result, solar modules generates variable current. Hence to increase the power output, the modules require to be changed electrically [17] and the evaluation of the soiling loss on the modules in any location involves the data collection from the fielded solar system [18]. Besides, the power quality is another main issue in the grid-connected solar system, so many researchers have proposed different techniques to improve the power quality of the system [19], [20]. The energy management schemes have been proposed to overcome the effect of rapid fluctuations of the loads and load demand can be fulfilled by storage system [21]. Also, there is a discoloration problem in dry and hot climate zone in the solar modules with the humid and hot zone coming in the second position [22]. Lately, solar based energy systems are connected with the microgrid with the maximum power tracking schemes and these systems are designed for overall routine operation with a consideration of the practical condition. Whereas, the challenges of solar energy integration with the utility grid and status of smart grid expansion need to be addressed through the policies measures and its proper implementation which focuses on future targets and role of alternative energy sources. Currently, about 79% of the electricity necessity is completed by the fossil fuel dependent plants. The generated electricity by these plants is expensive and generally leads to pollution and consequent health problems. Hence solar energy system as a replacement of coal-based plant is the better option for reducing the carbon footprints [23]. Rising concern of the lack of energy resources and dangerous result of fossil fuel emissions release has started new need of cleaner solar energy source [24]–[26]. But one needs to look at the viability of replacing coal-based power plants entirely with renewable energy systems looking at coal's dominance. Hence, proper arrangement and measures are required to achieve this ambitious target [27]. In the United States, due to awaiting regulations and possible greenhouse gas strategies could lead to a major withdrawal of coal-based plant. Whereas technology advances may reduce the cost of renewable energy sources [28]. Most of the homes in the rural areas still suffers from long hours of power cuts due to the load shedding in India. In the past, India has produced less power compared to the power demand for consumption, but the scenario has been changing over the last few years. Recently solar rooftop systems with the net metering scheme are promoted to overcome the power shortage issue [29], [30]. There is a need for proper modelling of the solar system to cover all the processes between the main demand and energy output with control design [31]–[33]. The solar power generation with significant potential today stands at efficiency of 16% with the load factor of 0.22, hence this can provide a huge amount of power [34]. Hence long term scalability and the sustainability of the solar energy system need to be examined before replacing the coal-based plant [35]–[37]. To check the reduction in carbon emissions using the Solar technology, proper analysis is required to know the total reduction of carbon footprint by replacement of coal-based power plants [38], [39].

The other renewable energy sources such as wind energy, tidal energy, hydro energy and geothermal energy also influences supply, global warming and security of energy supply. The harmful results of fossil fuel emission has started the new need of clean and reliable renewable energy sources. The wind and solar energy systems are more developing energy sources in comparison with other renewable energy sources. Valuation of wind energy sources installable potential at the various part of the India can be taken from the National

Institute of Wind Energy, Ministry of New and Renewable Energy, Government of India. So, it can be observed that wind energy sources also improve the supply, reduce the global warming and enhance the security of energy. Therefore, efforts have been made in this work to look into the overall outlook of solar energy and coal based generation by analyzing the present scenario, machineries use, availability, policies interventions, major assistances, future potentials and trends of solar energy systems and fossil fuels in the power sector.

The burdens on the conventional grid due to energy deficit, peak demand, and carbon footprint can be minimized by the alternative energy sources [24], [40]–[42]. Therefore solar energy system is a major substitute option in India with the capability to provide an improved supply, reduced global warming and improvement in the security of energy supply. In this paper, efforts have been made to highlight the present status of solar and coal technologies and their penetration. This paper also focuses on the existing government targets and policies for coal and solar based generation along with their future trends, targets and potential in coal and solar energy choices in Indian power sector.

In this work, a need for solar energy system in a restructured power system are discussed in Section II. Government proposals to encourage solar energy system in India is given in Section III. Feasibility analysis of solar technology implementation with replacement of coal-based plant is discussed in Section IV. Case study is discussed in Section V. results and discussion are presented in Section VI. Lastly, concluding statements are given in Section VII.

II. NEED FOR SOLAR ENERGY SYSTEM IN A RESTRUCTURED POWER SYSTEM

The use of solar energy system can be linked with the increase in the development of the country. The beginning of competition in the power markets requires reconsideration and planning of solar energy technology and its strategies. Apprehension about the solar energy systems used in economical surroundings can be delineated in the outline as electric power sector competition will support consumers to be more capable and decrease cost of electricity. The solar energy reduces the dependency on fossil fuels reserves and gives less pollutant than the coal-based plant. Today, the major share in the production of electricity is the coal-based plant and fuels are limited in nature. Furthermore, utilization of this has unfavourable effects on the environment. Therefore, the rising concern of environmental ruin and the lack of power have highlighted the requirement for a solar energy based power generation system for power production in India.

Solar energy based power is the power derived from the sun in the radiation form. It has the capability of becoming the major energy source in India with the ability to give a good and reliable power supply and enhance the security of the energy supply. The installed capacity of solar has reached 37 GW as of December 2020. The government of India had a previous goal of 20GW power for 2022. It has attained this target four years ahead of the agenda. In 2015, this target was revised toachieve100GW by 2022, aiming a venture of US$100 billion. The Prime Minister of India Mr.Narendra Modi and French President François Hollande laid the foundation for the International Solar Alliance control centre in Pahari, Gwal, Gurgaon in January 2016.

TABLE 1. India's Power at a glance.

Fuel	Power (MW)	Percentage of Total
Thermal	2,26,279	63.14%
Hydro	45,399	12.7%
Nuclear	6,780	1.9%
Renewable Energy Sources	78,359	22.0%

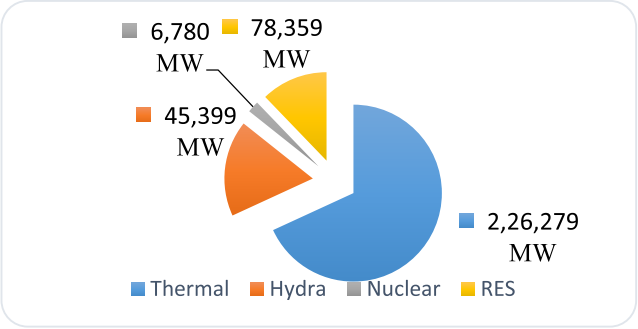

FIGURE 1. India's installed capacity Pictorial representation.

India's power sectors are dominated by the fossil fuels, and in specific the coal, and it generated about the three-fourths of the electricity during the year 2017-18. Now, the government is assertive for using of energy from the renewable based energy sources. The Indian Government has prepared the National Electricity Plan of 2018, which states that the country does not want more non-renewable based electricity plants in the power sectors till 2027, with contracting of 50,020 MW coal dependent power plants in construction and attaining 275,000 MW overall renewable power installed capacity when nearly 48,000 MW old coal based power plants is retired.

Whereas, the Overall generation in India which includes the power production from the grid connected renewable energy sources has been raised from 1110.456 BU during the year 2014-15 to the 1173.603 BU during the year 2015-16, 1241.689 BU during the year 2016-17, 1308.146 BU in the year 2017-18 and 1376.095 BU in the year 2018-19. The thermal, Bhutan import and nuclear generations are increased by 3.39%, 7.78% and 1.38% respectively and the hydro generation is decreased by 6.95% during the year 2018-19. The renewable energy sources based power generation is also increased by 24.47% during the year 2018-19. The key to the national economic growth is dependent on the growth of power sector. Table 1 shows the total installed capacity of the India as on 31th May 2019 and the Fig.1 presents the alike thing in a pie chart form.

Indian solar industry has gained major attention and has been developing since the announcement of National Solar

Mission (NSM) by the Ministry of New & Renewable Energy (MNRE), Government of India, an improved policy structure for better diffusion of solar power i.e. 100 GW capacity by the year 2022. The main mission of the proposed plan is to decrease the solar power production cost in the extended term, deployment in the large scale and subsequently reducing global warming.

In Andhra Pradesh, the installed capacity is more than 2600 MW as on 25th November 2018. Further, 1000 MW solar power plant has made at Kurnool. Whereas the capital of India i.e Delhi has some constraint in mounting the ground-based solar plants. But rooftop solar power system can be installed by taking fully adjustable net metering scheme. Delhi's installed capacity of the solar power system is 106 MW as on September 2018. In Gujarat, the installed capacity of the solar based system is 1640 MW as on 2019. Gujarat has been the main state for solar based generation in India because of its huge potential, accessibility of useful land, transfer and transmission infrastructure.

In Haryana, the installed capacity of the solar plant is 49MW as on January 2019. Haryana has the tender of 300 MW grid-connected solar system and extra 16MW for the canal-top solar energy. Karnataka and Kerala have the installed capacities are 5000MW at the 2018 and 500 kW respectively. Madhya Pradesh is one of the state with major solar installation, with 1117 MW of solar installation as on July 2017. The Welspun Solar MP project, the major solar power system was mounted at a prize of 160 million US$ and would give power at 8.05INR per kWh. Whereas the Sakri power plant has 125 MW capacity in Maharashtra. The total installed capacity in Maharashtra is 500MW. The installed capacity of Rajasthan is about 2290MW as of June 2018. Further, Tamil Nadu is in the 5^{th} position of operating the solar plant in India. The total installed capacity is 1.8GW as on July 2017. The installed capacity of solar in Telangana has reached 3400 MW and has a target of achieving 5000MW by 2022.

Installed solar power capacity of various states in India is shown in fig.2.. Hence, solar energy sources are the best sources among the different renewable energy available in India with low negative crashes on the environment.

Figure. 3. shows the development of the solar energy system concerning different issues. It can be noticed that although the major solar radiation is incident in Gujarat, Rajasthan, Andhra Pradesh, Tamil Nadu, Madhya Pradesh, Karnataka, the parts of other states in India also receives substantial amount of solar radiation as compared to other countries in the World.

III. GOVERNMENT PROPOSALS TO ENCOURAGE SOLARENERGY SYSTEM IN INDIA

India is gifted with a huge amount of solar radiation. It receives a reasonable amount of solar radiation per year i.e. more than 5000 trillion kilowatts per year. This is more than the energy requirement in India which can be used in various solar energy technologies. There are various solar technologies available which has applications in urban and rural areas as to reduce the burden on conventional units as well as to reduce the carbon footprint. Government of India had proposed the grid connected rooftop as well as a small capacity solar system with the budget 5000 INR crores for implementation within the period of 5 years up to 2019-20 under the National Solar Mission. Whereas Ministry of new and renewable energy is employing the scheme for mounting the grid connected rooftop solar systems in available locations. The economic growth is leading to a rapid increase in the power demand in the in India leading to increasing carbon emissions from conventional source of generations. There are many cities in India which has set targets and are bringing in policies to encourage the renewable to reduce the carbon emissions. The electricity utilities and the government are getting it hard to deal with the quick rise in the power demand. Hence ''Development of Solar Cities'' scheme is proposed to support the cities in becoming the solar cities. 60 cities are selected for this purpose during the 11 scheme period and this is supported by the ministry. The prime minister of India has launched the Jawaharlal Nehru National Solar Mission way back in 2010 and set the target of 20GW of the grid-connected

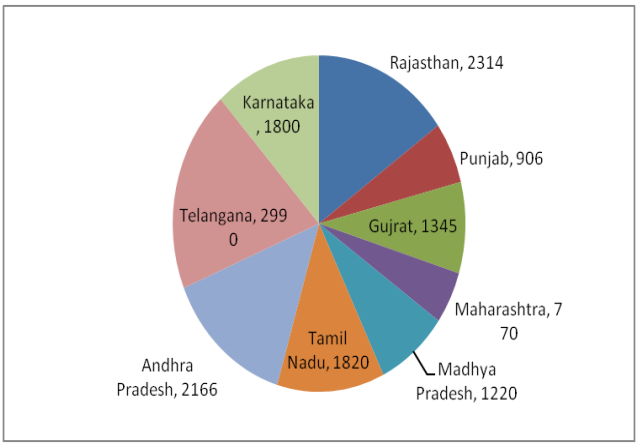

FIGURE 2. Installed solar capacity (in MW) in India.

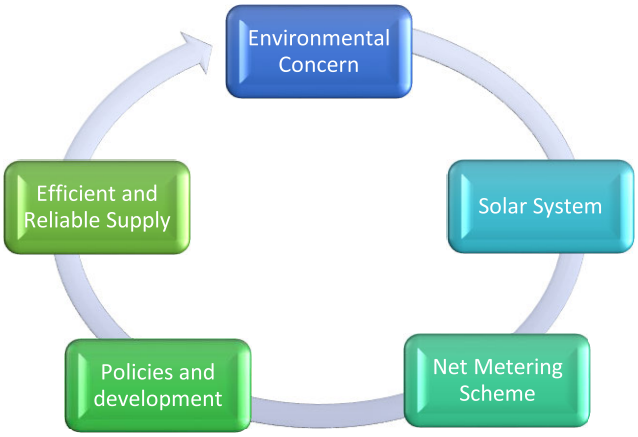

FIGURE 3. Solar energy system development.

TABLE 2. Coal Based Power Plant Retirement Rate in GW.

Description (GW)	2012	2017	2022	2027	2032	2037	2042	2047
Utility	-	(5.5)	(5.5)	(5.5)	(5.5)	(5.5)	(5.5)	(5.5)
Captive	-	(4.8)	(2.6)	(0.8)	(2.2)	(3.1)	(5.7)	-
Total	-	(10.3)	(8.1)	(6.3)	(7.7)	(8.6)	(11.2)	(5.5)

solar system by 2022. The government had revised the target of Solar to 100GW by the year 2022 approved by the cabinet in 2015. To boost the renewables and create the ease of implementation, government has taken many policy measures like net metering policies, formation of international solar alliance, Surya Mitra scheme, etc. Further, the government has made state nodal agencies at states and central level to increase the expansion of efficient energy usage of solar energy. The solar energy systems are expected to become the major source of electricity by the year 2050. Despite having many advantages, solar power system has limitations like not having continuous power generation because of the solar irradiance changing throughout the day. There are efforts going in this direction to make this system reliable. For this, schemes like net metering has been introduced which connects the solar system to the grid. The net Metering is the billing machinery which is sure to overcome the power shortage obstacle. When there is an excess power generated from the solar system, then this is fed to the utility grid. When there is less power available from the solar system, then this power is taken from the grid. This is calculated by the bidirectional meters. This scheme provides less bill, less maintenance, good electricity requirement and require fewer resources.

IV. FEASIBILITY ANALYSIS OF SOLAR TECHNOLOGY IMPLEMENTATION WITH REPLACEMENT OF COAL-BASED PLANT

India has an installed capacity of 374.2 GW as on 31st December 2020 which includes both utilities and captive units. Coal-based power plants has a share of 76% of the total capacity whereas the alternative power plants has a share of 15% of the total capacity. India's infrastructure researchers says that the overall installed capacity of coal-based power plants reached 198 GW in 2018 and the share of coal-based power plants in the total installed capacity has increased during 2012 and 2016. Since then, it has been on the decreasing trend. The carbon emission and integration of renewable energy sources to the utility grid are the main reasons of this decline. Renewable based power sources are expected to have a share of 35% of the total power generation by the year 2022. It is not possible to replace all coal-based power plants with the solar-based plant because of the intermittent and changeable nature of this source. Hence, Base load requirement is to be fulfilled by the coal-based power plants. In this study, India Energy Security Scenario 2047 (IESS 2047) version 2.0 (with updated latest data) (Aayog) has been taken for the analysis. Coal-based power plants have four trajectories. In this analysis, trajectory 2 has been chosen since it is the business as usual scenario in the case of IESS 2047. The parameters taken here are the total capacity, retirement rate, new capacity addition. Table 2 shows the coal-based power plants retirement rate in various years. This depicts the steady retirement rate of coal power plants with each time step [43]. In 2012, 94% Coal power plant installed were operating on subcritical technology. In 2017, 79% Coal power plant installed are operating on subcritical technology while 21% are from super-critical technology. More than 60% of energy demand is fulfilled by the coal-based power plant. In specific, the thermal power plant increases the carbon concentration in the environment and consequently have major contribution in global warming. In India, National thermal power corporation and many other power producing companies are affianced in running coal-based power plants. The coal-based plants cause the pollutants emission and this also contributes to the acid rain as well as air pollution. It is very hard to remove impurities from the coal due to its chemical structure. Although, now coal-based plants produce less pollution than older designed plant due to the new technology implementation. Still, the emission is high which is several times above the normal level. Table 3. depicts the total electricity produced and required in TWh in different years. Table 4. shows the Carbon emission in Mt CO_2 per year which shows that there are large carbon footprints produced by the coal-based power plant harmful to the environment.

Hence there is the need of replacement of the coal-based plant with solar energy system but there are various challenges that needs to be addressed, some of the major ones like technical, managerial, generation, grid-connection, expansion, etc. are as shown in Fig.4. Technical challenges involve the lack of transmission and distribution networks, losses due to transmission, grid maintenance, storage system, etc. Whereas the management and production challenges involve the resource issues, lack of fund and proper land, communication delay, planning, power monitoring, etc. There are some challenges in grid connection and plant expansion like stability issue, synchronization issues, reliability, controlling, lack of effective technology, scheduling, etc. Hence, solar technology implementation involves major challenges to be addressed. Due to the large initial investments in solar energy system, generators prefer coal-based plants. To curb these challenges, government has introduced many schemes to create easy market for this technology. India has huge solar energy potential geographically spread in a different area which is the reason India is taking steps to overcome the challenges.

TABLE 3. Energy produced and required in TWh.

Description	2012	2017	2022	2027	2032	2037	2042	2047
Electricity (supplied to grid)	746.5	1,024.4	1,099.5	1,286.0	1,423.8	1,562.0	1,712.0	1,899.1
Solid hydrocarbons	(2,066.0)	(2,796.6)	(2,987.0)	(3,472.7)	(3,813.5)	(4,124.5)	(4,447.0)	(4,846.5)
Conversion losses	1,254.6	1,683.1	1,791.9	2,074.8	2,265.8	2,426.7	2,586.1	2,782.2
Distribution losses and own use	64.9	89.1	95.6	111.8	123.8	135.8	148.9	165.1

TABLE 4. Carbon emission in Mt CO2/year.

Greenhouse gas	2012	2017	2022	2027	2032	2037	2042	2047
CO2	717.1	970.7	1,036.8	1,205.4	1,323.6	1,431.6	1,543.5	1,682.2

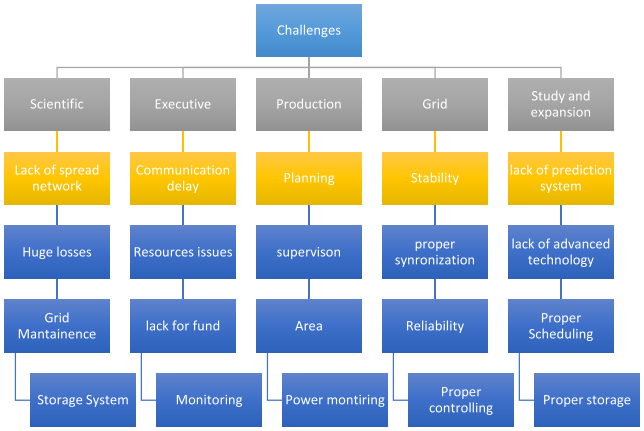

FIGURE 4. Challenges of solar development plant as a replacement a coal-based plant.

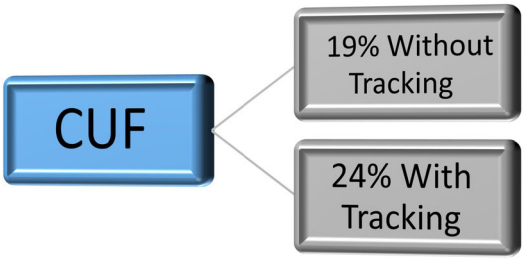

FIGURE 5. CUF with and without tracking system- Ground mounted system.

Various research and development projects are maintained by the research group of various ministries of the different governments and institutions. These entities have an appropriate arrangement for taking these type of projects in the solar energy systems. These solar-based projects are analyzed by the specialists and then sent to the ministry for permission. The ministry have provisions for solar energy based projects and they identify the key areas also that assist in solar energy system according to new renewable energy policy. The ground-mounted solar system generates electricity that is not necessarily used at the same location, but is also supplied to various places through grid connection. Hence, ground-mounted solar systems are centralized type of electricity generation whereas the rooftop solar system is a distributed type of generation of power which is utilized near to its generation point. But there are various reasons to opt the ground-mounted solar system, usually, the cost of the ground-mounted system is a bit higher than the solar rooftop system because of land cost and extra resources needed for the grid connection. Whereas the rooftop solar system depends on the roof characteristics on which they are mounted. If the roof condition is not good then the solar system gives less power. Besides this, the ground-mounted solar system can be mounted where the situations like solar radiations are at its best. Further, if a huge amount of power is required then the ground-mounted system is best suitable for this purpose as it does not have space restrictions. The ideal technical lifetime of the solar system is 25 years with a proper tracking system. The tracking systems can be added in the ground-mounted system with an option of the single or double axis system.

This system is very easy to install because it can be mounted in an open area. They do not need the roof drilling. Many types of research offers the ground mounted system and the cost of this system is same as that of solar rooftop system. The overall generation of the ground-mounted solar system makes the system cost-effective.

In IESS 2047 tool, the solar ground mounted system has four trajectories. In this analysis, trajectory 2 (Business as usual) is chosen. According to this, total installed capacity is considered. Whereas, Table 5 shows the domestic ground mounted solar system new installations. The capacity utilization factor is 24 % with tracking and 19 % without tracking as shown in Fig.5. Table 6 shows the domestic solar system cumulative capacity. Table 7 depicts the Capacity utilization factor and conversion efficiency in Table 8. The Grid-Connected solar power system available supply and generation is show cased in Table 9. The ground-mounted solar system is more productive because they are not dependent on the roof. The angle can be adjusted in the ground-mounted system to optimize the production of energy. Hence there is asubstantial amount of monetary savings. Further ground mounted systems are easy to access for maintenance purpose as well. If there is snowfall in the location then it can be easily swept out in ground-mounted solar system.

TABLE 5. Ground mounted, new capacity addition in GW.

Trajectory	2012	2017	2022	2027	2032	2037	2042	2047
1	0.94	10.9	37.1	26.3	17.2	21.0	18.4	29.0
2	0.94	10.9	59.1	58.1	51.9	70.0	80.9	87.0
3	0.94	10.9	69.1	76.1	74.0	90.0	130.9	157.7
4	0.94	10.9	79.1	92.2	97.8	120.0	175.9	186.0
Chosen	0.94	10.9	59.1	58.1	51.9	70.0	80.9	87.0

TABLE 6. Domestic solar system (in GW) cumulative capacity.

Trajectory	2012	2017	2022	2027	2032	2037	2042	2047
1	0.94	10.9	48.0	74.3	91.5	112.5	130.0	155.0
2	0.94	10.9	70.0	128.1	180.0	250.0	330.0	410.0
3	0.94	10.9	80.0	156.1	230.0	320.0	450.0	600.0
4	0.94	10.9	90.0	182.2	280.0	400.0	575.0	750.0
Chosen	0.94	10.89	70.00	128.15	180.00	250.00	330.00	410.00

TABLE 7. Capacity utilization factor in %.

Plant type	2012	2017	2022	2027	2032	2037	2042	2047
Solar	19.00%	19.10%	19.35%	19.75%	20.25%	20.50%	20.75%	21.00%

TABLE 8. Conversion Efficiency, incident sunlight to electricity.

Plant type	2012	2017	2022	2027	2032	2037	2042	2047
Solar	16%	17%	18%	19%	20%	21%	22%	23%

TABLE 9. Grid-Connecter solar system available supply and generation-Ground Mounted type.

Grid Connected Solar PV	2012	2017	2022	2027	2032	2037	2042	2047
Installed capacity in GW	0.9	10.9	70.0	128.1	180.0	250.0	330.0	410.0
× **Capacity factor %**	19%	19%	19%	19%	20%	20%	20%	21%
= **Available supply GW**	0.2	2.1	13.5	24.9	35.6	50.1	66.8	84.1
Generation in TWh	1.6	18.2	118.0	218.7	311.9	439.0	585.9	737.0

Today, most of the developing countries are increasing their solar installation by installing mainly the rooftop systems. India has been rapidly increasing its rooftop installations with the determination to lower costs. But large scale installation becomes an unintentional obstacle in the installation of rooftop part. India has a target of achieving 40 GW rooftop installations by 2022. Out of these, more than 70 % of the targeted installed systems is for industrial and commercial users and the residential users account for not more than 20% of the cumulative installed capacity. The economics of these systems is the main reason behind the commercial and industrial users preferring the solar rooftop systems. This is mainly due to cost of the solar rooftop based electricity which is lower than the electricity from the grid. Besides, users has the options available from solar energy service companies at competitive prices. But due to large scale installations by the industrial, government and commercial users, the intended residential users have lagged behind in terms of the installation rates. The rooftop systems have low distribution and transmission losses as the power generated is utilized locally. The main components of the rooftop system includes solar modules, installation system, wires, inverters, and other accessories. Solar rooftop systems are small as compared to the ground mounted systems which has the megawatt range capacities. The solar rooftop systems have capacities ranging from 2 KW to 25 kW for residential purposes and generally reaches 100 kW or more for commercial purposes. When these systems generate electricity more than the required demand, then this extra electricity is sold to the utility grid for utilizing it somewhere else in the grid wherever it is needed. This scheme of net metering gives the payback to the investor. As a result of these benefits, many users are focusing

TABLE 10. Trajectory Assumptions.

Number of Households (millions)	2012	2017	2022	2027	2032	2037	2042	2047
Rural	173	181	193	201	211	218	226	219
Urban	74	91	108	126	147	168	192	228
Total	248	272	301	327	358	386	418	447
HH penetration of DSPV in Residential								
	2012	**2017**	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**
Level 1	0.01%	0.3%	5.3%	5.3%	6.0%	8.9%	7.3%	7.9%
Level 2	0.01%	0.3%	6.6%	7.2%	8.7%	13.3%	12.4%	15.4%
Level 3	0.01%	0.3%	7.3%	8.9%	11.4%	16.9%	17.3%	21.8%
Level 4	0.01%	0.3%	8.0%	10.4%	13.6%	21.0%	23.2%	27.8%

TABLE 11. Distributed solar cumulative capacity (GW) - Rooftop scheme.

Trajectory	2012	2017	2022	2027	2032	2037	2042	2047
1	0.03	1.40	32.00	41.89	56.09	74.79	99.78	125.00
2	0.03	1.40	40.00	56.59	81.70	118.29	170.34	250.00
3	0.03	1.40	44.00	69.71	107.59	157.50	235.01	350.00
4	0.03	1.40	48.00	82.05	128.61	201.45	314.92	450.00
Chosen	0.03	1.40	40.00	56.59	81.70	118.29	170.34	250.00

TABLE 12. Capacity utilization factor (%) and land use (M ha/GW).

Capacity utilization factor- Fuel	Plant type	2012	2017	2022	2027	2032	2037	2042	2047
	Solar	16.00%	17.00%	17.25%	17.50%	17.75%	18.00%	18.50%	19.00%
Land Use- Fuel	Plant type	2012	2017	2022	2027	2032	2037	2042	2047
	Solar	0.0048	0.0045	0.0042	0.0040	0.0038	0.0034	0.0033	0.0032

TABLE 13. Grid-Connecter solar system available supply and generation-Rooftop type.

Grid Connected Solar PV	2012	2017	2022	2027	2032	2037	2042	2047
Installed capacity in GW	0.03	1.40	40.00	56.59	81.70	118.29	170.34	250.00
× **Capacity factor in %**	16%	17%	17%	18%	18%	18%	19%	19%
= **Available supply in GW**	0.0	0.2	6.9	9.9	14.5	21.3	31.5	47.5
Generation in TWh	0.0	2.1	60.5	86.8	127.1	186.6	276.2	416.4

on this scheme to profits yielded. There are many technical challenges to have the solar rooftop systems connected to the utility grid such as the reverse flow of power and ramp rates. The utility grid is not for two way flow of power. On the other hand, distribution feeders are of radial type for only one way transmission over the long transmission line. Hence the dual way of transmission of power has significant negative impacts on the protection system. Additionally, the variable nature of solar power generation due to solar irradiance changes causes unwanted voltage inconsistency in the distribution level and this decreases the stability of the grid. These challenges need to be addressed. By the advancement of the technologies, these challenges are being overcome.

In IESS 2047 tool, the solar rooftop system has also four trajectories. In this analysis, trajectory 2 (which is a business as usual) trajectory is chosen. Table 10 shows the trajectory assumptions. Table 11 shows the distributed solar cumulative capacity (GW) - Rooftop scheme and Table 12 shows the capacity utilization factor and land use (M ha/GW). Further, Table 13 shows the grid-Connected solar system available supply and generation-Rooftop type. Generation from the rooftop solar energy systems is expensive in comparison to

the coal-based plant but due to advances in the technology and various schemes, the cost has come down drastically.

V. CASE STUDY

The area selected for this case study is situated in Madhya Pradesh by the name of Singrauli. All the important companies related to energy sector are established in Singrauli. In the recent few years private companies are also situated there. Singrauli has good solar capacity so the scope of implementing the solar energy based power generation system is quite high, it has good average global radiation of the order of 7.6 kWh/m^2/day. An area is selected in Singruali, where around 14500 households are considered to supply the power from solar energy based power generation system. The Vindhyachal Thermal Power Station, Madhya Pradesh is selected for this analysis as the power will be not taken by this plant rather it would be taken by solar based power plant. The installed capacity is 4,760 MW of this coal based plant. Three types of loads are considered i.e. residential, industrial and commercial. The solar based power system is connected to grid which is also supplied by Vindhyachal Thermal Power Station.

For residential loads, 1000 MW solar based power systems is considered whereas commercial and industrial loads, 800 MW and 500 MW solar based power systems are considered. The 1000 MW solar based power systems provides 4000 units/day whereas 800MWand 200MW solar energy based power system provide 3200 units/day and 800 units/day respectively. So there are total 8000 units/day will not be taken from the selected thermal power plant. The life cycle cost of the solar energy systems can be calculated by including the cost of different items and it is presented in Table 14.

The lifetime L is considered 25 years for the solar energy based power generation systems. The net present cost M can be calculated by considering the repairing cost (P/year).

$$M = (P/year) \times \left(\frac{1+i}{1+2c}\right) \times \left(\frac{1-\left(\frac{1+i}{1+c}\right)^N}{1-\left(\frac{1+i}{1+c}\right)}\right)$$

The Overall cost of the proposed systems can be determined by

$$OC = -V_o + (K-O)\sum_{t=1}^{T}\left(\left[1+\left|\frac{c}{100}\right|\right]^{-t} + L_T\left[1+\left(\frac{c}{100}\right)\right]^{-t}\right)$$

where V_o = initial investment, K= annual welfares, O= yearly expenses, d= rate of discount, t=time period, Suppose that the K-O remain constantly in the lifecycle of the system.

If the coal-based plant is replaced with a solar energy based power generation power system in India then there is a decrease in overall CO_2 emissions. If one does not use solar energy system then the emissions increases at a rapid pace which is very dangerous to the environment. Hence coal-based power plant should be replaced with a reliable solar energy based power generation system. Besides, one unit of electricity generation from coal-based plant emits 0.814kg carbon emission. Table 15 shows the Solar based generation in India. This table shows the total generation cumulative capacity which includes solar rooftop and ground-mounted solar power system. Whereas Table 16 shows the carbon emission from the coal-based plant in India. Presently, coal-based plant are generating huge amount of carbon emissions which keeps on increasing day by day. But if this technology is replaced by solar based plant, the overall CO_2 emissions can be minimized significantly because fewer units will have to be taken from the utility grid in that case.

TABLE 14. Cost analysis of solar energy systems for residential, commercial and industrial loads.

System	Life (years)	Expense /year (INR)	Salvage Value(INR)	Overall Cost(INR)
Solar Energy systems for Residentail loads (1000 MW)	25	85065	56409600	86784000
Solar Energy systems for Commertial loads (800MW)	25	78050	45249750	69615000
Solar Energy systems for Industrial loads (500MW)	25	503296	29279250	45045000

- In the year 2012, the numbers of units generated from the coal based plant are 746 TWh.
- Carbon emission from these units in 2012 = 717$MtCo_2$
- Similarly for the year 2017, the carbon emission= 971 $MtCo_2$
- For the year 2022, the carbon emission from the generated units=1037 $MtCo_2$
- For the year 2027, the carbon emission from the generated units=1205 $MtCo_2$
- For the year 2032, the carbon emission from the generated units=1324 $MtCo_2$
- For the year 2037, the carbon emission from the generated units=1432 $MtCo_2$
- For the year 2042, the carbon emission from the generated units=1544 $MtCo_2$
- For the year 2047, the carbon emission from the generated units= 1682 $MtCo_2$

It can be inferred from this analysis that there is the huge amount of carbon emissions from the coal based plant. If these units are drawn from the solar power plant then there will be significant reduction in carbon emission there by reducing global warming.

VI. OUTCOMES AND DISCUSSIONS

National thermal power company and various other power generating corporations are engaged in running

TABLE 15. Electricity Generation from solar-based power in TWh.

Particulars	Unit	2012	2017	2022	2027	2032	2037	2042	2047
Generation from Solar from IESS 2047 Version 3	**TWh**	**2**	**20**	**179**	**306**	**439**	**626**	**862**	**1153**

TABLE 16. Emission from the coal-based plant in Mt CO2 eq.

Particulars	Unit	2012	2017	2022	2027	2032	2037	2042	2047
Coal Based Generation	**TWh**	**746**	**1024**	**1099**	**1286**	**1424**	**1562**	**1712**	**1899**
Emissions Coal Based Generation	**MtCo2 eq.**	**717**	**971**	**1037**	**1205**	**1324**	**1432**	**1544**	**1682**

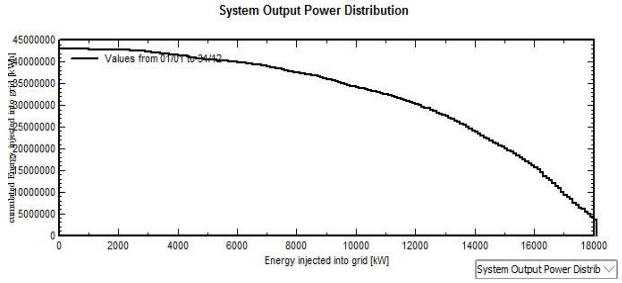

FIGURE 6. System output power distribution.

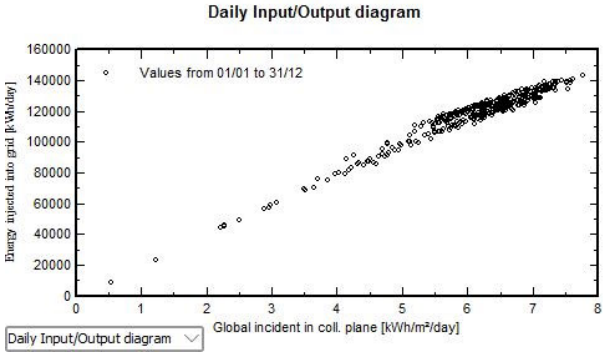

FIGURE 7. Daily input/output power distribution.

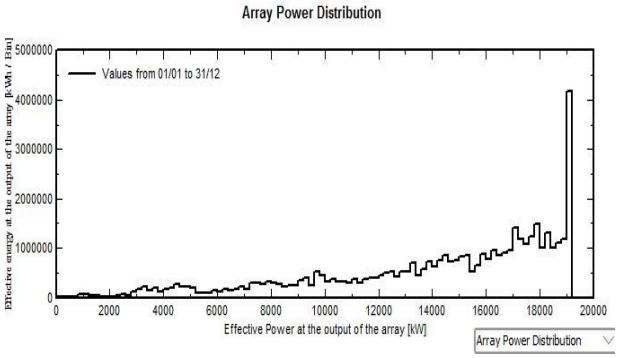

FIGURE 8. Solar array power distribution.

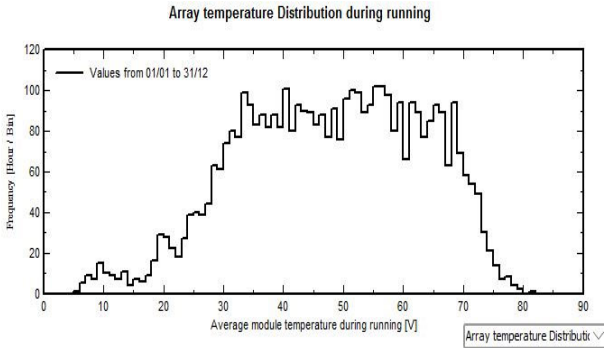

FIGURE 9. Solar array temperature distribution.

thermal-based power plants in India. In specific, the coal-based power plant raises the carbon concentration in the atmosphere and consequently creates global warming which is very harmful for the environment. The coal-based power generating plants releases a huge amount of pollutants in the atmosphere. Hence, it is very hard to remove impurities from such type of coal-based plant because of its chemical structure. Therefore, coal-based power plants needs to be replaced with solar energy based power generation system. If coal power plants generate less units and rest desired units are taken from the solar energy based power generation system then carbon emission will be reduced. This is commonly used these days for reducing the carbon emission in India. The performance of the system is evaluated for the particular location. Solar energy systems output power distribution is shown in fig 6. The cumulative energy injection into the grid is high because of using solar energy systems.

Fig. 7 and fig.8 show the Daily input/output power distribution and solar array power distribution. It shows the distribution is concentrated from 121 to 155 kWhr/day so energy injected into the grid is high specially when the global incident in coil plane is above 5 kWh/m^2/day and it is considerable low when the global incident in coil plane becomes low. By this analysis it is found that the variation is almost linear.

Fig. 9, fig 10 and fig.11 shows the solar array temperature distribution, array temperature verses effective irradiance of the solar array and Energy production from the one module respectively. The performance ratio varies from 0.72 to 0.87. Performance ratio is the ratio of the measured output to the expected output for a particular month. The performance ratio is highest in the month of January followed by February and then December.

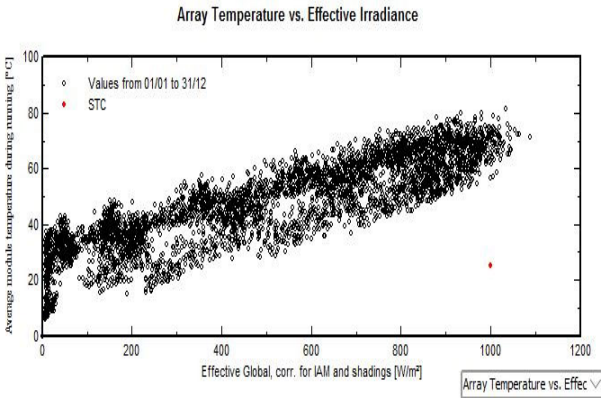

FIGURE 10. Array temperature verses effective irradiance of the solar array.

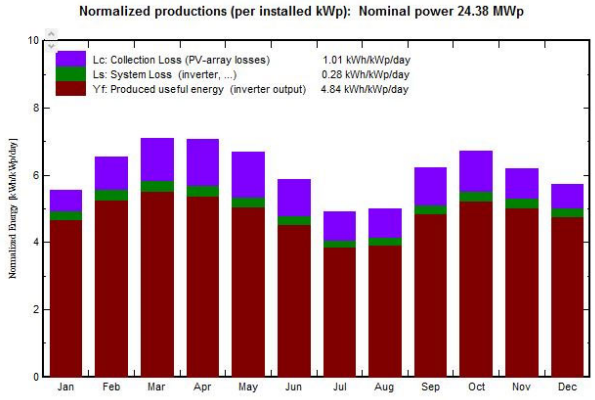

FIGURE 11. Energy production from the one module.

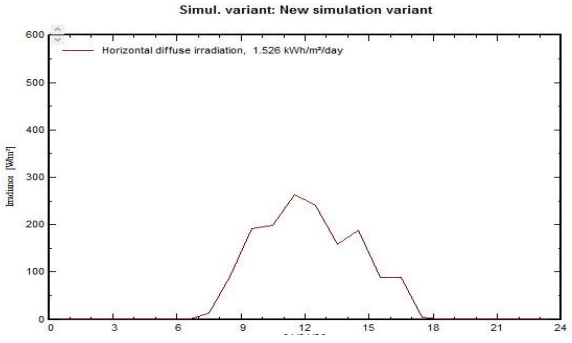

FIGURE 12. Solar irradiance during the day.

Fig. 12 and fig. 13 shows the solar irradiance during the day and global horizontal irradiance and horizontal global clear sky irradiance respectively. It can be seen that the proposed solar energy systems is best suited for Singrauli. As shown by the simulation results that Singrauli has good solar capacity and better solar power distribution capability so the scope of implementing the solar energy system is high, it has good average global radiation such as 7.6 kWh/m^2/day.

The coal-based power plants are designed for large scale power generation and for uninterrupted operation. These plants are installed not only in India but many other countries

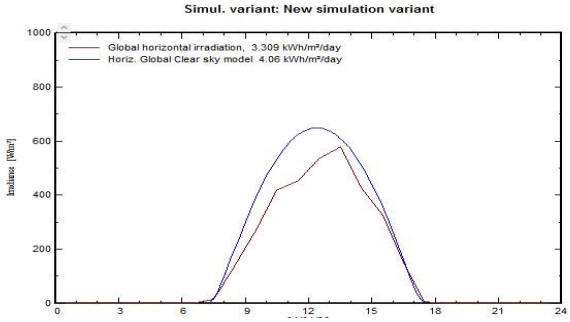

FIGURE 13. Global horizontal irradiance and horizontal global clear sky irradiance.

are also uses such these plants for power generation. The coal-based power plants have equipment to change the heat energy of the coal combustion into the mechanical energy and then this energy is used to operate the electrical generator. The carbon emission is the major emitter from the coal-based power plant, which is the main cause of global warming. The world health organization and many other related agencies are worried about the atmospheric effects of burning coal. The coal combustion gives the main pollution and acid rains. The acid rains are mainly cause by the different pollutants from burning of the coal. In United States of America, exacting lows of emission and reject in huge companies have decreased the atmospheric hazards related to the problem. But in India, there is huge amount of electricity needed, then it would be quite difficult to replace all coal-based plant with renewable-based power plant because of the intermittent nature of these resources. Although, initiative should be taken to replace some amount of coal based power plant because of technological advancement, the solar power systems have now high efficiency and reliability. It is quite difficult to replace all coal based power plant, but some percent of coal based plant can be replaced with solar energy based power generation system so that, carbon emissions can be reduced. In this analysis, there are two cases of coal based power plant replacement with solar energy based power generation system. In the first case 50% of coal based power plants are replaced with solar based power plant as shown in Table 16 and fig 15. In this case, in 2012 solar generation is 354TWh and coal generation is 354 TWh, the total energy needed is 708TWH as shown in Table 15. Earlier the carbon emission is reduced by 123 $MtCo_2$. Similarly, in 2017, 2011,2027,2037,2042 and 2047 the carbon reductions are 167$MtCo_2$,222$MtCo_2$,213$MtCo_2$,207$MtCo_2$,203$MtCo_2$, 19$MtCo_2$, and 186 $MtCo_2$ respectively. This shows the huge amount of carbon emissions reduction.

In the first case 50% of coal based power generation units are replaced with solar based generation units as shown in Table 17 and Figure.. In 2012,Coal based generation units replaced by solar generation is 373 TWh which results in reduction of carbon emission by 130$MtCo_2$. Similarly, in 2017, 2022, 2027, 2037,2042 and 2047 the carbon reductions are by 178$MtCo_2$, 191$MtCo_2$, 223$MtCo_2$,

TABLE 17. Case I - 50% of coal generation replaced by solar based generation.

Particulars	Unit	2012	2017	2022	2027	2032	2037	2042	2047
Solar Generation Replacing Coal generation	**TWh**	373	512	550	643	712	781	856	950
New Coal Generation	**TWh**	373	512	550	643	712	781	856	950
Emission Reduction	**MtCo2 eq.**	-130	-178	-191	-223	-247	-271	-297	-330

TABLE 18. Case II- 25 % of coal generation replaced by solar based generation.

Particulars	Unit	2012	2017	2022	2027	2032	2037	2042	2047
Electricity Demand	TWh	1041	1334	1818	2245	2773	3370	4002	4596
% Solar to fulfill electricity Demand	-	25%	25%	25%	25%	25%	25%	25%	25%
% Coal to fulfill electricity Demand	-	75%	75%	75%	75%	75%	75%	75%	75%
Electricity Generation from Solar to meet Electricity Demand	TWh	260	334	455	561	693	842	1000	1149
Electricity Generation from Coal to meet Electricity demand	TWh	781	1001	1364	1684	2080	2527	3001	3447
Emissions from 100% Coal	MtCo2 eq.	361	463	631	779	963	1170	1389	1595
Emissions from Coal at input % share	MtCo2 eq.	271	347	473	584	722	877	1042	1196
Emissions Reduction	MtCo2 eq.	-90	-116	-158	-195	-241	-292	-347	-399

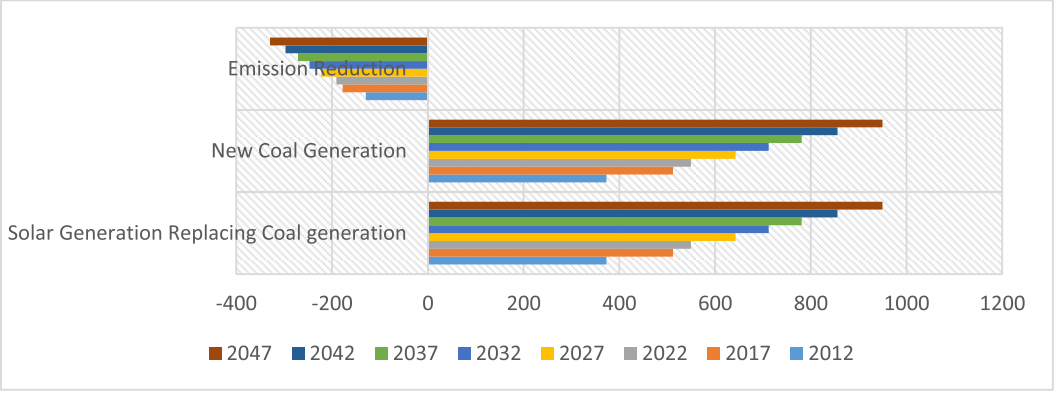

FIGURE 14. Carbon emission reduction with 50% replacement of coal based power generation with solar based generation.

247MtCo$_2$, 271MtCo$_2$, 297MtCo$_2$, and 330MtCo$_2$ respectively. This shows the huge amount of carbon emission reduction. Although there are various technical challenges involved in the replacement of coal based power plant such as power grid structure, grid care, transmission and distribution losses, storage scheme, converter technology, power tracking schemes, solar panels efficiency, costs, lack of funding, appropriate land, planning, etc. But, the government initiatives are overcoming these challenges. Government of India has introduced various schemes and allowed consumers to use the solar energy based system rigorously. This can be overcome easily in India since it has the abundant potential of solar energy which is geographically spread in a wide area.

In the Second case, 25% of electricity demand (Aayog) is met by solar based generation while 75% is met by coal based power generation. Emission reduction in this is compared with the case of 100% generation from coal to meet the demand. From Table 18 and Fig 15. It is inferred that the reduction of carbon emission in 2012 is by 90MtCo$_2$. Similarly, in 2017, 2022, 2027, 2037,2042 and 2047 the carbon emission reductions are by 116MtCo$_2$, 158MtCo$_2$, 195MtCo$_2$, 241MtCo$_2$, 292MtCo$_2$, 347MtCo$_2$ and 399MtCo$_2$ respectively. This shows the huge amount of carbon emission reduction.

In recent years, the government has given the loan facility for solar photovoltaic rooftop system installations through its various schemes for solar systems. The solar photovoltaic rooftop system provides various advantages to residential users and to the main grid. The solar photovoltaic rooftop systems results in lesser electricity bill for the households. Further, it reduces the carbon emission from the thermal power plant because these units is not required to be purchased from

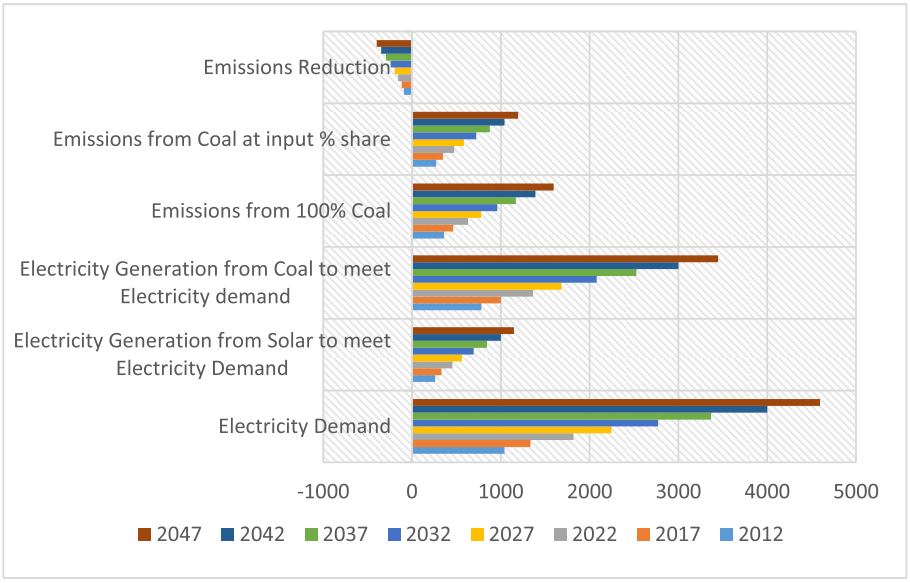

FIGURE 15. Carbon emission reduction with 25% replacement of coal based power plant with solar power system.

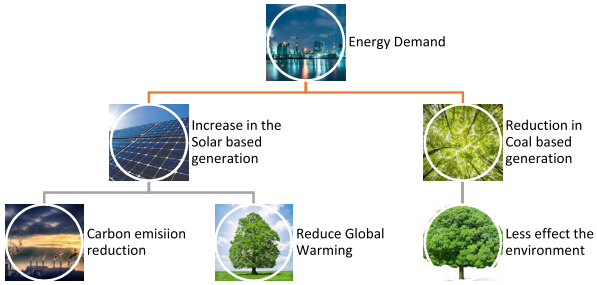

FIGURE 16. Energy demand fulfill by the coal ad solar based plants.

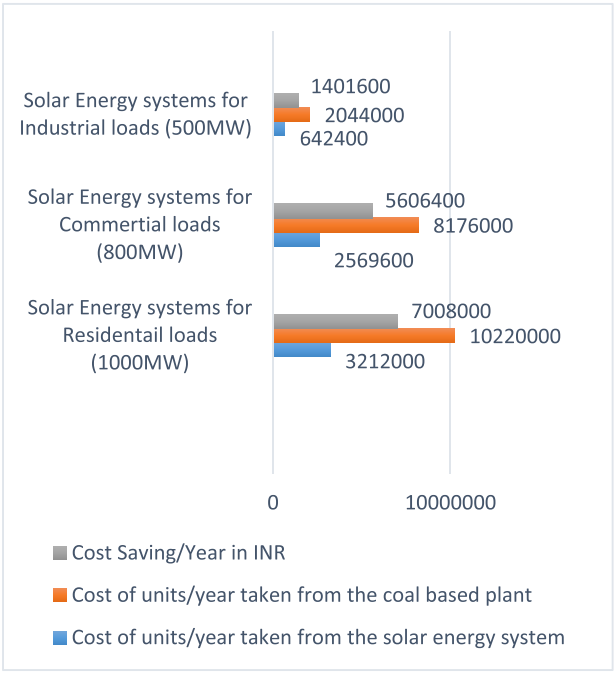

FIGURE 17. Cost saving/year in INR.

thermal power plants via grid network. The installation of the rooftop solar panel is easy since it involves solar panels assembling, wiring, solar panel and inverter connection, solar inverter and battery connection, inverter and grid connection.

The grid-connected solar power projects at isolated locations assists in satisfactory policy of tariffs recognized by the state regulatory commission in India. Whereas the solar system gives the chance to provide power on a circulated basis and allow fast capacity involvement in a short time. The off-grid solar system is beneficial for rural area electrification and meeting extra requirement of electricity for power in urban and rural areas. The solar system is the main reliable source among the all alternative energy sources in the energy security point of view. Subsequently, it is easily accessible and readily available. The solar energy system when used as a replacement of coal based plant making is environment friendly energy source to fulfill energy demand as shown in Fig.16. Rooftop solar energy system increases the efficiency as well since it incur less losses due to presence of load nearest to the solar system set up. Use of this type of systems reduces the demand on the utility grid. At the same time, solar rooftop panel can be connected to the DC appliance without using the inverter circuit which further reduces the losses. On the other hand, Ministry also promotes the grouping of the solar energy system and the residential buildings, to give the desired conditions for the energy uses throughout the construction and design. Furthermore, for technological improvement, research and development team comprises the strategies. Although, the research needs somewhat long time for the advancement of the new processes and tenders.

Although, these replacements involves addressing the challenges associated with the technology, its initial investment for solar energy system installation still demotivate the users to switch over from coal-based plants to solar energy based

power generation system. But this is gradually getting overcome by different policies/schemes initiated by the ministry in India. It can be said, that use of solar based generation can reduce the carbon emission as well as global warming. Further there is the gradual improvement in average fleet CUF from 19% in 2012 to 20.5% in 2047 due to increased use of tracking systems. By 2032, 25% of new installations are being installed with tracking systems while by 2047, nearly 40% of new installations arebeing installed with tracking. Hence, solar energy system also improves the CUF with the advancement in the tracking system, which is another major advantage of this technology.

Furthermore, the cost of 1460000 units/year generated from the solar energy system for residential load is 3212000. The cost of 1168000 units/year for the commertail loads would be 2569600 INR and the cost of 292000 units/year for the industrial loads would be 642400 INR. Whereas the cost of same units purchased from the Vindhyachal Thermal Power Station, Madhya Pradesh through grid is higher than this i.e10220000INR, 8176000 INR, 2044000INR respectively. Hence, the solar energy systems for residential, commercial and industrial loads in the Singruali give the huge saving as shown in fig. 17.

VII. CONCLUSION

A feasibility analysis of solar technology implementation with the replacement of coal based power plant was carried out for Singrauli, India. With the support of the government's policies and schemes, supervisory agenda and financial incentives, the solar energy based power generation system is expected to emerge as a major energy source in India's total energy mix. While the cost of solar energy based power generation is decreasing continuously with advancement in solar panel technology as result of which many issues are getting addressed. Analysis shows that the coal-based power plant generates a huge amount of carbon footprints and it can be reduced with the replacement of it with solar energy based power generation system. Consequently solar energy based power generation system is a key alternative for developing countries like India having similar metrological parameters with the capacity to provide an improved supply, decreased global warming and improve the energy security. Further, there is the gradual enhancement in average fleet CUF from 19% in 2012 to 20.5% in 2047 due to improved use of tracking systems. Further, it is observed that the proposed solar energy based power generation system is best suited for places like Singrauli. As indicated by the results presented in this paper the Singrauli area has good solar power generation capacity so the prospects of implementing the solar energy based power generation system are quite bright for places having similar metrological parameters.

REFERENCES

[1] N. K. Sharma, P. K. Tiwari, and Y. R. Sood, "Environmental friendly solar energy in restructured indian power sector," in *Proc. Int. Conf. Sustain. Energy Intell. Syst. (SEISCON)*, 2011, pp. 104–109.

[2] H. B. Azad, S. Mekhilef, and V. G. Ganapathy, "Long-term wind speed forecasting and general pattern recognition using neural networks," *IEEE Trans. Sustain. Energy*, vol. 5, no. 2, pp. 546–553, Apr. 2014.

[3] S. Upadhyay, D. P. Kothari, and U. Shanker, "Renewable energy technologies for cooking: Transforming rural lives," *IEEE Technol. Soc. Mag.*, vol. 32, no. 3, pp. 65–72, Fall 2013.

[4] K. Momaya and S. Chachondia, "Review of industrial competitiveness and growth of solar firms in India: Exploring role of technology management and policy," in *Proc. Conf.: Portland Int. Center Manage. Eng. Technol.; Infrastruct. Service Integr.*, Jul. 2014, pp. 370–385.

[5] N. Forouzandehmehr, Z. Han, and R. Zheng, "Stochastic dynamic game between hydropower plant and thermal power plant in smart grid networks," *IEEE Syst. J.*, vol. 10, no. 1, pp. 88–96, Mar. 2016.

[6] J. M. Foster, G. Trevino, M. Kuss, and M. C. Caramanis, "Plug-in electric vehicle and voltage support for distributed solar: Theory and application," *IEEE Syst. J.*, vol. 7, no. 4, pp. 881–888, Dec. 2013.

[7] H. Oh, "Optimal planning to include storage devices in power systems," *IEEE Trans. Power Syst.*, vol. 26, no. 3, pp. 1118–1128, Aug. 2011.

[8] L. F. Ramos, C. Kruger, and F. A. Farret, "Economical feasibility of alternative sources as secondary means for electricity generation in Brazilian gas stations," *IEEE Latin Amer. Trans.*, vol. 14, no. 4, pp. 1717–1723, Apr. 2016.

[9] D. Roy, U. K. Rout, S. Jonalagadda, and P. Behera, "A brief analysis on solar status of India," in *Proc. Int. Conf. Innov. Mech. Ind. Appl. (ICIMIA)*, Feb. 2017, pp. 451–456.

[10] V. Sharma, U. Mukherji, V. Joseph, and S. Gupta, "Optimal energy management policies for energy harvesting sensor nodes," *IEEE Trans. Wireless Commun.*, vol. 9, no. 4, pp. 1326–1336, Apr. 2010.

[11] I. R. Cole and R. Gottschalg, "Improved model for circumsolar irradiance calculation as an extended light source and spectral implications for high-concentration photovoltaic devices," *IEEE J. Photovolt.*, vol. 6, no. 1, pp. 258–265, Jan. 2016.

[12] S. K. Tiwari, B. Singh, and P. K. Goel, "Design and control of autonomous wind–solar system with DFIG feeding 3-phase 4-wire loads," *IEEE Trans. Ind. Appl.*, vol. 54, no. 2, pp. 1119–1127, Mar./Apr. 2018.

[13] A. Jhunjhunwala and P. Kaur, "Solar energy, DC distribution, and microgrids: Ensuring quality power in rural India," *IEEE Electrific. Mag.*, vol. 6, no. 4, pp. 32–39, Dec. 2018.

[14] C. J. R. Sheppard, A. Harris, and A. R. Gopal, "Cost-effective siting of electric vehicle charging infrastructure with agent-based modeling," *IEEE Trans. Transp. Electrific.*, vol. 2, no. 2, pp. 174–189, Jun. 2016.

[15] C. Lavania, S. Rao, and E. Subrahmanian, "Reducing variation in solar energy supply through frequency domain analysis," *IEEE Syst. J.*, vol. 6, no. 2, pp. 196–204, Jun. 2012.

[16] S. Kalyanaraman, "Back to the future: Lessons for Internet of energy networks," *IEEE Internet Comput.*, vol. 20, no. 1, pp. 60–65, Jan. 2016.

[17] T. S. Babu, J. P. Ram, T. Dragicevic, M. Miyatake, F. Blaabjerg, and N. Rajasekar, "Particle swarm optimization based solar PV array reconfiguration of the maximum power extraction under partial shading conditions," *IEEE Trans. Sustain. Energy*, vol. 9, no. 1, pp. 74–85, Jan. 2018.

[18] J. J. John, S. Warade, G. Tamizhmani, and A. Kottantharayil, "Study of soiling loss on photovoltaic modules with artificially deposited dust of different gravimetric densities and compositions collected from different locations in India," *IEEE J. Photovolt.*, vol. 6, no. 1, pp. 236–243, Jan. 2016.

[19] U. K. Kalla, B. Singh, S. S. Murthy, C. Jain, and K. Kant, "Adaptive sliding mode control of standalone single-phase microgrid using hydro, wind, and solar PV array-based generation," *IEEE Trans. Smart Grid*, vol. 9, no. 6, pp. 6806–6814, Nov. 2018.

[20] S. Kumar Tiwari, B. Singh, and P. K. Goel, "Design and control of microgrid fed by renewable energy generating sources," *IEEE Trans. Ind. Appl.*, vol. 54, no. 3, pp. 2041–2050, May 2018.

[21] N. R. Tummuru, M. K. Mishra, and S. Srinivas, "Dynamic energy management of hybrid energy storage system with high-gain PV converter," *IEEE Trans. Energy Convers.*, vol. 30, no. 1, pp. 150–160, Mar. 2015.

[22] S. Chattopadhyay, R. Dubey, V. Kuthanazhi, J. J. John, C. S. Solanki, A. Kottantharayil, B. M. Arora, K. L. Narasimhan, V. Kuber, J. Vasi, A. Kumar, and O. S. Sastry, "Visual degradation in field-aged crystalline silicon PV modules in india and correlation with electrical degradation," *IEEE J. Photovolt.*, vol. 4, no. 6, pp. 1470–1476, Nov. 2014.

[23] A. Aggarwal, A. Singhal, and S. J. Darak, "Clean and green India: Is solar energy the answer?" *IEEE Potentials*, vol. 37, no. 1, pp. 40–46, Jan. 2018.

[24] S. Kirmani, M. Jamil, and I. Akhtar, "Economic feasibility of hybrid energy generation with reduced carbon emission," *IET Renew. Power Gener.*, vol. 12, no. 8, pp. 934–942, Jun. 2018.
[25] R. Kaur, V. Krishnasamy, and N. K. Kandasamy, "Optimal sizing of wind-PV-based DC microgrid for telecom power supply in remote areas," *IET Renew. Power Gener.*, vol. 12, no. 7, pp. 859–866, 2018.
[26] R. Kamphuis, S. Galsworthy, and M. Stifter, "Integrating demand flexibility with distributed generation–renewable energy sources (DG-RES) at the residential household and commercial customer level in electricity grids," *CIRED-Open Access Proc. J.*, vol. 2017, no. 1, pp. 1827–1830, 2017.
[27] C. Edwards, "The 100 percent solution [renewable energy]," *Eng. Technol.*, vol. 11, no. 11, pp. 38–41, Dec. 2016.
[28] D. Manz, R. Walling, N. Miller, B. LaRose, R. D'Aquila, and B. Daryanian, "The grid of the future: Ten trends that will shape the grid over the next decade," *IEEE Power Energy Mag.*, vol. 12, no. 3, pp. 26–36, May 2014.
[29] A. Jhunjhunwala, A. Lolla, and P. Kaur, "Solar-dc microgrid for Indian homes: A transforming power scenario," *IEEE Electrific. Mag.*, vol. 4, no. 2, pp. 10–19, Jun. 2016.
[30] J. Michal, "Power/energy: TVA's Freeman settles in," *IEEE Spectr.*, vol. 15, no. 9, pp. 64–65, Sep. 1978.
[31] Q. Luo, K. B. Ariyur, and A. K. Mathur, "Control-oriented concentrated solar power plant model," *IEEE Trans. Control Syst. Technol.*, vol. 24, no. 2, pp. 623–635, Mar. 2016.
[32] L.-Y. Chen, Y.-T. Yin, T.-Y. Ho, and Y.-Z. Chen, "Sensitized solar cells via nanomaterials: A recent development in quantum dots-based solar cells," *IEEE Nanotechnol. Mag.*, vol. 8, no. 2, pp. 16–21, Jun. 2014.
[33] G. Kaplan, "Power/energy: I. Efficient devices/systems: Utilities explore new means to cut energy losses during transmission and distribution," *IEEE Spectr.*, vol. 18, no. 1, pp. 74–77, Jan. 1981.
[34] J. Parikh and K. Parikh, "Growing pains: Meeting India's energy needs in the face of limited fossil fuels," *IEEE Power Energy Mag.*, vol. 10, no. 3, pp. 59–66, May 2012.
[35] D. Abbott, "Keeping the energy debate clean: How do we supply the World's energy needs?" *Proc. IEEE*, vol. 98, no. 1, pp. 42–66, Jan. 2010.
[36] W. Sweet and M. Hood, "Can China consume less coal?" *IEEE Spectr.*, vol. 36, no. 11, pp. 39–47, Nov. 1999.
[37] W. B. Riley, "Southern California edison bets on energy alternatives," *IEEE Spectr.*, vol. 18, no. 8, pp. 40–45, Aug. 1981.
[38] H. Hayami, M. Nakamura, and K. Yoshioka, "The life cycle CO_2 emission performance of the DOE/NASA solar power satellite system: A comparison of altenative power generation systems in Japan," *IEEE Trans. Syst. Man Cybern. C Appl. Rev.*, vol. 35, no. 3, pp. 391–400, Jan. 2005.
[39] A. De, A. Choudhary, and M. K. Tiwari, "Multiobjective approach for sustainable ship routing and scheduling with draft restrictions," *IEEE Trans. Eng. Manag.*, vol. 66, no. 1, pp. 35–51, Feb. 2019.
[40] P. Sanjeev, N. P. Padhy, and P. Agarwal, "Peak energy management using renewable integrated DC microgrid," *IEEE Trans. Smart Grid*, vol. 9, no. 5, pp. 4906–4917, Sep. 2018.
[41] S. K. Reddy, L. K. Panwar, B. K. Panigrahi, and R. Kumar, "Modeling of carbon capture technology attributes for unit commitment in emission-constrained environment," *IEEE Trans. Power Syst.*, vol. 32, no. 1, pp. 662–671, Jan. 2017.
[42] I. Akhtar, S. Kirmani, and M. Jamil, "Analysis and design of a sustainable microgrid primarily powered by renewable energy sources with dynamic performance improvement," *IET Renew. Power Gener.*, vol. 13, no. 7, pp. 1024–1036, May 2019.
[43] I. Akhtar and S. Kirmani, "Flexible hybrid system power quality improvement using advanced control architecture," *J. Intell. Fuzzy Syst.*, vol. 37, no. 4, pp. 5335–5350, Oct. 2019.
[44] C. Bhattacharjee and B. K. Roy, "Advanced fuzzy power extraction control of wind energy conversion system for power quality improvement in a grid tied hybrid generation system," *IET Gener., Transmiss. Distrib.*, vol. 10, no. 5, pp. 1179–1189, Apr. 2016.
[45] M. Hamouda, H. F. Blanchette, and K. Al-Haddad, "A hybrid modulation scheme for dual-output five-leg indirect matrix converter," *IEEE Trans. Ind. Electron.*, vol. 63, no. 12, pp. 7299–7309, Dec. 2016.
[46] D. Q. Dang, Y.-S. Choi, H. H. Choi, and J.-W. Jung, "Experimental validation of a fuzzy adaptive voltage controller for three-phase PWM inverter of a standalone DG unit," *IEEE Trans. Ind. Informat.*, vol. 11, no. 3, pp. 632–641, Jun. 2015.
[47] *India Energy Securtiy Scenario 2047 Version 2.0*, Nat. Inst. Transforming India, Government India, New Delhi, India, 2015.

IRAM AKHTAR received the B.Tech. degree in electrical engineering from the Babu Banarasi Das National Institute of Technology and Management (BBDNITM), Lucknow, in 2010, the M.Tech. degree in power electronics and drives from Madan Mohan Malaviya University of Technology (Formerly Madan Mohan Malaviya Engineering College), Gorakhpur, in 2012, and the Ph.D. degree in electrical engineering from Jamia Millia Islamia (A Central University), New Delhi, India, in 2020.

She has published/presented more than 25 papers in various international journals/conferences. Her current research interests include new and renewable energy sources (solar and wind), resource assessment, smart grids, distributed generation, grid integration of renewable energy sources, application of intelligent techniques to electrical power systems, smart grid, and reactive power compensation.

SHEERAZ KIRMANI received the B.Tech. degree in electrical engineering from Aligarh Muslim University (A Central University), Aligarh, India, in 2005, the M.Tech. degree in energy studies from the Indian Institute of Technology Delhi, in 2007, and the Ph.D. degree in the area of distributed solar power generation from Jamia Millia Islamia (A Central University), New Delhi, India, in 2014.

Since December 2020, he has been working as an Associate Professor with the Department of Electrical Engineering, Aligarh Muslim University. Earlier, he has worked with the Department of Electrical Engineering, Jamia Millia Islamia (A Central University), and the Department of Energy and Environment, TERI University, New Delhi. He has published/presented many papers in various peer-reviewed international journals and conferences. He has also visited The Open University, Milton Keynes, U.K., under UKIERI grant. His research interests include smart grids, distributed generation, and grid integration of renewable energy sources.

Dr. Kirmani is also a Life Member of ICTP.

MOHAMMED JAMEEL received the Ph.D. degree from IIT Delhi, India. He worked with the University of Malaya, Malaysia, for eight years. He is a Charted Engineer and also affiliated to several international professional bodies. He has supervised 12 Ph.D. students. He received research funds USD 0.5 million from various agencies. He published more than 100 research articles in high impact ISI (SCI) international journals. He is having around 1750 citations and his H-index is 21. His research interests include risk and reliability assessment, ANN, structural health monitoring, and offshore structures. During his career he received Award of Excellence in teaching.

FARAZ ALAM received the master's degree in energy systems from the University of Petroleum and Energy Studies, Dehradun. He is currently an Energy Professional with experience in executing projects in the area of Energy and Climate Change. He had worked on various projects related to energy efficiency in buildings and industries in the initial phase of my career. Post that, he was associated with The Celestial Earth, Gurgaon, conducting Energy Systems Analysis and developing long term low carbon pathways for countries and states using quantitative techniques and Energy systems model. He is also working as a Manager-Research and Policy (Energy and Power sector) with the Vasudha Foundation, responsible for deepening the foundation's work in research and analysis of policies and regulatory issues in energy and power sector. This also includes the development of new programmes in the energy and power sector space.