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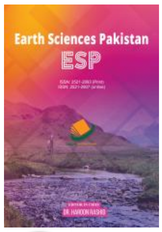

RESEARCH ARTICLE

EFFICIENT ENERGY SOLUTION FOR WASA FAISALABAD TAKING INTO CONSIDERATION THE ENVIRONMENTAL IMPACT ASSESSMENT

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ABSTRACT

This work describes the energy requirements for water supply and sewerage management of Faisalabad urban area and additionally suggests energy management improvements by incorporating grid connected renewable Photo-Voltaic (PV) based power generation. As the ground water in Faisalabad is mostly saline, Water and Sanitation Agency Faisalabad (WASA FSD) brings water from nearby soft water sources and pumps them to consumers within the city. To maintain water supply and sewerage disposal operations, WASA FSD requires to purchase 40k to 50k USD worth of electricity monthly from Faisalabad Electric Supply Company (FESCO) which is financially burdening for WASA. Additionally, as this energy demand is met from Pakistan's already strained national grid, there is a need to better manage Agency's energy requirements. In this work, we study utilization of an On-Grid PV solution for renewable power generation to meet the agency's requirement of are 3.238×10^6 electricity units per month. Such systems can, in principle, eliminate dependency of WASA on the National Grid and additionally provide WASA with an energy efficient and sustainable power generation system with low environmental impact. In this paper, simulate a solar energy system without any energy storage system to determine its feasibility. Here, we present simulation results to estimate successfulness of such a project. Additionally, financial and technical aspects of the project have also been discussed suggesting a payback period less than 7 years.

KEYWORDS

Photovoltaic system, Renewable energy, Environmental Impact Assessment, Cost Analysis, WASA, Water supply power management.

1. INTRODUCTION

Faisalabad being the third largest city in Pakistan with a population of over 4 million and a thriving industrial sector requires a very elaborate water and sewerage management system. This task has been assigned to a Public authority known as the Water and Sanitation Agency Faisalabad (WASA FSD). Unfortunately, clean drinkable soft water within the city is very scarce and WASA has resorted to using water pumping stations and tube wells to meet the city's needs. Most of this water is brought using pumping stations from nearby soft water sources around the city. Tube wells are also operated by the agency close to various water sources within and outside the Faisalabad city. To quantify the extent of WASA's operations, a total of 0.11 million domestic, 2,348 commercials and 92 Industrial connections have been registered with the agency [1]. Also 443 industrial aquifer connections are registered with WASA FSD. In addition, sewerage management from city's residential, commercial and industrial sector using disposal stations is also managed by WASA FSD.

To maintain a continuous water supply and waste disposal, heavy machinery needs to be operated by the agency demanding energy supply worth 40k to 50k USD from Faisalabad Electric Supply Company (FESCO). As an alternative to energy supplied by the National Grid through FESCO, WASA FSD's energy requirements could also be met through renewable energy sources. One such alternative is to convert solar radiation to electrical energy using Photo-Voltaic (PV) arrays. The unique geographical position of Faisalabad District with its desert like weather and an average yearly temperature of 24.2 °C, make it an ideal location for harvesting solar energy [2]. Although this region receives more than 340 mm of rainfall per year, most of it comes during Monsoon season peak in July and August. This corresponds to little cloud cover to obstruct operation of PV cells during the rest of the year. Thereby, solar energy system may be utilized to not only fulfill the needs of WASA Electricity load demand, but it may also generate surplus energy to be sold to National Grid.

From an environmental perspective, such a project also provides a clean, sustainable and efficient energy solution. A detailed feasibility study of this project has been performed suggesting a largely positive financial and environmental impact in the long run [3]. This includes an overview of site selection, construction and management guidelines. This work discusses impact of renewable systems and their relevance with the problem at hand. Later, an overview of the PV energy generation system and its constituent subsystems are described. Afterwards, results of the software simulations are described which provide overview of PV system's performance, cost and payback period.

2. BACKGROUND

WASA Faisalabad, is a Water and Sanitation Agency, working for the Government of Punjab, Pakistan. WASA FSD, working as a public Water and Sanitation Agency for Faisalabad region, has its overall peak electricity load demand of 11 MW. However, the Agency does not generate its own power and is dependent on National Grid to meet its energy requirements. WASA's average monthly expenditure in Faisalabad is 40k to 50k USD.

Additionally, the local Electricity distribution company is suffering from shortage of electricity, due to which WASA is suffering from electricity blackouts. This condition of energy shortage and blackouts is associated with Pakistan's energy crisis whose policy level study and remedial steps are being analyzed [4]. This This makes it difficult to operate heavy machinery installed in the area to supply water and to dispose sewage. As this option does not allow a continuous operation, an energy efficient solution is required to streamline WASA FSD's operations in the region [5].

As Faisalabad is an urban area with a booming industrial sector and an ever-increasing population, the environmental impact of any new industrial level projects in the area must be properly assessed [6]. Considering the large amount of pollutants introduced by the industrial sector in both the surrounding air and water, it is important to ensure that new projects do not negatively impact the environment. Thereby, it is imperative that the energy generation setup introduced by WASA FSD should be environment friendly to curb increase in regional pollution and to cut down on carbon emissions etc. [7].

Conventional energy generation sector has generally had a huge impact on our environment. Non-renewable energy systems have highly negative environmental effects and reserves of fossil fuels are rapidly diminishing. On the contrary, Renewable energy sources like Solar power generation using PV arrays and Wind power generation form wind turbines provides a sustainable alternative without any negative environmental impact. Although, potential for Wind power generation and wind turbine optimization is being studied for specific regions in Pakistan, it is not a suitable option for urban landscapes like Faisalabad City [8]. Proper renewable energy system deployment study is not only helpful in reducing carbonization but also increases the efficiency, reliability and security of the system if integrated with the National Grid. Among Currently, the power supply infrastructure in third world countries like Pakistan cannot keep up with a constantly changing demand for electricity [9].

Electricity from renewable energy sources can typically be generated very close to the end users providing a great deal of flexibility to the supplier [10]. An additional feature of renewable energy is the gradual reduction in electricity cost over time making it an economical source of energy. As compared to coal, prices of renewable energy sources are decreasing in direct proportion. Since 2008, the costs of solar panels have decreased 80% while it is halved for the windmill setup [11]. This trend of reduction in cost of renewable energies is making them ever more accessible [12]. Additionally, Net metering technique can also be used to provide any surplus renewable energy to the National Grid to achieve financial benefit [13, 14]. It is also possible to implement a smart gridding using to PV-Grid system with the integration of Information Technology (IT) with Power Generation, transmission, distribution, and storage [15].

3. SYSTEM DESCRIPTION

This section describes the design of the proposed PV-Grid system to provide efficient energy solutions for water industry without compromising on the environmental aspect. A detailed feasibility study, performed by WASA FSD, suggests that solar energy system could fulfill these working conditions and provide a sustainable energy system [2]. Renewable energy systems typically have a significant setup cost but are followed by negligible operational & maintenance cost. Also, the environmental impact assessment of such a system is also positive as no pollutant are produced resulting in zero Carbon emissions [9]. These aspects of the proposed PV-Grid system are further analyzed in the following subsections.

3.1 Design Concept

The solar energy system proposed for this work will be connected to National Grid. This aspect of the design is included as WASA FSD doesn't have any power distribution system. Thereby, an agreement has been made in this regard with FESCO, which is a local power distribution company. In this way, the electricity units produced by the solar energy system of WASA Faisalabad are sold to FESCO with the help of net-metering technology. Resultantly, the monthly energy expenditures would have been reduced to a considerable value. Per unit cost of the solar energy system is PKR 22 for the net metering of a 24 MW system as per the NEPRA (National Electric Power & Regulatory Authority) rules at that time. As the average units consumed monthly by WASA are 3.238 $\times 10^6$, this corresponds to a saving of approximately PKR 50 to 60 million for the agency against a peak load of 11 MW.

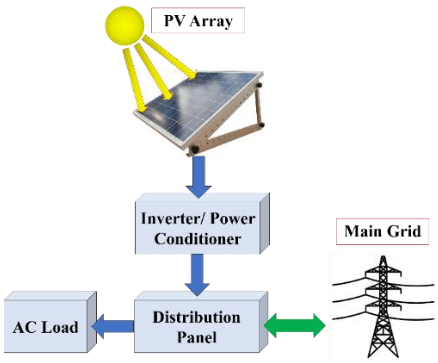

Figure 1: Structure of a solar energy system.

Transferring 24 MW power generation from conventional sources to renewable energy can not only benefit the environment but can also help curb electricity blackouts by providing surplus energy to FESCO. A basic PV system without battery backup is shown in Figure. 1. This figure describes interconnections of a grid-connected PV system. A similar design approach with additional net metering option has been adopted for the grid connected solar energy system in this work.

3.2 System Components

The solar energy system under consideration is a *Grid-tied system* without battery backup as shown in the Figure 2. In this system, the net power produced by the solar energy system is contained within the circuit using DC/AC inverters, charge controllers and other connected accessories for onward transmission to the grid.

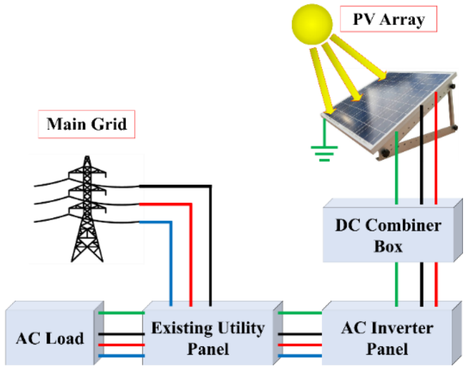

Figure 2: Grid tied PV without Battery Backup.

But before the power could be transmitted to the grid, there is another component, which comes across, which is known as a net meter. This technique is also shown in Figure 3. Net metering is a billing mechanism, which credits the consumer for adding additional electricity to the national grid as already discussed in the literature survey.

3.3 Environmental Impact Assessment

An Environmental Impact Assessment (EIA) study of the 24 MW solar energy project reveals that it would have negligible or minor adverse effects on the environment [3]. In fact, the proposed project will alleviate/offset the power crisis faced by WASA Faisalabad with the arrangement of cheaper and uninterrupted energy supply which will improve the sewerage system for the inhabitants of Faisalabad. However, during the project construction phase, it is imperative to follow strict environment friendly criteria.

The EIA study proposes that selected borrowed lands, for system installations, must be clearly demarcated before starting any soil removal/extraction and no soil removal/extraction should be carried out outside the demarcated areas. Six inches of the fertile topsoil should be removed and separately stored. Later, excavation of land up to a maximum of 3 feet should be performed and the separated topsoil should be placed back on the leveled area during the restoration process. To compensate for number of trees lost due to the construction of proposed project, at least 3-5 fold larger number of plants/trees should be planted later on.

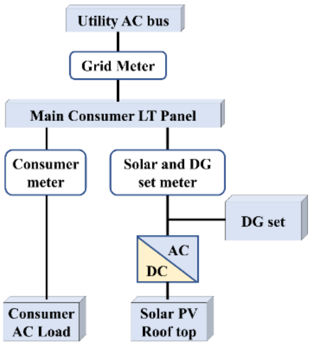

Figure 3: Net metering.

The construction site should be at least 500 meters away from the residential area to nullify the effects of construction [3]. Moreover, there should be a proper drainage mechanism at the site location. Pollution control mechanisms can be implemented at the site location and constantly monitored to avoid any inconvenience [16]. The timing of construction should be planned to avoid any disturbance in the daily routine life of the locals. It is further emphasized in that the contractors should ensure an environment in which due respect is given to the locals with due preference of job opportunities as well [3]. A Social Framework Agreement (SFA) may be signed with people of the adjacent villages based on a win-win policy. WASA may be advised to implement any good alternate to their existing practices of wastewater disposal through open pond system. It will give a great relief to the existing nearby settlements. Strengthening of road network, education facility and health improvement system may be enhanced as Area Development Plan. Additionally, Prior to project initiation, Environmental Approval (NOC) from EPA (Environmental Protection Agency), Punjab must be sought.

4. SYSTEM PERFORMANCE

To analyze performance of the proposed solar energy system in terms of its integration with the already available power distribution infrastructure, simulations have been performed using a commercially available PV system simulation software. The aspects of the system considered to analyze its performance are detailed in following subsections.

Table 1: Simulation Parameters Of Grid Connected System

Parameter	Value
Geographical site	Chokera (WASA)
Country	Pakistan
Latitude	31.4 degree North
Longitude	73.0 degree East
Altitude	180 meters
Collector plane orientation	28°
Horizontal shading	None
Vertical shading	None
Model used	Transportation (Porez)
Electrical Effect	50%

4.1 Simulation parameters

System simulation considers the simplified solar energy system model depicted in Figure 2. The basic components involved in the model include PV array, Inverter pack and corresponding interconnections. As battery storage system is not included in Figure 2, it is not considered in the simulation model as well. General simulation parameters associated with grid connected solar energy system and geographical and climatic aspects has been listed in Table 1. PV Module JAP6-6—260/38 manufactured by JA Solar has been considered. To obtain a maximum capacity of 24 MW, 92,300 such modules are utilized. Characteristics of PV array are listed in Table 2. The Inverter considered in the simulations is SUNGROW's SC500MX with a nominal 500 kW output AC power. A total of 42 Inverters are needed for efficient connection with the PV arrays as depicted in Figure 2. Inverter characteristics are listed in Table 3. To accurately estimate the performance of proposed PV-Grid system, electrical losses in the system need to be correctly modeled as well. Thereby, Loss Factors simulating ohmic losses in the PV array, external transformer, power cables etc. have been considered in the model. These Loss Factors have been listed in Table 4.

Table 2: PV Array Characteristics

Parameter	Value
PV Module	Model JAP6-6—260/388 (Polysilicon)
Manufacturer	JA Solar
Total no. of PV modules (no. of strings × no. of modules)	92,300 (20 × 4615)
Unit nominal power	260 W (Peak)
Array global power (peak)	23,998 kW
Array global power (operating)	21,533 kW (@ 50ºC)
Array Voltage (operating) [U_{MPP}]	548 V
Array Current (operating) [I_{MPP}]	39,317 A
Total Array Area	1,50,924 m^2
Total Cell Area	1,34,773 m^2
Cell Fill Factor	89.3%

Table 3: Inverter Characteristics

Parameter	Value
Inverter Model	SC500MX
Manufacturer	SUNGROW
DC Operating Voltage	500-820 V
Unit nominal power	500 kW AC
No. of inverters	42
Total Power	21,000 kW AC

4.2 Grid-Connection Study

The Grid Connection study is performed to analyze the output of PV generation depending upon the irradiance level of the incident sunlight rays which decreases or increases corresponding to Sun's direction. The ambient temperature also has a substantial effect on this output which can degrade at a higher temperature according to the design and material used in the solar panel. The second aspect which affects the output, is the rating of the inverter with respect to the temperature.

Technical feasibility of interconnections can be used to evaluate output power flow from the proposed solar power plant. Thereby, short circuit and load flow analysis has been performed to shortlist a scheme for power grid planning. Additionally, transient and power quality analysis are performed to understand its' influence on power grid operation. A stability analysis has also been carried out to check the dynamic impact on the solar power plant due to disturbances on the 132 kV network of FESCO, especially at sub-station, and vice versa. The dynamic model of the solar power park can be validated and tuned to the PV-Solar model.

For this purpose, the simulated system disturbances include the possibility of a *three-phase fault on the 132 kV* bus bar of solar power plant and trip of a single circuit emanating from that bus. Also, a *three-phase fault on the main system* bus bars can occur resulting in trip of a single circuit emanating from that bus. Finally, *trip of a generating unit* in the power plants in the FESCO network near the proposed power plant has been simulated.

4.3 System Ruggedness

To ensure that the performance of the system is impervious to environmental factors, system ruggedness has been simulated as well. Disturbances in temperature, irradiance and weather conditions could harm the efficiency of a solar system, which normally lies between 15 to 20% of nominal value. When an external disturbance is introduced, the peak output power changes. The solar energy system gives its best performance at STC (Standard test conditions) i.e. 25ºC and 1000 W/m^2 of the irradiance value. However, changes in these environmental conditions adversely affect overall system efficiency. Thereby, project site location with optimal environmental conditions can be advantageous. For this purpose, Chokera WASA has been selected after careful observations of the site environmental conditions.

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Table 4: System Loss Factors

Parameter	Value
Array soiling losses ($\mu_{Loss\ Fraction}$)	3.0%
Thermal loss factor (Uc)	29.0 W/m²K
Wiring ohmic loss (0.16 mΩ array resistance)	1% at STC
Module Quality loss	1.5%
Module Mismatch losses	2% at MPP
AC wire loss (Wires 3×30,000 mm²: 67 m)	1.0 % at STC
Total Power	21,000 kW AC
External transformer (Iron Loss with 24H connection)	23,573 W (0.1% at STC)
Resistive inductive losses	1.1 % at STC

5. RESULTS AND DISCUSSION

During performance analysis, two major scenarios have been simulated. These include simulations at optimal conditions and at nominal operating conditions. At STC, 23,998 kW(p) of output power has been estimated. On the contrary, 21,533 kW(p) recorded at normal operation conditions. Losses have also been considered in the simulation as described in Table. IV. 92,300 solar modules have been used in which 20 modules are connected in series to form a string and there are 4,615 strings connected in parallel. In this situation, Unit Nominal power per module is 260 W(p). Array and inverter operating characteristics are also given to have a detailed overview of the system. Total power output after incorporating all loss factors comes out to be under 21,000 kW AC. The exclusion of battery storage system from proposed system helps reduce system maintenance and capital cost. Additionally, the initial capital cost of batteries is also eliminated. However, this decision removes the possibility of energy storage and all excess energy must be sold to National Grid using net metering technique depicted in Figure 3. No horizon shading and external shading have been considered in the simulations which is approximately correct once we consider topology of selected site.

Table 5: Cost Estimate Of The Project

Items	USD (Million)
Module Cost (including $ 0.02 million/ MW for degradation)-Poly Crystalline	14.364
Inverter Cost-Central	2.268
Mounting structure-Fixed Tilt Ground Mounted	2.52
Cable and transformer	3.52
Civil & General work	2.52
Project Development Support	0.9324
Insurance during construction	0.252
Project Development	0.263
Contingencies & Misc.	
CAPEX (Capital Expenditure)	26.3764
Financing Fees & Charges 3 %	0.6804
IDC	0.4788
Module Cost (including $ 0.02 million/ MW for degradation)-Poly Crystalline	14.364
Inverter Cost-Central	2.268
Mounting structure-Fixed Tilt Ground Mounted	2.52

The payback period of the solar energy system is very competitive. The expenditure estimates to conceive this Solar power plant are provided in Table 5. A total amount of USD 27.7994 Million is required to execute this project. Whereas the Payback period can be calculated from the average Electricity units monthly consumed by WASA Faisalabad. Considering WASA's total monthly consumtion of 3.238×10^6 kWhr. On the contrary the proposed system working at nominal conditions for an average of 5.5 hours per day can generate a total of 21,000 kW ×5.5 hours × 30 days = 3.465×10^6 kWhr units which is sufficient to meet WASA's needs. Considering per unit price of 0.1 USD, this corresponds to monthly saving of 0.346 Million USD per month as WASA's customers would still pay for WASA's services. Consequently, payback period will be 27.7994/ 0.346 ≈ 81 months which corresponds to less than 6 years and 9 months. As the average life of PV modules and Inverters is typically around 10 years, this project can be profitable in the long run after even including maintenance/replacement expenditures.

Furthermore, as WASA Faisalabad is a water generation and distribution industry, and the rates of water supply are based on tariffs, which is further indirectly related with energy cost. When solar energy system would come practically into operation, the rates of water supply can automatically be reduced, and the benefit can be transferred to the citizens of the city accordingly.

6. CONCLUSION

The proposed work has provided an energy efficient and environment friendly solution to WASA's energy needs to maintain fresh water supply and sewerage disposal of Faisalabad region. Consequently, the WASA's energy demand of 3.238×10^6 kWhr per month can be met with a 24 MW Solar energy system. The payback period of this project is very good with the initial cost covered within first 7 years. However, in this work, horizon shading, humidity and weather conditions have not been incorporated which could come into play in the long run. The project has been designed to provide a noise free, pollution free & maintenance free system is an environment friendly efficient energy system. However, this can have a huge financial impact on the agency in the short term, but it is beneficial to the Agency and the society in the long run.

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