International Journal of Social Sciences Bulletin
Volume 2, Issue 4, 2024 ISSN: (E) 3007-1917 (P) 3007-1909

USING FUZZY LOGIC IN SOLAR POND AND PARABOLIC TROUGH COLLECTOR TECHNOLOGIES FOR POWER GENERATION PREDICTION: A CASE STUDY OF KHUZDAR REGION.

Ghulam Nabi[1], Abdullah Mengal[2], Naseer Ahmed[3]

[,1,2]Department of Mechanical Engineering, Balochistan University of Engineering & Technology, Khuzdar 89120, Pakistan
[3]Department of Computer Science, Balochistan University of Engineering & Technology, Khuzdar 89120, Pakistan

[3]naseerbajoi@gmail.com

Corresponding Author: *

Received	Revised	Accepted	Published
12 October, 2024	12 November, 2024	22 November, 2024	28 November, 2024

ABSTRACT
World is facing difficulties dealing with energy crisis due to the depletion of fossil fuels and other constraints like cost. In the current scenario, globally power generation is necessary for industrial and economic development, so efforts are required to be made to find out the ways to replace fossil fuels with more environmental-friendly alternatives. In today's era, renewable energy is considered a viable option as an alternative energy source. Solar Energy use for power generation is an area of research which has gained more popularity in recent times. Out of many options, Solar Pond and Parabolic Trough have been selected for this work. Researchers have argued that variations in the solar data cause ambiguities in the data. A review has been presented on the recent works on application of solar pond and parabolic trough technology in this area. Besides that, potential use of these technologies in Khuzdar region, a remote area of Pakistan has been described. Review shows that remote areas of Balochistan province especially Khuzdar region is very much feasible to use solar energy as replacement of conventional power generation resources with a focus on solar pond and parabolic trough collector technologies of renewable energy. To deal with this, fuzzy logic field of Artificial Intelligence has been selected to represent the ambiguities found in the solar data in terms of prediction of power generation ultimately beneficial in efficient solar pond and Parabolic Trough Collector Design suited to areas like Khuzdar where solar irradiance is very high. Three parameters namely Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI) and Diffused Horizontal Irradiance (DHI) have been selected. The data set used for the investigation has been taken from BUET Khuzdar weather station for the Khuzdar region for the years 2022 and 2023. This region has very high solar irradiance. A fuzzy Inferencing system has been generated with the help of these input variables. Each variable has been divided into three membership functions namely low, medium, and high. A rule set has been created which after Inferencing provides the output as power prediction with fuzzy values. Mamdani-type fuzzy Inferencing has been used. The output of the system is power prediction. Analysis has been done of the three data sets. The analysis shows that a developed fuzzy system can capture the complexities and variabilities of the data sets. It has also been discussed that the findings can be used for efficient power generation design by integrating fuzzy systems with solar ponds and parabolic trough collector technologies. Future work also mentions the potential use of Artificial Intelligence-based techniques to be used for solving problems related to power generation through solar energy.

Keywords: *Energy Crisis, Solar Energy, Solar Pond, Parabolic Trough, Fuzzy Logic, Power Prediction.*

INTRODUCTION

Renewable Energy (RE) application is an area of research that is gaining appreciation throughout the world. Electrical power systems are crucial for the economic development of any country. Now a day's most countries are interested in power generation from RE Sources. Alternative energy sources provide an environmentally friendly way for electricity generation [1]. Earth's temperature will keep on increasing if traditional sources are continued in the energy sector which can catastrophically damage the environment and can cause hazards. Solar technology can be used for electricity generation in multiple ways. One way is a Photovoltaic (PV) cell where solar energy is directly converted to electricity through a photovoltaic process. Another method is using Solar thermal technology where solar is used as a heating source and a receiver is used to capture the concentrated sunlight [2] . Solar Ponds and Parabolic Trough Collector (PTC) are related to solar thermal technology. Renewable energy (RE) sources are pivotal in addressing the global energy crisis and mitigating the adverse environmental effects of conventional fossil fuels [3] This paradigm shift towards sustainable energy generation has garnered significant attention, particularly in regions with abundant solar resources, like Khuzdar, Balochistan [4]. Solar energy technologies, including photovoltaic (PV) cells and solar thermal systems, offer promising avenues for harnessing this abundant resource PV cells directly convert sunlight into electricity, while solar thermal systems utilize concentrated sunlight for heating applications [5]Among solar thermal technologies, solar ponds and parabolic trough collectors (PTCs) have emerged as viable options for power generation [6]. Despite their potential, solar energy systems face challenges related to variability and uncertainty in solar radiation, which can impact their performance and efficiency[7]. To address this issue, researchers have explored various prediction and optimization techniques, including artificial intelligence (AI) [8]logic, a branch of AI, has proven effective in handling uncertainties and vagueness in solar radiation data, enabling more accurate power generation predictions [9], [10] This, in turn, facilitates the design of optimized solar pond and PTC systems tailored to specific geographical locations .[11] The integration of AI and solar energy technologies holds the promise of unlocking the full potential of solar power for sustainable and reliable electricity generation [12].

Part 2

Renewable energy (RE) sources are pivotal in addressing the global energy crisis and mitigating the adverse environmental effects of conventional fossil fuels [13]. This paradigm shift towards sustainable energy generation is particularly crucial for countries like Pakistan, which are grappling with energy shortages and seeking to reduce their carbon footprint [14].

Pakistan, with its abundant solar resources, particularly in regions like Khuzdar, Balochistan, possesses immense potential for solar energy utilization [15]. This research directly supports Pakistan's energy sector by focusing on solar energy technologies, including photovoltaic (PV) cells and solar thermal systems, as viable alternatives to traditional fossil fuels [16]. PV cells directly convert sunlight into electricity, while solar thermal systems utilize concentrated sunlight for heating applications [17]. Among solar thermal technologies, solar ponds and parabolic trough collectors (PTCs) have emerged as promising options for power generation in regions with high solar irradiance [18].

Despite their potential, solar energy systems face challenges related to variability and uncertainty in solar radiation, which can impact their performance and efficiency [19]. This research aims to enhance the efficiency and reliability of solar energy systems in Pakistan by addressing these challenges through the application of artificial intelligence (AI), specifically fuzzy logic . By developing a fuzzy inference system to predict power generation based on solar radiation data, this study can contribute to the design of optimized solar pond and PTC systems tailored to the specific conditions in regions like Khuzdar [20]. The integration of AI and solar energy technologies, as explored in this research, aligns with

Pakistan's goals of diversifying its energy mix and promoting sustainable development [21]-[22].

I. LITERATURE REVIEW

A. Solar Potential of Pakistan.

Solar energy has high potential as a RE source throughout the world including Pakistan. Authors in [23] found that trend of using solar energy as renewable energy resource is on the rise around the world and both developed and under-developed countries are making efforts to use this as an alternative to conventional energy resources which is healthier in terms of environment as well. The solar power development based on research is shown in Figure 1.

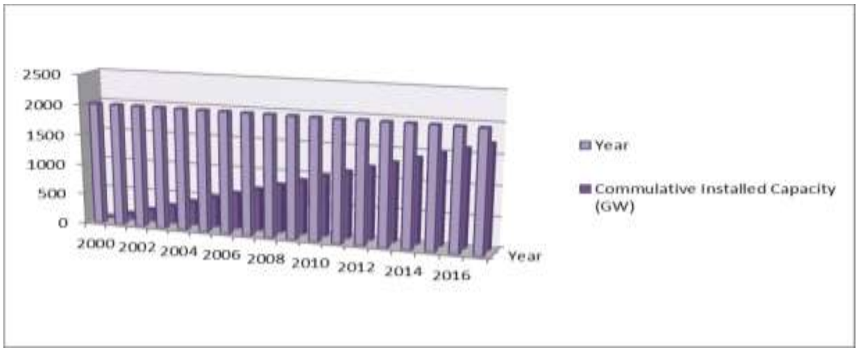

Figure 1 Chart Representing Year-Wise Solar Development [24]

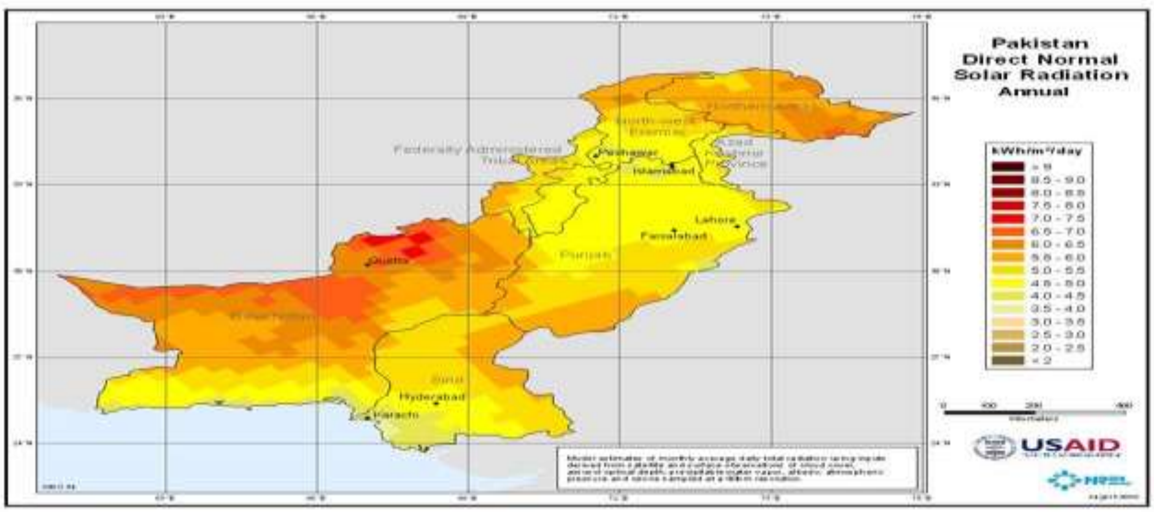

Figure 2 Pakistan Solar Irradiation Map [2]

In [2], authors have looked at trends for application of renewable energy sources as potential solution for power crisis in Pakistan. They investigated that Power sector of Pakistan heavily relies on conventional resources including thermal, hydal and nuclear. Out of these, main contributor is thermal power. It has been found that supply of fossil fuel is generally dependent on import. Increased prices of fossil fuels in international market as well as variance of price cause cost of electricity to become higher. Although energy produced by fossil fuel is appreciable but it also causes harmful emissions and considered dangerous for environment. An alternate energy resource to cater with the requirement is a must. Renewable energy provides a viable option to deal with the electricity problem of Pakistan. Out of many other renewable energy options available, it is estimated that around 2900GW solar potential is available in Pakistan. It is also estimated that solar irradiance of the country is 2200 KWh/m2. In

Pakistan, five places including Karachi, Lahore, Multan, Peshawar, and Quetta have facility to record this data. Other places have to rely on associated empirical data to be used as reference. A map of direct solar radiation of Pakistan is shown in Figure 2. In [25], authors have conducted SWOT (Strength, Weakness, Opportunities, Threat) analysis of current status along with future road map of Renewable energy sector in Pakistan. They have described that load shedding in Pakistan has risen on average upto 18 hours a day. It was described that wind and solar renewable energy methods can be very helpful in fulfilling the electricity demand of the country. It is estimated that 25 million people in Pakistan have no access to electricity. 6500 MW shortfall of electricity was recorded in 2017 [25] .

In the SWOT analysis, authors analysed that one of the strengths of the solar energy potential of Pakistan is availability of highly accurate solar maps. Other factors included reduction in environmental pollution and strong public acceptance of solar energy across Pakistan. Now we discuss solar pond and PTC technologies with aspect of power generation.

Solar Pond

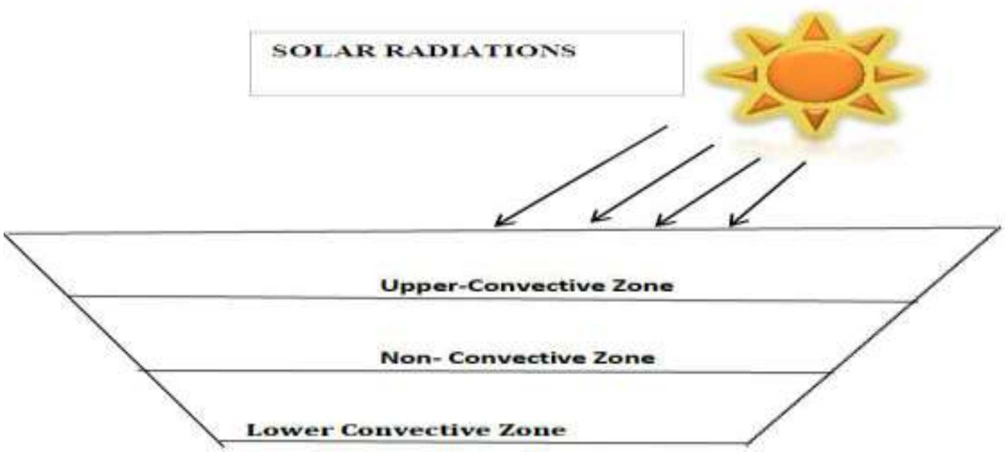

Figure 3 Structure of Salinity Gradient Solar Pond [6].

Solar Pond is used for collection and preservation in terms of storage of solar energy (heat). Different types of solar pond exist, examples include salt gradient solar ponds, partitioned solar ponds, membrane stratified solar ponds and others. A typical salt gradient solar pond is shown in Figure 3. It can be seen that its structure consists of three layers namely upper convective zone (UCZ), non-convective zone (NCZ) and lower convective zone (LCZ). UCZ is considered a zone of constant temperature and salinity whereas NCZ zone serves as an insulating layer. LCZ is of high temperature and used as storage layer for energy/heat etc [23]. Solar ponds are used to preserve solar energy which can be used for electricity generation in conjunction with steam, thermo electric generators (TEG). In solar pond, high temperature is maintained in the lower region and salt water is used to prevent it from convection that is why the term solar gradient pond is also used. A variety of solar ponds in size ranging from few hundred to thousand square meters have been constructed globally in last few decades. Authors in [26] have investigated that Solar energy resources have high potential to meet the energy demands of the world up to 100%. One of the requirements of making effective use of solar energy, storage mechanism is required especially when weather is rainy or cloudy.

Solar pond is helpful in these conditions because it has own energy storage. This might be sufficient for low energy requirements of heating and cooling of buildings. Authors performed thermal analysis of a salt gradient solar pond with heat extraction from lower convective zone. They recommended solar pond of 1.5m but also suggested that if quality is compromised than smaller ponds can also show good results. They concluded those solar ponds are sufficient to meet the energy requirements of a small building or house.

In a research, authors found out that Salinity gradient solar pond is one type of solar collector with the ability to store thermal energy for long period of time and lower cost of construction compared with the other type of solar collector. It can collect and store solar heat at temperatures up to80oC. From the results of experiment by using water as working fluid, the temperature of the solar pond in lower convective zone is at 50 C. The thermoelectric is able to generate electricity at 36.25 mV. Using R134a as a working fluid, the temperature of heat pond in lower convective zone is at 41C. Due to this, thermoelectric generates electricity at 234.25 mV. Research results in the work indicate that there is a significant potential for electric power generation from small solar ponds through a simple and passive device incorporating thermosyphons and thermoelectric cells [27].

B. **Parabolic Trough Collector (PTC)**

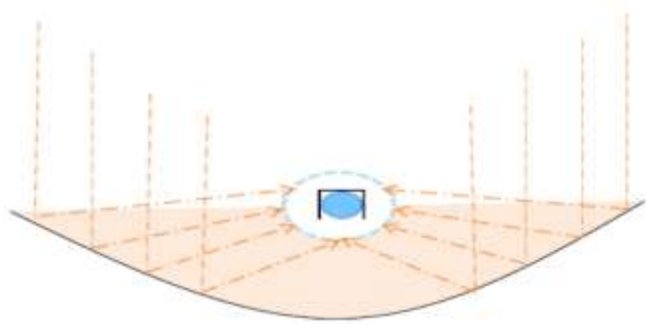

Figure 4 Example of Parabolic Trough/Dish Collector [11].

A PTC is described as a linear concentrating system. Long mirrors/ silver coatings with parabolic structure mirrors are generally used for construction of PTC. It also has a receiver tube placed along the focal axis of the parabola. In this way, DNI is able to be concentrated onto the receiver tube absorbing the solar energy by the HTF. Common PTCs can achieve concentration ratios of 50, whereas HTF temperature can reach up to 400°C. PTC can be placed in solar field with various arrangement and architecture [28]. An example of PTC is shown in Figure 4.

PTC can be helpful in electricity generation. In [29], authors have described the design of a 100MW CSP using PTC technology with 6 hours thermal energy storage. They argued that performance of Photovoltaic is inferior when compared with CSP. System Advisor Model (SAM) was used for simulation. The results indicated that proposed system was able to 244,688,560 KWh of electricity. Authors concluded that results were appreciable and further work is required to be done in this regard with CSP to become a key factor in electricity generation through solar energy. Authors in [30] have discussed Concentrated Solar Power (CSP) as a popular renewable energy option. Parabolic Trough configuration of CSP has been used for 50MWe PT plant of Abu Dhabi UAE. The aim was to look at the performance in terms of improvement in energy and being economical. System Advisor software model was used to carry out the simulation work. Results indicated that utilization of CSP technology in conjunction with appropriately selected technology could be beneficial in reducing cost of energy as well as limiting environmental pollution. In [31], authors have looked at the performance with economic analysis of Concentrated Solar Power (CSP) generation in Pakistan. The results indicated that Quetta region of Balochistan Province was among areas found suitable for CSP based projects. Use of Parabolic Trough was also among the suggested one method for development projects related with CSP. In [32], it was argued that Parabolic Trough Solar Collector (PTSC) is considered a technology working on medium temperature range which can be efficiently used as RE option to deal with the energy crisis of Pakistan. The authors performed a detailed study with comprehensive analysis with integration of Combined Cooling and Power Plant (CCP) operated by PTSC. Data of Quetta and Lahore city of Pakistan was used, and analysis of results was presented and discussed. In [29], authors have reported the effects of solar radiations and weather conditions based on data collected from five major cites of Pakistan using PTC. MATLAB software was used to carry out analysis. It was analyzed that although Pakistan has diversified weather, still availability of solar beam radiations intensity of these cities is high. June-July has maximum radiation while December and February have the least values. It was concluded that PTCs have strong feasibility to be used in diversified climatic conditions of Pakistan. PTC gets heat from the incident solar radiations. The obtained heat is transferred to the Heat Recipient

Fluid (HRF). It is then circulated through a centrally heat pipe of the collector. This heat can be used for a variety of applications including power generations, and other high temperature applications. Parabolic troughs are very reliable, and efficient solar thermal collectors and that is why more researchers are inclined towards use of PTC. Authors in [33] performed a study where they investigated the performance of PV, PTC, and wind power plants with 10MWe capacities for the data taken from the City of Multan Pakistan. In terms of electrical energy generation, they found that PTC took the lead over other systems with 7.5h storage with 45.96% capacity factor. In terms of PTC, authors concluded that it was a viable option for non-sunny days however the cost would be higher as compared to PV system. Many solar technologies have been demonstrated; parabolic trough solar thermal electric power plant technology represents one of the major renewable energy success stories of the last two decades. Parabolic troughs are one of the lowest-cost solar-electric power options available today and have significant potential for further cost reduction. Nine parabolic trough plants, with over 350 megawatts (MW) of electric generation, have been in daily operation in the California Mojave Desert for up to 18 years. These plants provide enough solar electricity to meet the residential needs of a city with 350,000 people. They have demonstrated excellent availabilities (near 100% availability during solar hours) and have reliably delivered power to help California meet its peak electric loads, especially during the California energy crisis of 2000–2001. Several new parabolic trough plants have been built or are currently under development. Growing interest in green power and CO2 reducing power technologies have helped to increase interest in this technology around the world. New parabolic trough plants are currently under construction or in the early stages of operation in support of solar portfolio standards in Nevada and Arizona and a solar tariff premium in Spain [34].

C. Solar Potential of Khuzdar

Khuzdar is considered of significant importance in Balochistan province after Quetta. Balochistan is the largest province of Pakistan area wise where 77% of population reside in rural areas. It is estimated that 90% villages do not have proper electricity. Demographic nature of the province makes it hard to provide electricity at all places [29] . Solar energy provides a solution to provide electricity in far flung areas of Balochistan Solar potential of Balochistan province is very high. 40% of the province land area has solar insolation of 6kwh/m2. Even remaining province receives direct solar radiation of 4.5kwh/m2. Developing large scale solar projects require more investment, however, their maintenance cost is low. For Balochistan, mini projects can be initiated. As Balochistan is the hub of activities for the CPEC, with the co-operation of Chinese Government, more mega solar projects with a specific focus on Balochistan can be started thus providing better facilities especially for the rural areas of Balochistan [29].Authors in [35], have explored renewable energy resources in Pakistan. They analyzed that along with other areas, Balochistan province has maximum solar energy generation potential in Pakistan. They concluded that at least 10% of energy demand can easily be achieved through use of RE with solar providing a viable option. In [36], results of solar potential of Balochistan province have been reported. The parameters used were global horizontal radiance (GHI), direct normal irradiance (DNI), diffuse horizontal irradiance (DHI), air temperature and relative humidity. Results from Khuzdar area of Balochistan are presented in Figure 5[2].

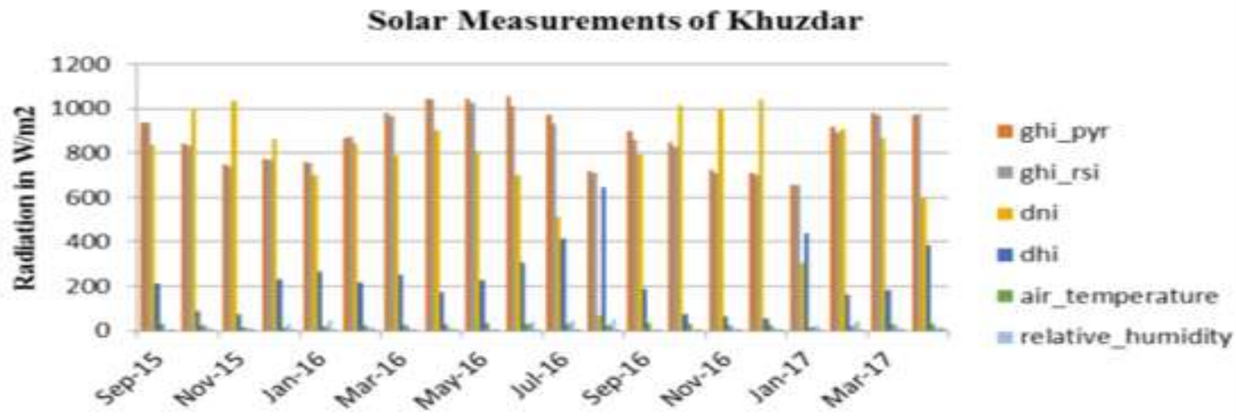

Figure 5 World Bank Solar Measurements of Khuzdar [2].

It can be clearly seen that all parameters indicate the high potential of Khuzdar region of Balochistan making it strongly feasible to use solar renewable energy source for practical applications for socio economic development. The priority should be electricity generation. In [37] , authors while investigating solar potential of Pakistan found that Sindh, Balochistan and southern parts of Punjab have maximum solar potential in Pakistan. The global insulation of Balochistan is 19-20MJ/m2 per day with average mean sunshine duration of 8-8.5h. Such values indicate that Balochistan is highly feasible for solar energy applications. Furthermore, one of the weather stations in Pakistan is located in Balochistan University of Engineering and Technology Khuzdar providing round the clock updated data of the region. It can be very helpful in initiating solar energy projects including electricity generation because of availability of authenticated data from weather station of Khuzdar. Authors also investigated the barriers found in promotion of solar energy application in Pakistan. One of the major obstacles was unawareness of people regarding solar energy products in rural areas. As mentioned before, majority of persons live in rural areas in Balochistan. With awareness campaign, utility of solar energy in power generation could be high with the co-operation of local community. Government of Pakistan has initiated solar energy electricity program for rural areas of Pakistan. Reportedly 400 villages of Balochistan are initially part of the project. There is need to increase the number to overcome the electricity crisis in Balochistan. Authors concluded that solar energy can solve the energy problem of Pakistan as it is cheaper than wind, economical and has less maintenance cost as well. We have also shown that Solar Pond and PTC technology provide a viable option to be used for electricity generation. For Khuzdar region, where solar parameters as shown in Fig 2.4 are high, the Government should be encouraged to invest on projects with Solar Pond and PTC technology in Khuzdar region. Although initial investments would be on higher side, but once installed, cost of electricity would reduce and also maintenance cost would also be significantly low. The ultimate beneficiaries would be underprivileged people living in remote areas of Balochistan in general and Khuzdar specifically with cost effectiveness in terms of long-term initial investment resulting into sustainable growth of inhabitants. In the next stage of this work, experiments based on empirical data of Khuzdar would be performed and investigation would be done to deal with any complexities found using intelligent methods of Artificial Intelligence.

As per the Annual Performance Report (APR) of NTDC for the year 2014-15, it has been indicated that variation in voltage limits beyond the permissible limits of ±5% (Normal Condition) and ±10% (N-1 Condition) of nominal voltage. Such deviations of NTDC from the permissible voltage limits reveal the voltage profile for 220 kV Sibbi and Khuzdar Grid Stations remained as low as 180 kV and 185 kV respectively under normal conditions [38]. It also emphasizes that more efforts are required to meet the demands of electricity in the region thus providing a cogent argument for using solar energy as one of the viable renewable energy options.

D. Fuzzy Logic and Fuzzy Inferencing System

Fuzzy logic is also considered related with the concept of Artificial Intelligence. It is described as a multivalued logic where degree of membership lies in between 0 and 1. Zadeh in 1965 through his research work introduced this concept. The advantage of fuzzy logic over traditional crisp logic or Boolean logic is that as values can be in between 0 and 1, therefore, it facilitates in dealing with ambiguities involved in data. It has been very successful in dealing with complex data sets and getting valuable information out of them [39]. Fuzzy inference system (FIS) is also called Fuzzy Expert System (FES) and Fuzzy Logic Controller (FLC) depending upon the area of its application. It is a rule-based system that uses fuzzy logic, rather than Boolean logic, to reason about data.

A fuzzy Inferencing system has following four main components:

- First a Fuzzifier converts real input into fuzzy acceptable format.
- An inference engine which is used to draw a conclusion based on rule set and Inferencing mechanism.
- DE fuzzifier, which translates the fuzzy output into realoutput.t
- Knowledge base, which contains fuzzy rules to be used for Inferencing and based on fired rules.

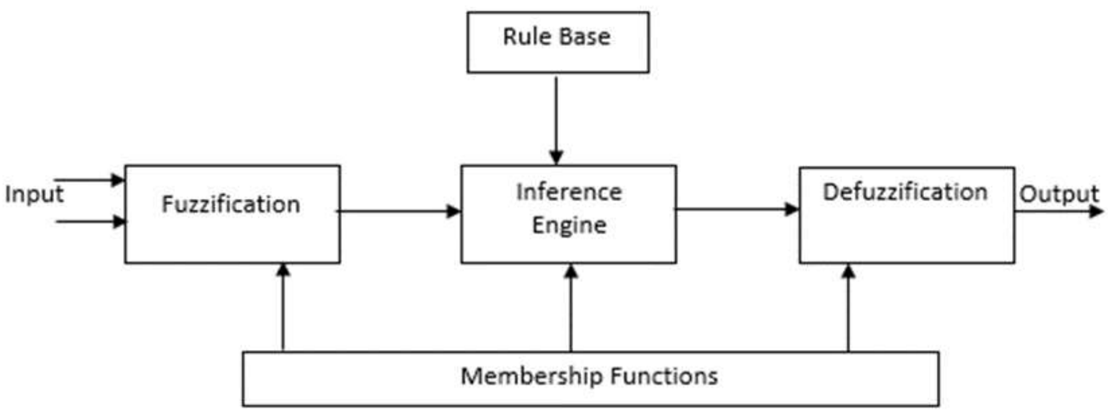

Figure 6 Structure of Fuzzy Inferencing System.

These main components of fuzzy Inferencing system have been shown in Figure 6 [40].

There are various defuzzification methods that exist in literature; however, we have used centroid defuzzification method as it commonly used. Two types of Inferencing systems exist. One is called Sugano system where output is either linear or constant. Such a system is used where generally complexity level is low. Other is called Mamdani inferencing system where besides input, output also has membership functions. Mamdani system is preferred for design where complexity level is high. Rule base has rules which are connected through AND, OR or NOT operators. Generally, Zadeh's conventional operators are used. However, different scientists have created other systems as well but are not common. Besides other application areas, fuzzy logic in the literature has been used in Solar applications including solar pond and PTC technologies. A review is presented in the next section.

E. **Fuzzy Logic and Solar Applications**

In [41], authors have developed a fuzzy control algorithm of the sun tracker to increase the efficiency of tracking. In this work, Water distillation yield prediction is made with reference to high temperature. For experimentation data of Amman Jordan was used to measure the values of solar radiation and maximum power. The results showed that two axis tracking enhances the daily power produced by more than 50% in summer which can be very beneficial. In [42], authors have provided a detailed review on using optimization techniques based on Artificial Intelligence methods for hybrid energy systems. They analysed more than 100 papers regarding renewable energy. They also included hybrid approaches for optimization. They found out that Artificial Intelligence based techniques are very useful in terms of better accuracy and also reducing computational times. It shows that Artificial Intelligence is playing a vital role in renewable energy research including solar energy. In [43], significance of solar power In power generation has been highlighted. Authors have elaborated that in tropical and equatorial countries like in middle east. They argued that abundance of sunshine can be efficiently used for power generation. It was highlighted that electricity generation from solar ponds is an emerging field and is gaining popularity among renewable energy techniques. It was also emphasized that the brine inside the pond is the key agent in trapping of the heat energy and its preservation should be done very carefully. Another important work carried out in this research was development of a fuzzy controller for stable power generation. They used Mamdani inferencing method and center of gravity defuzzification method for development of fuzzy logic controller. The output of the system was change of duty cycle and input was the temperature difference arising due to different metal plates. It was concluded that, as the salinity of the LCZ increases, it also results in increase of the temperature of the LCZ and efficiency of the pond. The investigations also revealed that the solar pond with a polyethene is technically more feasible as compared to the conventional solar pond. In [44], authors have developed a two-axis sun tracking solar energy system with a fuzzy logic as intelligent quality policy. In this research, a fuzzy logic controller has been designed as the software architecture of the system which determines the timing for tracking the sun. The direct sunlight is obtained from the database for this purpose. The developed fuzzy logic-based controller was able to reduce the starting motors and less energy loss in difficult and tricky weather conditions. The summary of the research gap with the help of significant papers is shown in the Table 1. It can be seen that authors have previously investigated solar energy applications with fuzzy logic and there is need to do further research in terms of power prediction using solar energy with fuzzy logic. In context of Pakistan and with a specific focus on Khuzdar region, there is gap to investigate use of fuzzy logic in power prediction and then providing an insight into using it in solar pond and PTC technologies for high performance power prediction.

Table 1 Research Gap Summary

S.No	Title of paper	Year of Publication	Work done	Results
1	Fuzzy based state observer of a solar trough field [49]	2019	In this work an observer is presented, based on a fuzzy inference system, for the estimation of the temperature profiles of the loops that make up the solar field.	Two cases have been simulated in which different set-points of temperature are applied throughout the day. In these simulations each loop has a different reflectivity. The simulations show good performance at estimating the states of the loops even with different reflectivities.

2	Effect of ground heat extraction on stability and thermal performance of solar ponds considering imperfect heat transfer [45]	2020	This work revisited the idea of ground heat extraction in solar ponds by addressing various limitations associated with the conventional assumption of perfect heat transfer.	The article presented analytical solution to assess the thermal performance of solar ponds assisted by heat recovery from the ground beneath considering an actually realizable condition
3	Strategic renewable energy resources selection for Pakistan: Based on SWOT-Fuzzy AHP approach [46]	2020	This study has identified main factors through SWOT analysis that impede the utilization process of RE resources.	It was concluded that he Fuzzy AHP method is useful to prioritize suitable RE resources of Sindh and Balochistan province for sustainable electricity generation. The results of Fuzzy AHP reveal that wind resource is ranked first followed by solar and biomass, respectively.
4	Design of Solar Pond for Electricity Production [47]	2019	Authors designed a pond for electricity generation of 10MW and results shows that solar pond is the batter way of storing thermal energy which in terms gives electricity	It was concluded that the increase of thermal power produced from solar pond will increase electricity production.
5	The prediction of solar radiation using fuzzy logic: A case study [48]	2018	Authors Studied for prediction of the use of solar radiation for solar energy to produce electricity in Duhok city due to the fact that “national electricity” is not enough for the great number of consumers.	The four fuzzy systems are created using the available data in Duhok City in 2016. Daily observations for temperature, humidity and wind speed for four seasons are analyzed to estimate the solar radiation. The predicted outputs of fuzzy logic system are compared with the actual solar radiation.

II. METHODOLOGY

A. Research Paradigm

The current research work is based on quantitative research paradigm. In this research, data sets obtained from BUET Khuzdar’s weather station for the Khuzdar region would be used for developing and analysing the system. Fuzzy inferencing system based on quantifiable rulesets, input, output variable and closed set answers of power prediction ranging from 0 to 1 as fuzzy prediction will be used. Balochistan University of Engineering and Technology is the oldest Engineering University of Balochistan. It was initially established as Engineering College and later on upgraded to the level of university in 1994. It is located near Khuzdar City of Balochistan which is considered strategically very important. N25 National Highway connects Balochistan with Sindh province and to the Quetta which is provincial capital of Balochistan. BUET Khuzdar is the hub of academic and research activities in science and technology in the region. It has a state-of-the-art weather station which has been installed on the main auditorium building of the University. This operates 24 hours a day and information is sent internationally to be used for research and analysis. The datasets used in the current research have also been obtained from this weather station. It is for the first time that data of this type has been used for research and analysis within university. Figures 7 show the weather station and its maintenance process for quality data collection.

Figure 7 A View of BUETK Weather Station

Selection of Data Set

For this research work, a main contribution is use of data sets obtained from the Weather Station installed at Balochistan UET Khuzdar. This weather station records data round the clock and is of international standards. The parameters which are recorded by the weather station are given in Table 2.

Table 2 Parameters Recorded by BUET Khuzdar Weather Station.

S. No	Parameters recorded by weather station
1	Global Horizontal Irradiance (GHI)
2	Direct Normal Irradiance (DNI)
3	Diffused Horizontal Irradiance (DHI)
4	Air Temperature
5	Weather Humidity
6	Wind Speed
7	Wind Direction
8	Biometric Pressure

The. data of three years has been selected for the analysis using fuzzy inferencing system These years are 2015, 2016 and 2017. The reason is that data recorded by the weather station requires pre-processing to be done outside Pakistan. The procedure is time taking and as the duration of the research work to be carried out was limited, therefore, only three years data could be available although the target was to obtain the latest data. As the dataset trends are generally consistent, therefore, we envisage that the latest data might have similar trends thoughts it needs empirical verification not done in this research.

B. **Selection of Parameters**

Three parameters have been selected for the development of fuzzy inferencing system. The selection has been made on the basis of the fact that these parameters play a vital role in power generation analysis of solar energy. Also, their detailed analysis can be very beneficial in power generation in context of these parameters. They are:

i. GHI Global Horizontal Irradiance
ii. DNI Direct Normal irradiance
iii. DHI Diffused Horizontal irradiance.

Three years data (2015, 2016, and 2017) of these parameters has been used for the execution of fuzzy inferencing system.

C. **Global Horizontal Irradiance**

It is the total solar radiation incident on a horizontal surface. It is the sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance, and ground-reflected radiation. It can be described by the Equation 3.1[50]

$$\mathbf{GHI = DHI + DNI * Cos(\theta)} \quad \textbf{.........(1)}$$

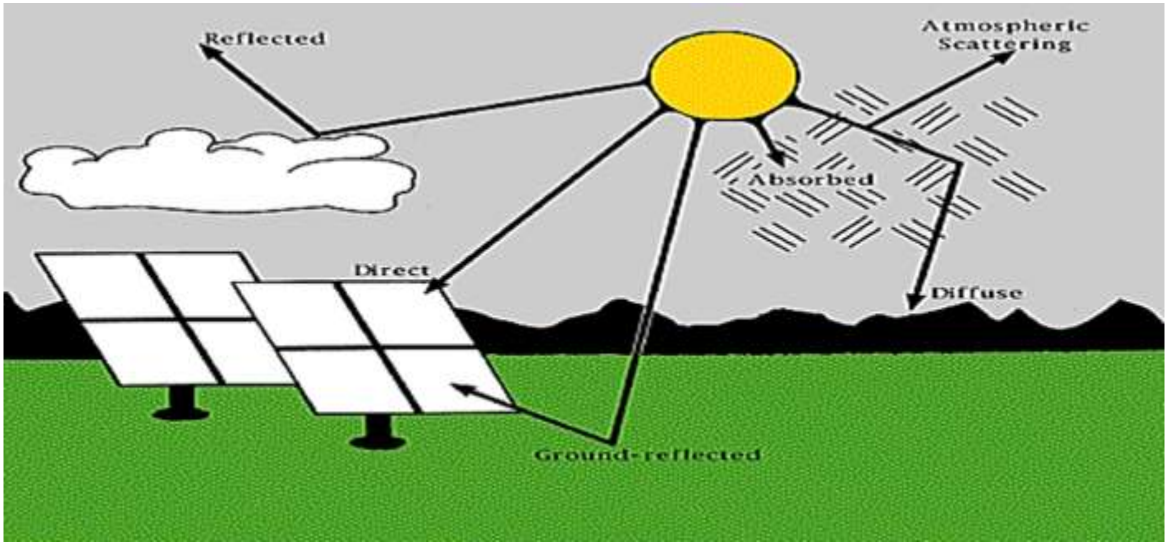

Figure 8 Working of GHI [51]

Normally, on a sunny day the insolation is 100% GHI with 20% DHI and 80% DNI · cos (θ). A sample working of GHI can be seen in Figure 8.

D. **Direct normal irradiance (DNI)**

The amount of solar radiation received per unit area by a surface perpendicular (normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. It can be described by the Equation 3.2 [50] and shown in Figure 9.

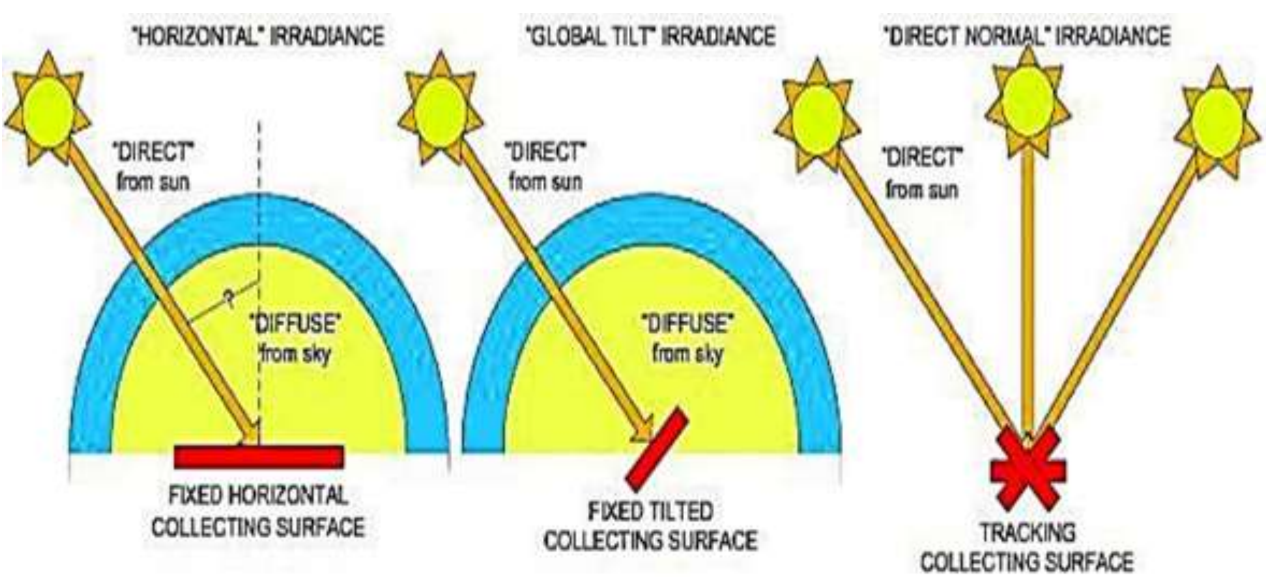

Figure 9 Working of DNI and DHI [52].

DNI = $\frac{\textbf{GHI} - \textbf{DHI}}{\cos(\theta)}$**…………… (2)**

E. **Diffused Horizontal Irradiance (DHI)**

The amount of radiation received per unit area by a surface that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere. Basically, it is the illumination that comes from clouds and the blue sky. It can be described by the Equation 3.3 [50]:

DHI = GHI - DNI • cos (θ)………… (3)

F. Development of Fuzzy Inferencing System

For the fuzzy inferencing system, the selected parameters are input variables to the fuzzy system. The system uses Mamdani inferencing mechanism as it is found be frequently used in the literature. For each of these three input variables three membership functions called low, medium and high have been assigned. These membership functions are of triangular type. This selection is also based on the literature of the fuzzy system which reflects that triangular membership functions are commonly used for the development of fuzzy inferencing system. Centroid defuzzification method has been used. The input variables and their ranges are given in Table 3.

Table 3 Input Variables and their Ranges (as per data set Ranges of Weather Station Khuzdar).

S.NO	Input Variable	Membership Functions	Range
01	GHI	Low, Medium, High	0 to 1091
02	DNI	Low, Medium, High	0 to 1054.1
03	DHI	Low, Medium, High	0 to 597.42

The output of this system is called Power and it shows the prediction of obtaining Power based on these solar parameters. This prediction can be used for power generation from Solar Pond and PTC as well. The range of the output and associated membership functions are shown in Table 4. It can be seen from the Table that the Range of the Power generation prediction is between 0 and 1. Where 0 indicates zero or no power generation and as value approaches 1, the likely hood of power generation with the fuzzy system reaches its maximum value. Thus, it indicates that values close to 1 are indicators that power generation is maximum at those times and can be used potentially to maximize power generation.

Table 4 Output Variable and its Range.

S.NO	Output Variable	Membership Functions	Range
01	Power (generation prediction)	Low, Medium, High	0 to 1

The fuzzy inferencing system (FIS) has been developed using MATLAB Fuzzy Logic Toolbox. The basis structure of system has been shown in Figure 3.9. The input variables GHI, DNI and DHI have been shown in Figures 3.10, 3.11 and 3.12 respectively. It can be seen that tall variables have three fuzzy membership functions low, medium and high. The Footprint of Uncertainty (FOU) is there in all variables with overlapping membership functions showing the complicated nature of the design and significance of using fuzzy inferencing system. For developing the rule set, all possible combinations have been considered. Based on the values of variables as L (Low), M (Medium) and H(High), the output which is Power prediction is inferenced. In this way, 27 rules have been created. The output variable and its membership functions have been shown in Figure 3.13. These rules have the following format.

IF (Antecedents) THEN (Consequents)

Antecedents are variable membership function values as L, M or H. These Antecedents are connected by fuzzy AND operator based on Zadeh's mathematical principles. The Consequent is also inferenced as L, M or H based on Mamdani Inferencing. As in this initial study, a generic ruleset has been created, therefore, all weights of rules are set to 1. It means that all rules have higher priority. Based on the input provided, a certain rule is fired and Consequent value is obtained.

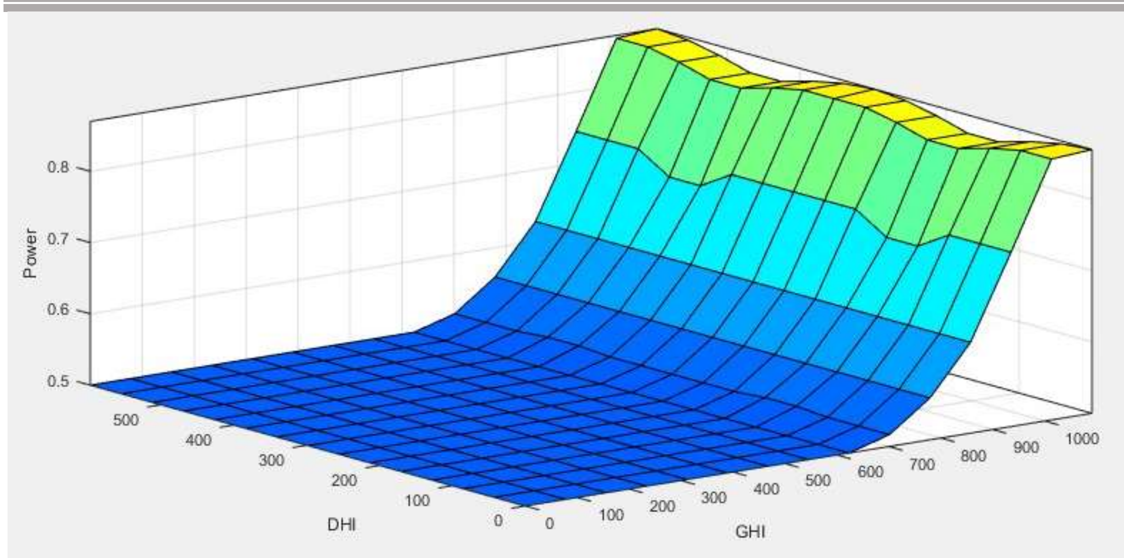

Figure 10 Surface view with DHI and GHI with Power Prediction.

Similarly, the surface view of combination of DHI and GHI can be seen in Figure 3.17. It is evident from the figure that lower values do not provide increase in power generation prediction after GHI reaches more than 600 then there is sharp increase in power generation prediction by the inferencing system. The last surface view is shown in Figure 3.18. It can be seen that variations in the values of GHI and DNI results in slow level increase in power prediction. These views indicate that data complexities are captured by the fuzzy inferencing and a more rational power generation prediction is made which is not the case if fuzzy system is not used. After the fuzzy inferencing system is created, it is saved as file in the computer. The system used for the research has a Core i3 processor with 4GB RAM and MATLAB installed with fuzzy logic toolbox. In the next Chapter, we describe the dataset used with results obtained after running the fuzzy inferencing system with analysis and discussion on results in context of using them with Solar Pond and PTC technologies for Power generation.

III. RESULTS AND DISCUSSION

A. Results of Dataset for the Year 2022

For 2022, data for the months of October, November, and December as winter season was considered. Values of the input variables from 6a.m to 6p.m were given as an input to the system. The fuzzy power generation prediction for a single day for the Month of October 2022 has been shown in Figure 11. It can be seen from the figure that the curve slowly increases from lower fuzzy value to higher indicating the rise in solar rays and after mid-day decreases but due to other factors such as temperature or humidity, peaks and drops and again peaks. This indicates that fuzzy system is able to capture the ambiguities of the data. In Figure 11, power prediction based on solar data for the November 2022 has been shown. It can be seen that during mid-day, although the curve reaches peak and power prediction of fuzzy system touches the peak reaching at almost value of 1. However, it can also be seen that curve is not exact smooth and this might be result of other factors including humidity, temperature not included in the fuzzy system but as a complexity of the data, the system is able to reflect it and this can be useful in design of a power generation system.

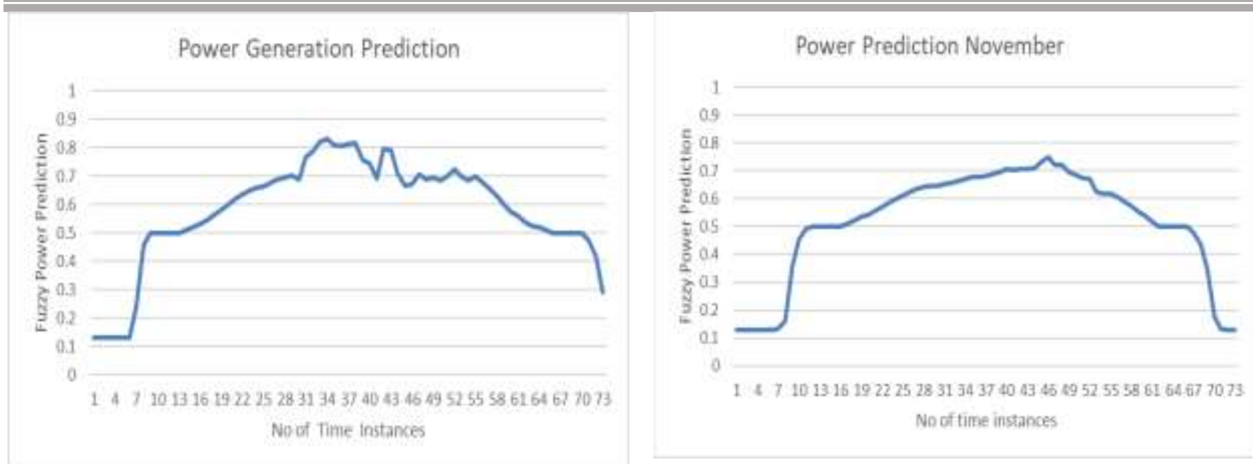

Figure 11 Fuzzy logic Power Generation Prediction 2022

B. Results of Dataset for the Year 2023

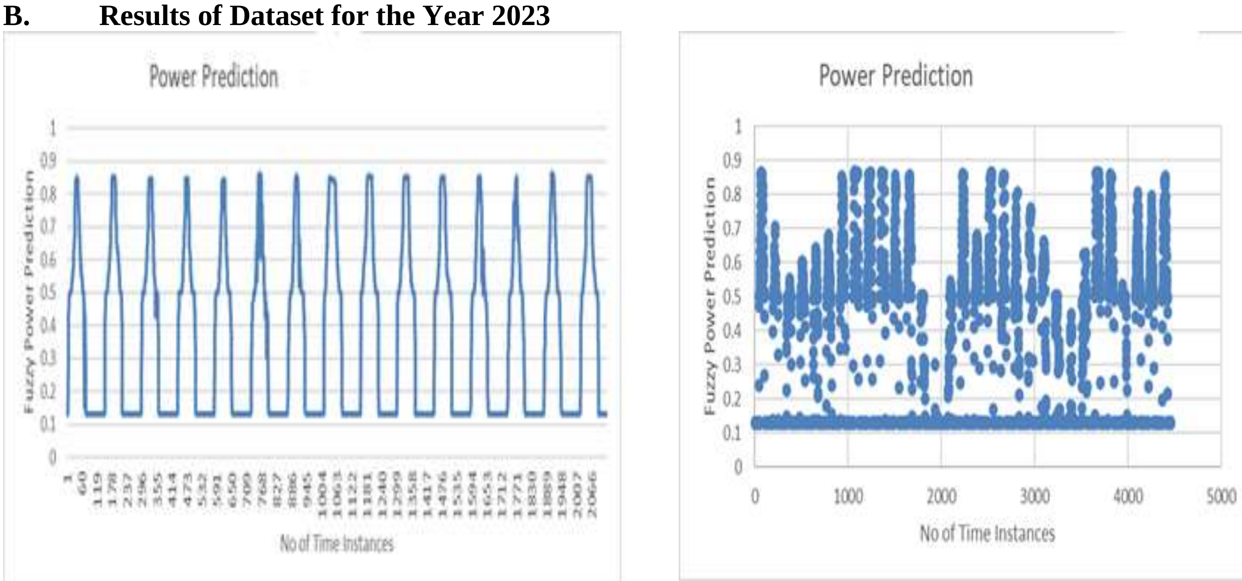

Figure 12 Fuzzy Power Prediction for 15 days of April 2023 and January 2023 Data.

For the 2023 data of Khuzdar, trend of power generation prediction is shown in Figure 4.9. It can be seen in the Figure that as it is winter time, therefore, power generation value reaches peak less than in summer days and is overall low as compared to long sunny days of June and July in general. This information is helpful in designing a balanced power generation system which can work both in summer and winter weathers. As in previous cases of 2021 and 2022, trend of 15 days is highlighted in Figure 11. As data after April 2023 was not decoded therefore, as last available month of 2023, this trend has been shown of 24 hours cycle and it is similar as that of 2021 and 2022.

C. Peak time Analysis

In this investigation, we have also closely monitored the result of the fuzzy inferencing system in terms of maximum availability of Sun during the summer times. Table 5 shows the power prediction values obtained for peak times during the months of June and July for the year 2023 It can be seen that during mid day values are higher and are close to 1 indicating maximum power generation possibility and lower at other times.To show the latest data available and to show the winter season analysis, Table 5 shows the peak time record for 1st January 2023. It can be seen that even during winter abundance of sunshine at peak times is available which is an indicator of using it power generation.

Table 5 Peak Time Data for the Year 2023

S. No	Time of the Day	Fuzzy Power Prediction value
1	01-01-23 12:00	0.85951
2	01-01-23 12:10	0.85889
3	01-01-23 12:20	0.85858
4	01-01-23 12:30	0.85754
5	01-01-23 12:40	0.8582
6	01-01-23 12:50	0.85842
7	01-01-23 13:00	0.85832
8	01-01-23 13:10	0.80536
9	01-01-23 13:20	0.85872
10	01-01-23 13:30	0.8356
11	01-01-23 13:40	0.77097
12	01-01-23 13:50	0.82916
13	01-01-23 14:00	0.81887
14	01-01-23 14:10	0.79609
15	01-01-23 14:20	0.80227
16	01-01-23 14:30	0.75813
17	01-01-23 14:40	0.76103
18	01-01-23 14:50	0.72121
19	01-01-23 15:00	0.66539

Figure 4.2 shows the same trend with a focus on graphical representation at peak time of 12pm to 3pm. It can be seen that trend shows maximum rise and higher values and any variations captured by the fuzzy system.

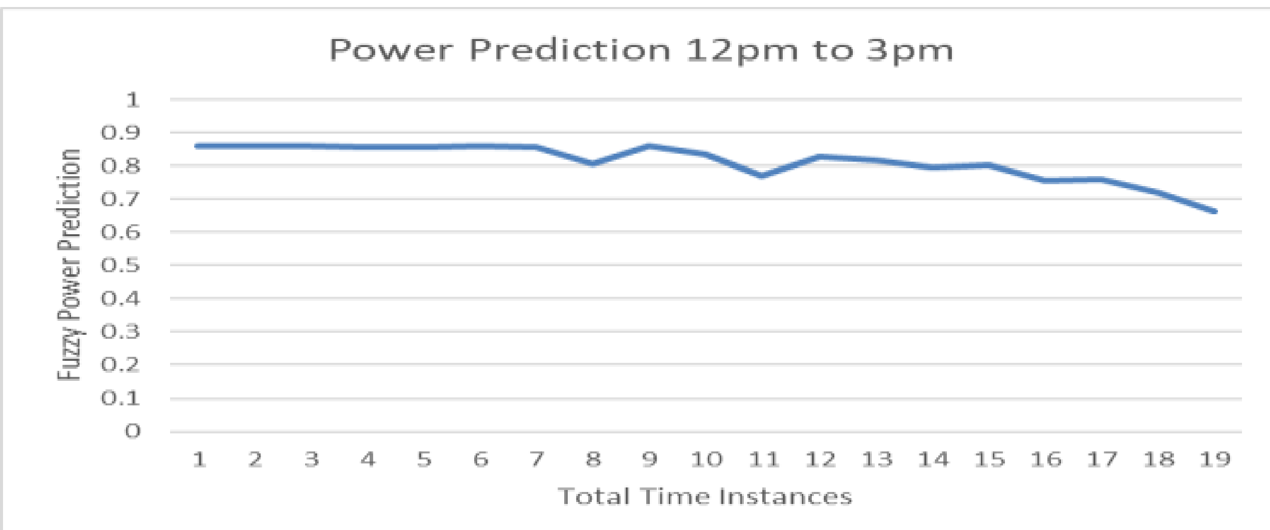

Figure 13 Peak Time Trend (12pm to 3pm)

IV. DISCUSSION

The above analysis shows that Khuzdar region has abundance of sunshine available which can be utilized for power generation. The analysis also shows that due to diversified weather, simple observations cannot completely reflect upon the power generation prediction whereas fuzzy inferencing with rule set provide better insight into the complexities of the variance of solar energy available. As in the literature review, we have already shown the significance of Solar Pond and PTC technologies in the power generation. The fuzzy system used for power generation prediction can be used in conjunction with solar pond and PTC technologies for creating sensitivity-based power generation where fuzzy system can identify complexity in terms of variance of data during different times of hour. This analysis can then be used for efficient power generation through pond and PTC. We have already mentioned that cost of power generation might be high but linking methods of power generation like solar pond and PTC with Artificial Intelligence based technique can substantially increase the power production efficiency. We have not focused integration methods like the one we created using fuzzy inferencing with solar pond and PTC technologies, rather than we have showed that such integration has a strong potential in applying Artificial Intelligence based techniques in Renewable Energy applications with a emphasis on power generation.

V. CONCLUSION FUTURE WORK

This research focuses on providing insight into use of fuzzy logic into representing the complexities of the solar data to be used for power generation analysis using Solar Pond and PTC technologies. For the first time, BUET Khuzdar weather station data has been used in a university stage for the development of such system. Three key parameters namely GHI, DNI and DHI have been used to create the fuzzy prediction system. Each variable used three membership functions, low, medium and high. Mamdani fuzzy inferencing system was used. 27 rules were created. Output of the system is from 0 to 1 where 0 indicates low power prediction and 1 indicates maximum power prediction. Data of three years was analyzed especially for sunny days. Results indicated that the proposed fuzzy system was able to reflect the variances of the input variables in a better way capturing complexities of the data. These results are beneficial in a manner that they can be used to improve the power generation with solar pond and PTC technologies as fuzzy controllers can be developed to be integrated with Solar Ponds and PTC applications.

VI. LIMITATIONS OF THE RESEARCH

- During the analysis, only three variable GHI, DNI and DHI have been considered for creating fuzzy system
- Overlapping of fuzzy sets is based on default values and no separate study was done on optimization of fuzzy sets
- Literature review on power generation was only limited to Solar Pond and PTC technologies
- Dataset was limited to two years (2022-2023)

VII. DIRECTIONS TOWARDS FUTURE WORK

- In addition to power generation, we can investigate using AI in future to make water treatment for Khuzdar region by using solar pond and PTC techniques (i.e., solar water distillation process)
- A fuzzy logic based PTC system can be made to track the intensity of solar in any time in terms of automation
- Fuzzy logic controllers for solar pond linked with flat plate collators can collect maximum radiations for batter output power, while tracking the intensity of solar radiations properly
- Fuzzy logic techniques for high power generations like compact linear Fresnel reflector (CLFR), parabolic trough technology, and solar pond can be used for power generation of Balochistan remote areas according to the order of performance
- Other AI techniques including Internet of Things, Clustering algorithms, Deep learning can be applied on Solar data for analysis and their results can be compared to find the optimal methods suited to such kind of data
- In this system, weights of all the rules are set to 1, based on empirical analysis, different weights can be set for rules that might be helpful in obtaining more in depth analysis resulting in meaningful information.

We have used only Khuzdar data for this research, it will be interesting to obtain data of different areas and then compare the results.

REFERENCE

A. Kapitonov, V. I. Voloshin, T. G. Filosofova, and D. N. Syrtsov, “Development of experience in the application of technologies in the field of alternative energy: World experience, Russian practice,” Renew Energy, vol. 165, pp. 773–782, 2021, doi: https://doi.org/10.1016/j.renene.2020.11.063.

A. B. Awan and Z. A. Khan, “Recent progress in renewable energy – Remedy of energy crisis in Pakistan,” Renewable and Sustainable Energy Reviews, vol. 33, pp. 236–253, 2014, doi: https://doi.org/10.1016/j.rser.2014.01.089.

H. Lund, “Renewable energy strategies for sustainable development,” Energy, vol. 32, no. 6, pp. 912–919, 2007, doi: 10.1016/j.energy.2006.10.017.

M. A. Moktadir, T. Rahman, M. H. Rahman, S. M. Ali, and S. K. Paul, “Drivers to sustainable manufacturing practices and circular economy: A perspective of leather industries in Bangladesh,” J Clean Prod, vol. 174, pp. 1366–1380, Jan. 2018, doi: 10.1016/j.jclepro.2017.11.063.

N. S. Lewis, “Research opportunities to advance solar energy utilization,” Science, vol. 351, no. 6271. American Association for the Advancement of Science, Jan. 22, 2016. doi: 10.1126/science.aad1920.

V. Velmurugan and K. Srithar, “Solar stills integrated with a mini solar pond - analytical simulation and experimental validation,” Desalination, vol. 216, no. 1–3, pp. 232–241, Oct. 2007, doi: 10.1016/j.desal.2006.12.012.

H. Wang, Z. Lei, X. Zhang, B. Zhou, and J. Peng, “A review of deep learning for renewable energy forecasting,” Energy Conversion and Management, vol. 198. Elsevier Ltd, Oct. 15, 2019. doi: 10.1016/j.enconman.2019.111799.

H. Wang, Z. Lei, X. Zhang, B. Zhou, and J. Peng, “A review of deep learning for renewable energy forecasting,” Energy Conversion and Management, vol. 198. Elsevier Ltd, Oct. 15, 2019. doi: 10.1016/j.enconman.2019.111799.

A. Mellit and S. A. Kalogirou, “Artificial intelligence techniques for photovoltaic applications: A review,” Progress in Energy and Combustion Science, vol. 34, no. 5. pp. 574–632, Oct. 2008. doi: 10.1016/j.pecs.2008.01.001.

M. Borunda, O. A. Jaramillo, A. Reyes, and P. H. Ibargüengoytia, “Bayesian Networks in Renewable Energy Systems: A 1 Bibliographical Survey.”

M. Borunda, O. A. Jaramillo, A. Reyes, and P. H. Ibargüengoytia, “Bayesian Networks in Renewable Energy Systems: A 1 Bibliographical Survey.”

O. Isaac Abiodun, A. Jantan, A. Esther Omolara, K. Victoria Dada, N. AbdElatif Mohamed, and H. Arshad, “State-of-the-art in artificial neural network applications: A survey,” Heliyon, vol. 4, p. e00938, 2018, doi: 10.1016/j.heliyon.2018.

H. Lund, “Renewable energy strategies for sustainable development,” Energy, vol. 32, no. 6, pp. 912–919, 2007, doi: 10.1016/j.energy.2006.10.017.

M. A. Moktadir, T. Rahman, M. H. Rahman, S. M. Ali, and S. K. Paul, “Drivers to sustainable manufacturing practices and circular economy: A perspective of leather industries in Bangladesh,” J Clean Prod, vol. 174, pp. 1366–1380, Jan. 2018, doi: 10.1016/j.jclepro.2017.11.063.

N. S. Lewis, “Research opportunities to advance solar energy utilization,” Science, vol. 351, no. 6271. American Association for the Advancement of Science, Jan. 22, 2016. doi: 10.1126/science.aad1920.

S. A. Kalogirou, “Solar thermal collectors and applications,” Progress in Energy and Combustion Science, vol. 30, no. 3. pp. 231–295, 2004. doi: 10.1016/j.pecs.2004.02.001.

V. Velmurugan and K. Srithar, “Solar stills integrated with a mini solar pond - analytical simulation and experimental validation,” Desalination, vol. 216, no. 1–3, pp. 232–241, Oct. 2007, doi: 10.1016/j.desal.2006.12.012.

J. Antonanzas, N. Osorio, R. Escobar, R. Urraca, F. J. Martinez-de-Pison, and F. Antonanzas-Torres, “Review of photovoltaic power forecasting,” Solar Energy, vol. 136. Elsevier Ltd, pp. 78–111, Oct. 15, 2016. doi: 10.1016/j.solener.2016.06.069.

J. Antonanzas, N. Osorio, R. Escobar, R. Urraca, F. J. Martinez-de-Pison, and F. Antonanzas-Torres, “Review of photovoltaic power forecasting,” Solar Energy, vol. 136. Elsevier Ltd, pp. 78–111, Oct. 15, 2016. doi: 10.1016/j.solener.2016.06.069.

S. A. Kalogirou, “Solar thermal collectors and applications,” Progress in Energy and Combustion Science, vol. 30, no. 3. pp. 231–295, 2004. doi: 10.1016/j.pecs.2004.02.001.

O. Isaac Abiodun, A. Jantan, A. Esther Omolara, K. Victoria Dada, N. AbdElatif Mohamed, and H. Arshad, “State-of-the-art in artificial neural network applications: A survey,” Heliyon, vol. 4, p. e00938, 2018, doi: 10.1016/j.heliyon.2018.

H. Wang, Z. Lei, X. Zhang, B. Zhou, and J. Peng, "A review of deep learning for renewable energy forecasting," Energy Conversion and Management, vol. 198. Elsevier Ltd, Oct. 15, 2019. doi: 10.1016/j.enconman.2019.111799.

A. A. El-Sebaii, M. R. I. Ramadan, S. Aboul-Enein, and A. M. Khallaf, "History of the solar ponds: A review study," Renewable and Sustainable Energy Reviews, vol. 15, no. 6, pp. 3319–3325, 2011, doi: https://doi.org/10.1016/j.rser.2011.04.008.

R. M. Elavarasan, "The Motivation for Renewable Energy and its Comparison with Other Energy Sources: A Review," European Journal of Sustainable Development Research, vol. 3, no. 1, pp. 1–19, 2018, doi: 10.20897/ejosdr/4005.

M. Kamran, M. R. Fazal, and M. Mudassar, "Towards empowerment of the renewable energy sector in Pakistan for sustainable energy evolution: SWOT analysis," Renew Energy, vol. 146, pp. 543–558, 2020, doi: https://doi.org/10.1016/j.renene.2019.06.165.

N.-U.-H. Shah, A. Arshad, A. Khosa, H. Ali, and M. Ali, "Thermal analysis of a mini solar pond of small surface area while extracting heat from lower convective layer," Thermal Science, vol. 23, no. 00, pp. 166–166, 2017, doi: 10.2298/tsci170129166s.

S. Tundee, N. Srihajong, and S. Charmongkolpradit, "Electric Power Generation from Solar Pond Using Combination of Thermosyphon and Thermoelectric Modules," Energy Procedia, vol. 48, pp. 453–463, 2014, doi: https://doi.org/10.1016/j.egypro.2014.02.054.

M. Orosz and R. Dickes, "Solar thermal powered Organic Rankine Cycles," in Organic Rankine Cycle (ORC) Power Systems, E. Macchi and M. Astolfi, Eds., Woodhead Publishing, 2017, pp. 569–612. doi: https://doi.org/10.1016/B978-0-08-100510-1.00016-8.

K. Liaqat, M. Anss, A. Ali, and A. N. Mengal, "Modeling and Simulation of a 100 {MW} Concentrated Solar Thermal Power Plant Using Parabolic Trough Collectors in Pakistan," IOP Conf Ser Mater Sci Eng, vol. 414, p. 12032, Sep. 2018, doi: 10.1088/1757-899x/414/1/012032.

T. Solar et al., "Performance Improvement and Energy Cost Reduction under Di ff erent Scenarios for a Parabolic," Processes, vol. 7, pp. 1–23, 2019.

M. I. Soomro, A. Mengal, and Y. A. Memon, "Performance and Economic Analysis of Concentrated," Processes, vol. 7, 2019.

S. S. Khatti, A. G. Memon, and S. Qureshi, "Parametric Study of Combined Cooling and Power ({CCP}) Plant Integrated with Parabolic Trough Solar Collectors ({PTSCs})," IOP Conf Ser Earth Environ Sci, vol. 281, p. 12032, Jun. 2019, doi: 10.1088/1755-1315/281/1/012032.

S. M. S. Sadati, F. U. Qureshi, and D. Baker, "Energetic and economic performance analyses of photovoltaic, parabolic trough collector and wind energy systems for Multan, Pakistan," Renewable and Sustainable Energy Reviews, vol. 47, pp. 844–855, 2015, doi: 10.1016/j.rser.2015.03.084.

U. D. of Energy, "Parabolic Trough Solar Thermal Electric Power Plants," 2006.

M. A. Sheikh, "Renewable energy resource potential in Pakistan," Renewable and Sustainable Energy Reviews, vol. 13, pp. 2696–2702, 2009, doi: 10.1016/j.rser.2009.06.029.

M. Shahid, S. A. Kalhoro, D. Ara, N. Bano, and R. Perween, "Wind and Solar Energy Potentials Around Southern Sindh & Southern Baluchistan Provinces, Especially Karachi of Pakistan," 3C Tecnología_Glosas de innovación aplicadas a la pyme, no. May, pp. 116–141, 2019, doi: 10.17993/3ctecno.2019.specialissue2.116-141.

M. Irfan, Z. Zhao, M. Ahmad, and M. C. Mukeshimana, "Solar Energy Development in Pakistan : Barriers and Policy Recommendations," Sustainability, vol. 11, no. 4, p. 1206, 2019, doi: 10.3390/su11041206.

NEPRA, "State of Industry Report," 2015.

S. Naqvi, "Modellig Spectral Data with Type-1 and Type-2 fuzzy sets for breast cancer grading," University of Nottingham, UK, 2014.

S. Karim et al., "A Fuzzy Inferencing System for Stress Management of University Students in COVID-19 for Pakistan," in 2nd International Conference on Computational Sciences and Technologies, 17-19 December 2020 (INCCST'20), MUET Jamshoro, 2020, pp. 5–10.

R. Mamlook, O. Badran, S. Nijmeh, S. M. Abdallah, A. Aljumah, and I. M. A. Arafat, "Advanced Fuzzy Control innovative solar tracking system for solar distillation system," International Journal of Computer Science and Information Security, vol. 14, no. 11, pp. 659–670, 2016.

S. M. Zahraee, M. Khalaji Assadi, and R. Saidur, "Application of Artificial Intelligence Methods for Hybrid Energy System Optimization," Renewable and Sustainable Energy Reviews, vol. 66, pp. 617–630, 2016, doi: https://doi.org/10.1016/j.rser.2016.08.028.

P. Pitchandi and M. Rajendran, "Design considerations and construction of a solar pond for efficient energy harvesting using a fuzzy controlled TEG," International Journal of Computer Aided Engineering and Technology, vol. 11, no. 4/5, pp. 430–438, 2019.

C. H. Huang, H. Y. Pan, and K. C. Lin, "Development of Intelligent Fuzzy Controller for a Two-Axis Solar Tracking System," Applied Sciences, vol. 6, 2016.

S. Verma and R. Das, "Effect of ground heat extraction on stability and thermal performance of solar ponds considering imperfect heat transfer," Solar Energy, vol. 198, pp. 596–604, 2020, doi: https://doi.org/10.1016/j.solener.2020.01.085.

Y. Wang, L. Xu, and Y. A. Solangi, "Strategic renewable energy resources selection for Pakistan: Based on SWOT-Fuzzy AHP approach," Sustain Cities Soc, vol. 52, p. 101861, 2020, doi: https://doi.org/10.1016/j.scs.2019.101861.

F. L. Rashid, I. K. Fayyadh, and A. Hashim, "Design of Solar Pond for Electricity Production," British Journal of Science, vol. 3, no. 2, pp. 104–109, 2012.

J. A. K. Mohammed and B. H. Mahdi, "The Prediction of Solar Radiation using Fuzzy Logic: A Case Study," Journal of Duhok University, vol. 21, no. 2 SE-Pure and Engineering Sciences, pp. 34–44, Jul. 2019, doi: 10.26682/sjuod.2018.21.2.4.

A. J. Sánchez, J. M. Escaño, C. Bordons, and E. F. Camacho, "Fuzzy based state observer of a solar trough field," in 2019 30th Irish Signals and Systems Conference (ISSC), 2019, pp. 1–7. doi: 10.1109/ISSC.2019.8904927.

M. J. Reno, C. W. Hansen, and J. S. Stein, "Global Horizontal Irradiance Clear Sky Models: Implementation and Analysis," 2012.

H. Pro, "Homer Pro Website." [Online]. Available: https://www.homerenergy.com/products/pro/docs/latest/global_horizontal_irradiance_ghi.html

F. Green, "First Green Consulting Website." [Online]. Available: https://firstgreenconsulting.wordpress.com/2012/04/26/differentiate-between-the-dni-dhi-and-ghi/