168. Design of Solar Coal Hybrid Power Plant: Techno-economic Analysis

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Abstract

Electricity is the basic need of this era and power demand is rising over the worldwide day by day. There are many factors impacting the energy market, so the energy system is becoming more and more complex. Four core challenges are needed to be addressed whenever to install a power plant; reliable power supply, economic efficiency, resources efficiency and environment protection. The research focuses on a conceptual 100 MW solar-coal hybrid power plant design that can be possibly through integration of both resources (Solar + Coal). Pakistan lies in a belt where the both resources are easily available. The theme of work is to provide solar energy directly to the feed-water heating system by using Parabolic Trough Collector (PTC) due to of its high efficiency that increases the enthalpy rate of the steam, so the fuel consumption requirements can be possibly reduced through it. The rate of feed-water heating depends upon the DNI, (W/m^2) level that is highest in the month of June in Pakistan and the designing of the plant will be considered accordingly. The reduction in fuel (coal) consumption, associated penalties in terms of, Carbon Dioxide, CO_2, emission as well as, attaining Clean Development Mechanism (CDM) also be achieved in this process.

Keywords: *"Direct Normal Irradiation", "Parabolic Trough Collector", "Clean Development Mechanism", " Photo-voltaic", "Heat Transfer Fluid","Solar Collector Assembly","Megawatt Thermal", "Carbon Dioxide"*

1. Introduction

Pakistan has coal reserves more than 185 billion tones. It is expected that Pakistan's coal assets might generate more than 100,000 MW of electricity for next 30 years [1]. Coal is the reliable source to generate the electricity from it. Pakistan has also lies in the area of great solar radiation capacity. On the typical average 5 to 8 kWh/m^2/day of Insolation exists in the state more than 95% of its area with resolution factor of over 85% [2, 3, 4]. The mostly cities of the country receives 250 sunshine hours in a month [5]. Most part of the state where the average sun shines hours is about 8 to 8.5 hours a day [6]. In Pakistan, both resources are easily available which can be used for electrical power generation to keep our country out from the running energy power crisis. The research focuses the phenomena of integrate of both resources to make a system reliable and efficient.

A Hybrid energy system usually consists of two or more energy generating resources together that can increase system efficiency as well as greater balance in energy supply [7]. According to Green Peace International report (GPIR), Pakistan deserts areas are the most suitable for generation of electricity through solar thermal power in the world [8].Solar energy can be converted from solar energy in to two ways, PVs and Solar Thermal collector. In the research, the phenomena of integration by exchanging heat in feed-water heating system of coal-fired power plant through solar is used and as for this, solar power taken from solar thermal collectors. Normally, three types of solar thermal collectors are used; parabolic trough collectors, Solar Tower and Dish type's collectors. The research has remained emphasis on Parabolic Trough Collectors which is one of the finest trust-able technologies for solar power use to produce electricity. In the world, many power plants are running on solar thermal. The total capacity of the production is about 1750 MW in which 96% of the generation taking from parabolic trough technology [9, 10].Different intent technologies have been established but presently are below expansion for numerous applications. The Parabolic Trough Solar Collectors scheme will undoubtedly deliver within subsequent decade a major involvement to efficient, cost-effective, maintainable renewable and clean energy supply to emerging countries with positive influence on environment. The collector materials used on basis of conversion proficiency, abundance of the material, low cost arrangements, affluence of application, estimated lifetime, and the accessibility of space at the collection site.

A parabolic trough solar collector is planned to deliberate sun rays through parabolic curved solar reflectors onto a heat absorber component – a "receiver" – situated in the optical focal line of the collector. The arrays of the collector are possibly 100 meters long. The single-axis stalking System used the position of both solar collectors and receivers in the direction of the sun [11]. The receiver comprises of an especially coated absorber tube, which is fixed in an evacuated glass envelope. The absorbed solar radiation warm up the HTF flowing over the absorber tube to nearly 400°C. This is presented beside a heat exchanger in which steam is created, which then produces power in the turbines. Tracking is mainly significant in solar energy collection systems that work beneath intense light. The parabolic concentrators continuously need the alignment near the sun. By tracking the sun-commencing sunrise to sunset, the parabolic collectors concentrate the sun's radiation with their parabolic mirror aspects on the absorber tubes beside their focal line to assemble the heat. The reflected troughs expression the sky and straight sunlight to a large metal and glass receiver in the internal of trough that embraces circulating oil. The thermal competence of a parabolic trough solar collector is influenced on the precision with which the collector tracks sun. There are different Heat Transfer Fluid (HTF) used inside Dewar tube to absorb the concentrated ratio of solar energy. It is be possible to achieve 400^oC by increasing the temperature of the fluid. The common fluids that are synthetic oil, pressurized seam and molten salt. It has thermal efficiency between 60-80% and mostly used in generation of electricity by solar energy.

2. Literature Review

In this section, two different generation resources will be discussed that how it works and what kind of problems seems to be observe while generation from those.

2.1 Coal fired Power Plant

In these plants the generation of steam can be achieved to heat the water in the boiler and given it to the next stages of turbine that is extract further H.P and L.P stage to provide the mechanical movement force and run the generator to generate the electricity. The outlet temperature and pressure of a turbine would be low as compare to Inlet of turbine because of extraction of steam in the turbine. The enthalpy of the steam depends on the temperature and pressure rate which is also low at the out let of the turbine. The extract steam from turbine is then given to the condenser for cooling purpose and some part of extraction steam provided to the feed-water heating system to increase the steam temperature and its enthalpy before providing inlet of the boiler is called bleeding steam. The main advantage of this concept, the less fuel will be required in steam generation process. The fuel (Coal) is using in coal-fired power plant is large in quantity, so the little handsome consumption of fuel can be save from feed-water heating concept which also gives benefit in reduction of Carbon Dioxide emission and its associated penalties.

2.2 Solar Thermal Power Plant

The basic principle of solar thermal power plants is the usage of concentrating parabolic dish arrangements in large-scale solar fields that focus the solar emission against receiver. All arrangements are essential track the sun in demand to be capable to concentrate the direct radiation. This emission is initial transformed in a distinct absorber scheme (receiver) hooked on thermal energy on temperatures in the range of around 200 to above 1,000 °C (depending on the system). These systems have benefit that they have nor environmental polluted but the main disadvantage is that they are totally depended upon solar energy. The sun energy is not available all the time so they have must require a backup source of energy like batteries but the cost of the plant would be more in this respect. So, the stand alone solar power plant can only give the better efficiency at the day time hours when the sun energy is easily available.

3. Methodology

In the coal fired power plant, the coal is used in large quantity for the generation of electricity because they are totally depended upon coal source. As the coal consumption rate increases, the carbon emission rate has also been increased which cause environmental damages such as global warming while solar thermal power plant totally depends upon solar intensity, so the both system has their own demerits. The 100 MW solar-coal hybrid power plant is proposed in the research. There is using the concept of integration to combine both resource and generate the electricity. The contribution of solar energy in the existing or new coal fired power plant can be possibly and for this purpose solar collectors will be used for the same. Parabolic trough collectors are the high efficient and mostly used all over the world, so this type of collector has been selected for the hybrid system. The calculation is based on the DNI, (W/m^2) rate that is available in Pakistan discussed in [12, 13].

Table 1. DNI, W/m^2 Availability in Pakistan Different Month Year

Month	**Average Rate of DNI (W/m^2), Different Months of the Year**
January	293
February	356
March	430
April	455
May	468
June	**559**
July	527
August	500
September	388
October	433
November	317
December	235

In the designing procedure of Solar Field, there are some terms to explain and calculate. Primarily, we will get the whole design of solar field as per our requirement. Then find the solar field area calculations which are given in m^2 and the land requirement according to the solar field, calculate the overall efficiency of the solar collector which is according to the DNI (W/m^2), calculating the SCA that how much it has to be used and lastly the loops requirements. The whole calculations for the solar design will be discussed in this section. In the same scenario, the DNI, (W/m^2) data is considering for Pakistan at their availability at different months of the year. The highest value of DNI, (W/m^2) average rate is observed i.e. 559 W/m^{2}in the month of June thatin the month of June. So, in the designing procedure, the highest DNI, (W/m^2) rate will be considered. For this purpose, parabolic trough collectors are using which receives solar energy and transfer energy to the H.P and L.P feed-water system and improves the thermal efficiency of the system in term of saving fuel like; coal.

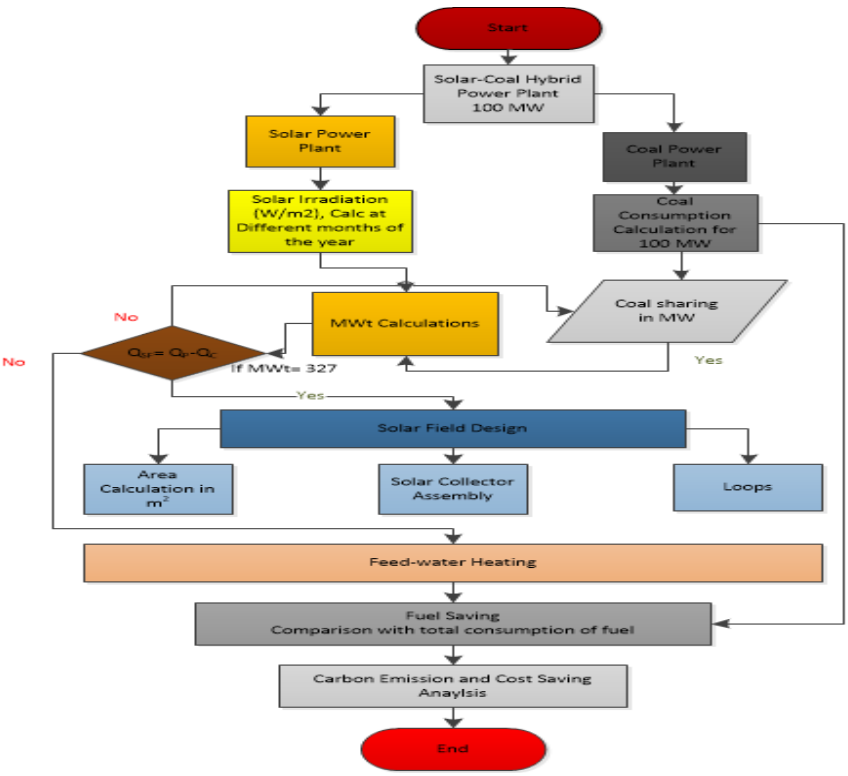

Fig. 1. Flow Chart for the Proposed Project

The contributions of solar energy through these phenomena's and interact with coal fired power plant, gives handsome amount of saving coal and decreasing the fuel cost rate. If the coal usage low then the impact on the environment is in decreasing penalties of global warming. The overall methodology of the project is defined given in the Chart.1. For the designing procedure of solar collector system assembly the available DNI data is been considered. For a 100 MW system, it is define how much the Megawatt Thermal (MW_{th}) energy will be required for feed-water heating system. The rate of MW_{th} is directly proportional to the value of DNI, W/m^2, so the system will be design according to it.

It has considered that the availability of solar energy is about 14 hours a day, so it still feeding the thermal energy through solar system in the same hours. So, in the remaining 10 hours, the Megawatt thermal requirement will be achieved from giving the bleeding steam process. We can save the most of fuel consumption at the day time hours by the contribution of solar energy in coal-fired power plant. The overall capacity of the plant is taken 100 MW and in the night hours the total energy will be provided from coal source.

4. System Designing of Solar-Coal Hybrid Power Plant

As we discussed the both phenomena's of stand-alone coal-fired and solar power plants have their own merits and demerits. The concept discuss in the research work is to integrate both phenomena's together and achieve the better response as well. For the same purpose, at the feed water heating system the external energy would be provided from the solar energy, where no more bleeding steams require heating the feed-water heating at the those hours where the solar energy is available easily. The rate of exchanging heat in the feed water heating system is depending upon DNI, (W/m^2) rate. As the level of DNI, (W/m^2) increases, the contribution of heating from the sun is also increases. The basic Rankine cycle efficiency date for a 100 MW Power Plant [14] is given in Table. 2:

Table 2. Basic Rankine Cycle Efficiency Data for 100 MW Power Plant

Operating characteristics of Rankine Cycle for (100 MW)	Values
Boiler inlet	150°C, 80 bars
High pressure turbine inlet (Temp)	480 °C
H.P heater inlet	20bars
High pressure turbine inlet (Pressure)	80bars
Low pressure turbine inlet (Temp)	440 °C
Low pressure turbine inlet (Pressure)	70 bars
Open feed-water heater inlet	3 bars
Low pressure turbine outlet	0.08 bars
Condenser outlet	Saturated, 0.08 bars
L.P heater outlet	Saturated, 3 bars
Steam flow rate	280,000 kg/hr,77.78 Ton/sec
Power output	100 MW
Boiler efficiency	90%
Generator efficiency	90%

In the calculation procedure, the coal consumption on the given value of boiler inlet 150°C, 80 bars, is about 50.1 ton/hr. The temperature of boiler inlet can be increase by providing solar energy to feed-water heating systems (H.P and L.P) through parabolic trough collectors. The maximum temperature of the boiler inlet is raises through solar contribution from 150 ^{0}C to 330 ^{0}C keeping in view of the limitations of flue gas temperature and other technical and technological aspects. The outlet temperature and pressure of the boiler remained constant however the inlet temperature of the boiler varies according to temperature rises of the feed-water heating scheme. The structure of the whole plant is similar to a coal fired power plant, however the addition in this technique is to provide solar contribution at feed-water heating scheme. The designing of solar-coal hybrid power plant is given in Fig. 2:

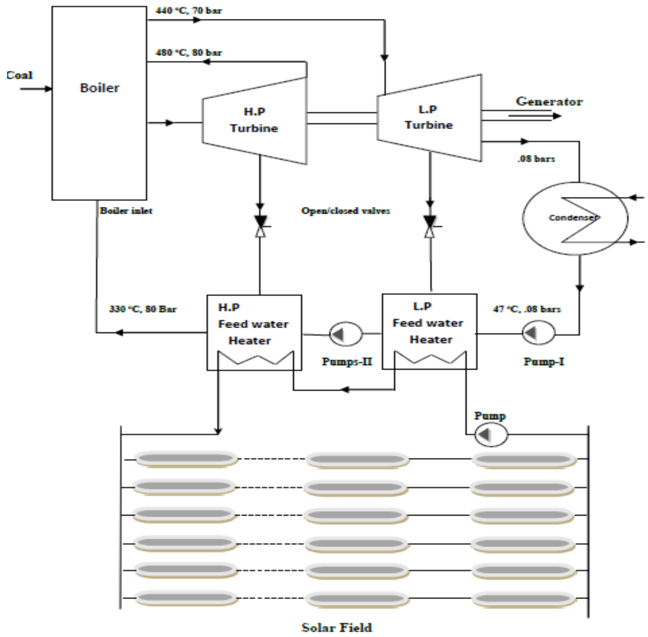

Fig. 2. 100 MW Solar-Coal Hybrid Power Plant.

4.1. Coal Consumption for 100 MW Power Plant

The coal consumption of the power plant calculated to compare the solar field contribution and to establish the feed-water temperature relationship with fuel utilization in the boiler. To find out the coal requirement the following relationship is used.

$$B= (Q_t \times 100)/ (Q1 \times \eta_{net}),\ kg/sec \tag{1}$$

Where, B is fuel quantity (coal consumption) in kg/sec, Qt is the total amount of heat given to the boiler in kW, Q_l is available heat in kJ/kg and η_{net} is the net efficiency of the boiler.
The amount of accessible heat (enthalpy) is considered in terms of kJ/kg. The overall efficiency of the boiler is considering in calculation is 90 %. The value of Q_t is given in "Eq. (1)" that can be determined from "Eq. (2)".

$$Q_t = \ m\ (h_{steam} - h_{feedwate}r) + Dbb\ (h_{boilingwater} - h_{feedwater}),\ kW \tag{2}$$

Where, m is steam consumption in kg/sec, h is the enthalpy of saturated steam in kJ/kg, $h_{feed\text{-}water}$ is the enthalpy of feedwater in kJ/kg, $h_{boilingwater}$ is enthalpy of boiling water in kJ/kg and D_{bb} is the quantity of boiler blow down is kg/sec.

Steam consumption rate which is considered here as 77.78 kg/sec and the enthalpy of saturated steam is calculated at 480 ^oC, 8 MPa (80 bar) pressure level. The enthalpy of feed-water and boiling water are in kJ/kg. To find out the quantity of D_{bb} (boiler blow down) in Eq-1.2 can be calculated as;

$$D_{bb} = p.\ D / 100 \tag{3}$$

Where, p is the value of continuous blow down given in kg/sec that value taken around (2 – 5 % of D), where D is the flow rate of steam, kg/sec. The available heat energy in kJ/kg can be determined as:

$$Q_l = Q_{coal} + Q_{air},\ kJ/kg \tag{4}$$

Where, Q_{coal} is the net calorific value of the coal in kJ/kg and $Q_{air}$is the heat energy of the hot air entering in the boiler in kJ/kg.The coal is selected for the proposed solution, so the calorific value of the coal is taken 16300 kJ/kg. The heat energy is also being considered in the case of boiler, the hot air entering in the boiler which is given in term of kJ/kg. To find out Q_{coal}, the equation is given below;

$$Q_{coal} \ = \beta\ (H_{hotair} - H_{coolair}) \tag{5}$$

Where, H_{hotair} is the enthalpy of hot air, $H_{coolair}$ is the enthalpy of cool air and β is the hot air coefficient and can be determined as:-

$$\beta = \alpha''_T - \Delta\alpha'_T - \Delta\alpha_{ie} - \Delta\alpha_{ae} \tag{6}$$

Where, α''_T, $\Delta\alpha'_T$, $\Delta\alpha_{ie}$, $\Delta\alpha_{ae}$ are the coefficients of excess air at the exit of the furnace, suction air in the furnace, suction air in the dust system and air flows from air in the gas path of air heater respectively. Different variation of temperature across feed-water heaters is analysed and the coal consumption ton/hr is calculated. As per calculation, the rate at which the boiler temperature and pressure available, the consumption of fuel (Coal) required is around 50.1 ton/hr for a 100 MW power plant given in Table 3.

Table 3. Calculation of Coal Consumption at different Temperature

Temp ^oC	Enthalpy Feed-water (kJ/kg)	Coal Consumption (Ton/hr)
150	636.87	50.1
180	766.75	47.6
210	899.94	45.1
240	1038.21	42.5
270	1184.57	39.7
285	1262.93	38.3
300	2776.14	9.8
315	2851.46	8.4
330	2913.57	7.3

The coal consumption decreases from 50.1 ton/hr to 7.27 ton/hr as the temperature surges. As the coal consumption lessened considerably, the Greenhouse gases (GHG) discharge has also correspondently decreased which specifies the economic feasibility of solar related coal fired power plants. It has also shown that upon feed-water heating the coal consumption reduced as the enthalpy of the feed-water is improved.

4.2. Solar Contribution in Coal-fired Power Plant

The mathematical equations derived for calculation of solar contribution Qs, focused on feed-water heating. The solar contribution is in the form of heat energy delivered to the feed-water of the boiler, resulting in rise of the enthalpy of the feed-water and reduction in the ton/hr of coal consumptions for thermal power plant. As a result economical and environment pleasant energy could be produced as a solar associated coal fired power plant the CO2, NOx and SOx discharges are minimum. Solar contribution in feed-water heating has examined at L.P and H.P heaters beside with its effects on coal consumption ton/hr in the boiler. The mathematically solar contribution has been calculated as under:-

$$Qs = m\,[h_{(H.P\ heater)} + h_{(L.P\ heater)}] \quad (7)$$

Where, m is the water quantity entering into the feed-water heaters, ton/hr, $h_{(H.P\ heater)}$ is the enthalpy change due to solar feed-water heating across H.P heater, kJ/kg and $h_{(L.P\ heater)}$ is the enthalpy change due to solar feed-water heating across L.P heater, kJ/kg. At the temperature of 150 ^oC the plant generally works on coal and the rate of coal consumption is 100% but as the sharing of the feed-water temperature through solar contribution the coal involvement will be less even at 330 ^oC the value of sharing of coal is reached to 15 % while the contribution of solar is 85%. It means that as we are sharing the solar contribution, the coal saving rate will also be increases.

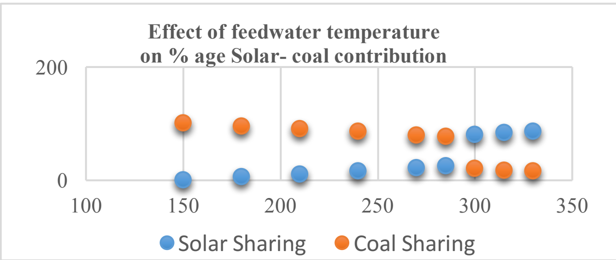

Fig. 3. Effect of Feed-water temperature on solar coal contribution %

As the coal consumption will be decreases the associated penalties of Carbon emission will also reduce that is in the manner of economic benefits. The CDM (clean development mechanism) benefits can be achieved if the reduction of carbon dioxide emission is achieved.

4.3. Thermal Input Requirement, Solar Collector Design and Land Requirements

The thermal input is calculated in this section, it is the total energy required to power plant in the sense of solar contribution. The thermal energy is calculated in terms of MWth. After calculating the value of Q_{SF} requirement for 100 MW power plant that is given below;

Q_{SF} = 327 MWth

From the output result solar field must provide sufficient thermal power in MWth for 100 MW power plant. So, the design procedure of solar thermal field depends according to it which is given in the Table. 1.4: The values of MWth are calculated at different rate of DNI, (W/m^2) with respect to different month average rating of the year. According to the calculated data, it has also been calculated the solar collector assemblies and number of loops requirements for the same thermal output.

In the month of January, the solar field area requirement is much higher as compare to other months which is 1506655 m^2 and the MWth share in the term of solar sharing is 52% and 48% of more thermal energy required for stabling the output demand. So, the left amount of thermal energy will be provided from coal power system**.** The calculation of solar collector assembly (SCA) will be taken at different months of the year. As per calculated results, the number of loops requirement will decrease as the rate of Direct Normal Irradiation, W/m^2 increases. The calculation of solar collector assembly has been considered which is install 6 in numbers per loop. So, in the January the number of loops required for the same output is 307 and that will be further less if we assume it to in June or July month. For the current calculation data, it reveals that solar field area given in m^2 required less in the month of June because of high DNI, (W/m^2) level.

Table 4. MWth, Assembles, Loops and Land requirement for Proposed Project according to changing in DNI, different months of Year

Month	DNI W/m^2	SCA	loops	Land (acres)	Area in Km^2	Solar Field Area (m^2)	(MWth) required	Solar Sharing %	MW solar input in 100 MW
Jan	293	1844	307	372	1.50	1506655	171.39	52	44.55
Feb	356	1518	253	306	1.24	1240028	208.25	64	54.13
Mar	430	1257	209	253	1.03	1026628	251.53	77	65.38
Apr	455	1188	198	239	0.97	970220	266.16	81	69.18
May	468	1155	192	233	0.94	943269	273.76	84	71.16
Jun	**559**	**967**	**161**	**195**	**0.79**	**789714**	**327**	**100**	**85**
Jul	527	1025	171	206	0.84	837666	308.28	94	80.13
Aug	500	1081	180	218	0.88	882900	292.48	89	76.02
Sep	388	1393	232	281	1.14	1137758	226.96	69	58.99
Oct	433	1248	208	251	1.02	1019515	253.29	77	65.84
Nov	317	1705	284	344	1.39	1392587	185.43	57	48.20
Dec	235	1808	301	284	1.25	1250567	206.49	42	35.73

The area of solar field has been calculated by keeping in view desired temperature of the feed-water i.e. 330 ^{0}C. From the results of the solar field area calculations, it is evaluated that for 100 MW solar associated thermal power plant requires average 195 acres land to install. As per mentioned information at NREL site; generally a parabolic power plant required 5 to 10 acres land per megawatt of electric capacity that depends on whether or not the solar field has been oversized to take advantage of thermal energy storage [15]. If the storage capacity is installed with the plant, the field requirement for installation of solar thermal power plant will be increases. The result of solar filed area has been calculated by taking different values of DNI, W/m^2, in different months as solar data and is placed in Table. 4:

The Land area required at different DNI, (W/m^2) average related to different months of the year is given. The calculations shows, as the quantity of DNI, (W/m^2) increases, the required solar field area with land requirements (acres) will be decreased. In the month of June, the solar radiation intensity is high, so the solar field area with land requirement is much less as compare to other months which is approximately 195 acres. In the research the assumption is preferable and taken at the month of June.

5. Results

In this section, solar collector efficiency, generation cost, fuel saving ratio of solar-coal hybrid power plant, reduction in carbon dioxide emissions and along with getting CDM benefits will be discussed.

5.1. Solar Collector Efficiency Calculations

As the rate of DNI, (W/m^2) increases, the efficiency of the collector will also increase. From calculated results, it is depicted that the collector efficiency will be varying from 42 % to 47%. In the month of June, the efficiency of the collector will be high as compared to other months.

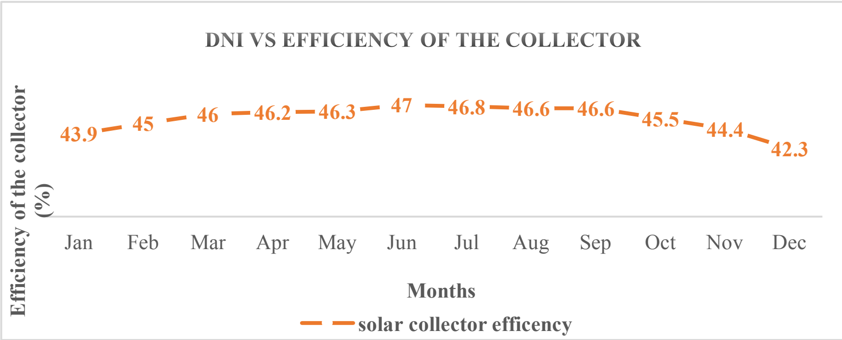

Fig. 4. Effect of Feed-water temperature on solar coal contribution %

It reveals that as the DNI, (W/m^2) increases the efficiency of the collector will also increases and the maximum efficiency is taken in the month of June. The results show the efficiency of the collector is higher in the months of June and July that will be approximately 47% where the DNI, (W/m^2) average rate is highest in these months is 559 and 527 respectively.

5.2 Fuel Saving Ratio and Carbon Dioxide Emission Calculation in 100 MW Solar-Coal Hybrid Plant

The fuel consumption from coal-fired power plant and hybrid power plant has been calculated in the research. From the giving results, the ratio of fuel saving for 100 MW hybrid power plant has been calculated which is approximately 35.6 %. Due to solar contribution the plant will also contribute less carbon emission and 35.6 % in cost saving ratio. The overall emission of carbon dioxide for a coal fired power plant is around 798000 per kg for daily average because they are running continuously for 24 hours. If the values are taken in Tones then it will be around 798 Tons/day. In case of Hybrid power plant, the rate of carbon dioxide emission is getting around 588 tons approximately. The saving of carbon dioxide emission can be achieved by using a hybrid system is around 210 tons/day that is in percentage around 27 % of overall contribution.

5.3 Cost of Generation

Normally, in Pakistan a newly coal-fired power plant generation, cost of electricity is approximately 5 cents per kWh. The generation cost depends upon the installation cost of the power plant; equipment's, maintenance, laboring etc. The calculations are taking for a 100 MW coal-fired power plant. The cost of the generation is found out that is approximately 0.05 $ per kWh for a pure coal-fired power plant. For the calculation of solar-coal hybrid system, is taken around at day and night time. The sun energy is not available in the evening, so the hybrid power will run on coal for 10 hours. The total cost of generating will be taken for a day is around 88000 $ and the production rate will be 0.036 $ / kWh. Here, it is revealed that the generating cost of solar-coal hybrid power generation will be less as compare to coal-fired power plant.

5.4 Profit Margin and Payback Period of Solar-Coal Hybrid

In the solar-coal hybrid power plant, the cost of the generation calculated is less as compare to the coal-fired power plant which is approximately 0.036 $/kWh. It is because of cost of fuel saving ratio and reduction penalties of carbon emissions also help in reduction of installation cost of the generation. In the day time hours, when the solar energy is available then the plant will run for 14 hours from solar power. Normally, the average sale price / kWh is approximately 0.12 cents/kWh in Pakistan. In the night hours, when the solar contribution is not available then the plant runs on coal only, so the total duration is about 10 hours to run coal-fired power plant, so the average margin calculation is around, 117600 USD ($)/day. The data can be calculated for a month is around 6,048,000USD ($)/month while annual 72,576,000 USD ($)/year respectively. The labor and O&M charges will also be included that is approximately 20% and in the net profit the CDM (clean development Mechanism) benefits will also be added by saving the carbon emission penalties, so the payback period of the plant will cover in 8 years.

Table.5.Profit Margin and Payback Period of Solar-Coal Hybrid

Year	Out Flow ($)	In flow ($)	Profit	DCF(13)%	PV($)	NPV($)
0	300000000	0	0	1	-300	-300
1	14515200	72576000	58514400	0.884955752	51782654.87	-248217345
2	14515200	72576000	58514400	0.783146683	45825358.27	-202391987
3	14515200	72576000	58514400	0.693050162	40553414.42	-161838572
4	14515200	72576000	58514400	0.613318728	35887977.36	-125950595
5	14515200	72576000	58514400	0.542759936	31759272	-94191323.1
6	14515200	72576000	58514400	0.480318527	28105550.44	-66085772.6
7	14515200	72576000	58514400	0.425060644	24872168.53	-41213604.1
8	14515200	72576000	58514400	0.376159862	22010768.61	-19202835.5
9	14515200	72576000	58514400	0.332884833	19478556.29	275720.79
10	14515200	72576000	58514400	0.294588348	17237660.44	17513381.2
11	14515200	72576000	58514400	0.260697653	15254566.76	32767948
12	14515200	72576000	58514400	0.230705888	13499616.6	46267564.6

The overall installation cost of the hybrid power plant is consider here 300 million USD ($) approximately while the discount factor is taken around 13 % at the total investment.

6. Conclusion

Solar-coal power plants application is quite feasible in Pakistan to integrate with existing coal fired power plants or with new power plant. The power generated through the integration solar power gives significant saving of coal i.e. up to 42.8 ton/hr of coal during the solar contributions hours (i.e. 8:00 am to 18:00 pm). Solar contribution is maximum in the month of June i.e. 85 % sharing when DNI (Direct Normal Irradiation) is 559 W/m^2. Solar contribution is available throughout the year to provide cost-effective and environment friendly energy. The designing of solar field which is based on the maximum Direct Normal Irradiance (W/m^2) provides 100 % sharing and cost of the solar field would be optimum to avail maximum benefits out of it throughout the year. Although, the hybridization of the power plant is a good initiative escorted by better profit margin; clean way of power generation and long span merit of reduced greenhouse gases (GHGs) emissions. CO_2 emissions of proposed power scheme has been significantly reduced i.e. 75600 ton/annum.

The integration of solar in coal-fired power plants is a sustainable procedure of power generation. A solar-coal hybrid power plant has got high in the initial capital cost of the solar field but the advantages of solar field that required limited maintenance and operational costs as paralleled to a coal-fired power plant. The price of energy generated is also low i.e. 0.036 $/ kWh as compared with the 0.050 $/kWh. Project payback period in case of solar-coal fired power plant is less than that of coal fired power plant due to the contribution of CDM benefits in term of reduction in GHG emissions. Utilization of energy resources would also be helpful to reduce Green House Gas Emissions (GHG) such as reduction of CO_2 emissions which will helpful to make the projects environment friendly. Renewable energy resources especially utilization of solar power potential could also contribute to provide the country with affordable energy, which ultimately play a key rule towards country economic growth. Thus make the solar-coal power plant economically viable.

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