Grid-Assisted Rooftop Solar PV System: A Step toward Green Medina, KSA

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ABSTRACT

The increasing demands of fossil fuels and its depleting resources are a major concern all over the world. In the Kingdom of Saudi Arabia (KSA), the electrical energy is produced mainly by petroleum products. This is not only increasing the carbon footprint and pollution levels, but also depleting the natural resources faster. Therefore, there is a need for the use of renewable energy sources. Considering the high levels of solar radiation, solar-powered systems are potentially the best suited for the Kingdom of Saudi Arabia. The techno-economics of a grid-assisted solar powered water pumping systems is presented for two different cases using HOMER software. This paper presents two case studies for the city of Medina KSA for rooftop solar PV panels. For the purpose of reduction of load on the electrical grid, a grid-assisted solar PV system is proposed in the paper. By using this system, a considerable amount of pollution mitigation is also achieved for the city of Medina.

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1. Introduction

Grid-assisted solar photovoltaic (SPV) system has many advantages over grid tied SPV systems. In grid-tied SPV system, there are many regulations to be followed before anyone can feed electricity generated by SPVs into the grid [1,2]. Special solar inverters are required which are very costly [3,4]. In most developing countries, the utility grid is not ready to accept power back into the grid [5,6]. Therefore, to reduce the load on the electric grid, the load to the grid has to be reduced. This can be done by the use of grid-assisted SPV system. In this system, the apparent load to the grid is drastically reduced by the use of SPV panels having large ratings. In a grid-assisted SPV system, the load is fed by the electricity generated by the SPVs. When the electricity generated by the SPVs is less than the load, the load is then fed from the electric grid. This way, the apparent load on the grid gets reduced to a large extent.

Moreover, with the decrease/depletion in the fossil fuels and thus with an ever increasing fuel prices is affecting the pumping requirements of community water supplies and irrigation [12]. A solar PV pumping system is a viable option for fulfilling the requirements of the community water supplies and irrigation [13]. In rural/far off areas, the solar water pumps have become very popular as generally the remote located areas are devoid of grid-connected electricity [14]. In this paper, design of SPV pumping system is also covered. Two cases are considered wherein first a direct solar water pump system is considered followed by the discussion of battery-assisted solar water pump.

One very pertinent issue with the design of the SPV system is its techno-economic analysis for the proposed area. Researchers have widely accepted the techno-economic analysis using a suitable software as a means for finding out the feasibility of the proposed project before installations. It has been followed across the globe. Some of the case studies are presented here:

(i) The optimal energy cost and economic analysis of a residential grid interactive SPV system for the case of eThekwini municipality in South Africa is discussed in [14].
(ii) Performance analysis of various grid-connected SPV systems with capacity of 20 kW is performed for humid tropical climate in [15].
(iii) Economic feasibility for grid-connected SPV home systems in Palestine is discussed in [16].
(iv) Preliminary assessment of a small-scale rooftop PV-grid tied in Norwegian climatic conditions is discussed in [17] and the analysis for 2.1 kW rooftop photovoltaic-grid-tied system is discussed for Norway in [18].
(v) Technical analysis of 5.05 kWp grid tied SPV system is discussed for climate of western India in [19].

The case studies for different regions are covered in detail; however, a case study for the case of Medina is not reported in the literature. Hence, the authors have presented the grid-assisted solar powered water pumping systems for Medina in this paper which will lead toward a greener Medina. In this paper, the techno-economics of a grid-assisted solar powered water pumping systems have been presented. This paper also presents case studies for rooftop solar PV panels for different loads. In the first case, the load under consideration is the water pump and the common loads in the apartments. In the second case, the complete load of the apartments being fed by the solar panels has been considered.

2. SPV Pumping

SPV-powered water pumping applications are mainly of two types: (i) direct solar water pump and (ii) battery-assisted solar water pump. The block diagrams of both the types are shown in Figure 1(a,b) respectively. In the former, whatever the incident solar radiation is available gets converted into electrical energy. This generated power has to be instantaneously utilized as there is no storage device in the system. When the generated electrical power is more than the required level, the extra power gets wasted. This renders SPV generator to be underutilized. When sunshine is less than the required level, the power generated is inadequate and the motor is rendered inoperable in the case of a stand-alone SPV system, whereas in the case of grid-assisted SPV system, the pump receives additional supply from the grid. Thus, utilizing the available solar energy [20,21].

In the battery-assisted solar water pumping system, the SPV generator charges the batteries when excess power is generated. This not only conserves the power but also enables the pumps to operate during the night.

![Figure 1. (a) Direct solar water pump. (b) Battery-assisted solar water pump.](image-url)
In the situation when less power is produced from the SPV generator, batteries supplement the power to run the pump. The main demerit of this system is the additional cost of the batteries required, which is quite high. Thus, the battery-assisted water pumping system is not studied.

3. Grid-Assisted SPV System

A Hybridized Solar PV-AC Grid power system was developed earlier to operate along with AC grid [22]. This system consists of SPVs installed on the rooftop of apartments and houses, a hybrid power controller (HPC), and an inverter. This controller works in such a way that the maximum available solar power is utilized for a particular load. The remaining deficit power if required is drawn from the utility grid. Unlike grid-tied SPV systems, the grid-assisted system acts like a load to the utility grid without interfering the functioning of the grid [23]. In the absence of grid supply, the electrical energy generated by the SPV can still be used to supply the loads [24]. However, this cannot be done in a grid-tied SPV system. Another advantage of this hybrid system is that the installation of solar panels on the roof top of the houses and apartments will not require the costly lands for SPV installation.

The block diagram of a grid-assisted solar PV system is shown in Figure 2(a). In this system, a solar PV generator is feeding the load through an inverter. This inverter is connected to a power controller to which the AC grid is also connected. The algorithm of the power controller has been shown in Figure 2(b). In this system, the controller first checks for power coming from the PV panels. If there is no power being generated by the panels, the load is given supply from the mains supply. For the case when the panel is generating power, the controller checks the level of power output. This level is compared by that of

![Figure 2](image-url)
the load. Accordingly, if the load requires more power, the grid will supply power to it. In this way, the load is supplied partially through the PV panels and the AC grid [25]. This controller is not only helping the load to receive power from the panels and the AC grid simultaneously but also helping in peak load management as well.

4. Environmental Data of Medina

Medina (24.28 N and 39.36 E) lies in the Eastern part of Al Hijaz region of the Kingdom. It is located in the north-western part of the Kingdom, to the east of the Red sea and is surrounded by a number of mountains as shown in Figure 3. A large number of inhabitants are scattered in small nomadic communities where energy consumption is low and are not connected to the electric grid. Distribution line extension cost is quite high, thereby making availability of electricity economically unattractive. However, ground water and sunlight are available, which makes decentralized SPV-powered water pumping more cost-effective.

In the city of Medina, the municipal corporation which is locally known as Baldia supplies the city with potable water for its daily needs. The water is pumped to an overhead water tank after the due processing. Since the processed water does not have enough potential/gravitational energy to reach the storage tanks at the rooftops, and therefore, the filtered water coming from the main tank has to be stored in an underground tank constructed in the basement of the housing societies. This processed water is then pumped up from the underground tank to another storage tank situated on the roof of the building for supplying the water to the residents of the house. This requires an additional pumping to perform the task. This pumping is done with the use of electricity, supplied power from the secondary electricity supply. To reduce the load on the grid, this paper proposed the use of a grid-assisted solar PV system.

The meteorological data for the city has been obtained from the NREL database for solar energy and NASA’s database for surface meteorology and solar energy data [NASA and NREL [8 and 9]]. The data for daily temperature and daily radiation for the Medina region are shown in Figure 4(a,b), respectively. The data obtained have been used for various calculations that have been presented in this paper. For the simulations performed using MATLAB, the model presented in [26] has been modified and used. These results were found to be very close to those obtained from HOMER. The energy extracted from the PV panels having 1 kW-peak rating during the day throughout the year is given in Table 1.

5. Design of the Grid-Assisted SPV System

The grid-assisted system has to be designed keeping in view the loads of the whole housing complex. A typical housing complex consists of six 4 bedroom apartments. The typical electrical energy consumed by an average family of six in a single apartment is given in Table 2. The common loads in such an apartment consist of the corridor lights, the staircase lights, and the water pump. The water pumps are general induction motor water pumps of 0.5 HP rating. Water pumping is done four times.
times a day. The load profile of the water pump and the other loads common in the apartments is shown in Figure 5(a). The peaks appearing in the load profile are depicting the usage of the water pump. The load profiles of residential usage for Medina has been calculated based on the data of two cities of Saudi Arabia, Makkah [29] and Yanbu [30] as there is a similar trend throughout Saudi Arabia. The average daily load profile of the six apartment buildings in Medina is given in Figure 5(b).

Two cases have been analyzed. In the first case, the common loads as depicted in Figure 6(a) are used as the loads to the grid-assisted SPV system. The rating of the SPV used in the grid-assisted system is of 1 kW. The schematic diagram for this case is given in Figure 6(a). For the second case, the loads under consideration are the common loads and the combined residential loads of the six apartments. The schematic diagram for the second case is shown in Figure 6(b). In this case, the SPV considered has a rating of 5 kW. The total available rooftop area is of 420 m² [31], and the area required by a 5 kW SPV system is 45 m² to avoid self-shading as per the product specifications given by the Foshan Tanfon Energy Technology Company. Assuming that 70% of the roof area is available for the installation of SPVs. Therefore, the maximum rating of SPVs that can be easily

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Table 1. Daily and monthly energy yields from a 1 kW-peak PV generator in Medina.

| Month    | Average daily yield | Yield for the month |
|----------|---------------------|---------------------|
| January  | 4.61                | 142.91              |
| February | 4.68                | 131.04              |
| March    | 5.09                | 157.79              |
| April    | 4.96                | 148.80              |
| May      | 4.67                | 144.77              |
| June     | 4.76                | 142.80              |
| July     | 4.79                | 148.49              |
| August   | 4.55                | 141.05              |
| September| 4.56                | 136.80              |
| October  | 4.65                | 144.15              |
| November | 4.27                | 128.10              |
| December | 4.29                | 132.99              |
| Total    | 4.66                | 1699.69             |

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Table 2. Home appliance power ratings and their estimated usage [27,28].

| Appliance           | Quantity | Power rating (W) | Daily (h/day) | Monthly (h/month) | Annual energy consumption (kWh/year) |
|---------------------|----------|------------------|---------------|-------------------|--------------------------------------|
| Air conditioner     | 2        | 2000             | 10.00         | 300               | 14,400                               |
| Washing machine     | 1        | 750              | -             | 8                 | 72                                   |
| Dryer               | 1        | 3500             | -             | 8                 | 336                                  |
| Electric stove      | 1        | 4000             | 1.00          | 30                | 432                                  |
| Water heater        | 1        | -                | -             | -                 | 4800                                 |
| Fridge              | 1        | -                | -             | -                 | 1000                                 |
| Television          | 2        | 100              | 8.00          | 480               | 576                                  |
| Computer            | 2        | 250              | 4.00          | 240               | 720                                  |
| Lights              | 20       | 40               | 3.00          | 1800              | 864                                  |
| Vacuum cleaner      | 1        | 1200             | 0.50          | 15                | 216                                  |
| Sound system        | 1        | 400              | 2.00          | 60                | 288                                  |
| Microwave           | 1        | 1000             | 0.50          | 15                | 180                                  |
| Toaster             | 1        | 700              | 0.30          | 9                 | 130                                  |
| Coffee maker        | 1        | 600              | 0.30          | 9                 | 65                                   |
| Iron                | 1        | 1500             | 0.50          | 15                | 270                                  |
| Hair dryer          | 1        | 1500             | 0.50          | 15                | 270                                  |
| Misc. appliances    | -        | 1000             | 1.00          | 30                | 360                                  |
| Total kWh/year      |          |                  |               |                   | 24,979                               |
installed is 30 kW. The grid-assisted SPV system is easily available in multiples of 5 kW ratings. So, a comparison has been done for the complete range in steps of 5 kW.

6. Techno-Economic Considerations

Case 1: Loads common to all apartments (20.8 kWh/day); SPV rating = 1 kW.
The cost of electrical energy without government subsidy is $0.10/kWh, Saudi Electricity Company [7]. For the energy generated by a 1 kW SPV system (i.e., 1700 units), the cost of the energy is $170 on an annual basis. The cost of the 1 kW SPV system including a single phase grid-assisted inverter is currently $2500 as quoted by the Foshan Tanfon Energy Technology Company. The expected life of the SPV is 25 years. So, it will have to be replaced once during the lifetime of the panels.

The recovery period of the initial investment = (cost of installation)/(cost of energy yielded) = ($2500)/($170/year) = 14.7 years

So, in a period of just 60% of life, the investments are recovered. After this period, the SPV system saves $170 annually for approximately 10 years. This means that at least $1700 is gained by the grid-assisted system if only the common loads are connected to it.

**Case 2:** Maximum solar panel rating = 30 kW-peak; complete load of apartments (410 kWh/day)

The cost analysis and energy comparison for the various SPV ratings are given in Table 3. It is evident from Table 3 that the installation of solar PV panels of 30 kW-peak is the most promising case financially. This case is also the most eco-friendly case among all the cases analyzed. For this case, the emission levels of CO₂, SOₓ, and NOₓ have been shown in Table 3.

### 7. Environmental Effects

For every unit of electricity generated from a conventional power plant, 632 g of CO₂ emission takes place [10,11]32. By the energy generated from the solar panels (i.e., 1700 units), approximately 1071 kg of CO₂ is mitigated on a yearly basis from a single building. In a locality, around 100 such apartments are present. When the system of grid-assisted solar panels is applied to a locality of a hundred such houses, almost 107 tonnes of CO₂ emission is reduced. This reduction in the emission of CO₂ has a positive impact on the environment. Table 4 gives the summary of the reduction in pollution levels for the case when a 1 kW-peak PV panel is used with the grid. The emissions of CO₂, NOₓ, and SOₓ have been given from a conventional power plant for the generation of 1700 units. The simulations have been done on HOMER. This has been done to simulate the various emissions from the power plant to generate the equivalent power. In Table 5, a comparison of the various emissions has been done for PV panels having larger ratings. The first condition is for when the power is being supplied from the grid only. There are a total of seven conditions with an increment of panel rating by

### Table 4. Comparison of pollution levels by gas based power plants for the generation of energy equivalent to that generated by solar PV system.

| Pollutant          | Emission from a power plant to deliver 1700 units of energy (kg) | Emission from a power plant to deliver 1700 units of energy when PV generator is used (kg) | Reduction in emissions (%) |
|--------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------|-----------------------------|
| Carbon dioxide     | 4798.10                                                         | 3725.50                                                                                   | 22.35                       |
| Sulfur dioxide     | 20.8                                                            | 16.15                                                                                     | 22.36                       |
| Nitrogen oxides    | 10.17                                                           | 7.9                                                                                       | 22.32                       |

### Table 3. Comparative cost analysis of different rating SPV panels installed on the rooftops.

| Quantity                        | No panels | 5 kW-peak | 10 kW-peak | 15 kW-peak | 20 kW-peak | 25 kW-peak | 30 kW-peak |
|---------------------------------|-----------|-----------|------------|------------|------------|------------|------------|
| Energy purchased from grid (kWh) | 157277    | 148791    | 140305     | 131819     | 123342     | 115218     | 108108     |
| Energy saved from grid (kWh)    | 0         | 16972     | 33902      | 50233      | 63936      | 73644      | 80168      |
| Energy available to sell back to grid (kWh) | 0         | 0         | 0          | 0          | 9          | 372        | 1747       |
| Net energy purchased (kWh)      | 157277    | 148791    | 140305     | 131819     | 123333     | 114846     | 106361     |
| Energy saved without sellback (kWh) | 0         | 8486      | 16972      | 25458      | 33935      | 42059      | 49169      |
| Energy saved with sellback (kWh) | 0         | 8486      | 16972      | 25458      | 33944      | 42431      | 50916      |
| Cost of panels and inverter ($)  | 0         | 8000      | 16000      | 24000      | 32000      | 40000      | 48000      |
| Renewable penetration without sell back option (%) | 0         | 5.40      | 10.79      | 16.19      | 21.58      | 26.74      | 31.26      |
| Renewable penetration with sell back (%) | 0         | 5.40      | 10.79      | 16.19      | 21.58      | 26.98      | 32.37      |
| Payback period (years)           | -         | 9.43      | 9.43       | 9.43       | 9.43       | 9.43       | 9.43       |
| Payback period in terms of percent of life of the system (%) | -         | 37.72     | 37.72      | 37.72      | 37.72      | 37.72      | 37.72      |
10 kW-peak. The maximum rating of the PV panel considered is 60 kW-peak.

8. Conclusions and Future Work

The techno-economics have been carried out for rooftop grid-assisted SPV system by considering the panels to be installed having 1 kW rating in the first case. The load to the SPV system was a common load of 20.8 kWh/day with a peak consumption of 2.52 kWh. In the second case, the load of housing complex consisting of six apartments was considered. The load had a daily average consumption of 430.9 kWh with a peak load of 27.62 kW. The techno-economic analysis has been done for panels having ratings to a maximum of 30 kW. A comparison has been done for each case taking an increment of 5 kW rated panels. This increment has gone to a maximum of 30 kW.

The grid-assisted solar power system can be used to supply loads not only from the solar panels, but also from the AC grid. The techno-economics presented in this paper shows that the use of larger rating solar panels is more beneficial to the consumers. However, by installing large number of panels, our carbon footprint is reduced. In the era that we live in, care for the environment is a must. Installing of large number of panels by the consumers benefit in the long run, but also help in reducing the emission levels. This will help in improving the overall condition of the environment of the city of Medina, KSA.

In the future work, development of 1.5 kW power SPV system-based water pumping system shall be undertaken. A detailed study is being done by the author on the possibility of using impedance source converter for inversion of dc power to ac power. An SPV system can be developed in future which includes Z-Source/Quasi Z-Source inverter. Distributed solar panel-based powering will result in the efficient and optimized operation of the SPV system as there will be minimal effect of shading on it.

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References

[1] Russell MC. Grid-tied PV system modelling: how and why. Photovoltaic Energy Conversion, 1994, Conference Record of the Twenty Fourth. IEEE Photovoltaic Specialists Conference-1994, 1994 IEEE First World Conference on; Dec (Vol.1, pp. 1040–1043). IEEE; 1994, Waikoloa, HI, USA.

[2] Bharatiraja C, Munda JL, Bayindir R, et al. A common-mode leakage current mitigation for PV-grid connected three-phase three-level transformerless T-type-NPC-MLI. 2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA), pp. 578–583; Birmingham; 2016.

[3] Zhang L, Sun K, Li WY, et al. A distributed power control of series-connected module-integrated inverters for PV grid-tied applications. IEEE Trans Power Electron. 2018 Sep;33(9):7698–7707.

[4] Tariq M, Iqbal MT, Iqbal A, et al. Comparative analysis of carrier schemes for PWM in multilevel PUC inverter for PV applications. 2016 4th International Conference on the Development in the in Renewable Energy Technology (ICDRET), pp. 1–6; Dhaka; 2016, IEEE Xplore proceedings.

[5] Chiu HJ, Lo YK, Yang CY, et al. A module-integrated isolated solar microinverter. IEEE Trans Ind Electron. 2013;60(2):781–788.

[6] Kristine B, Duncan C, Arif M. Benefits and challenges of expanding grid electricity in Africa: a review of rigorous evidence on household impacts in developing countries. Energy Sustainable Dev. 2018;44:64-77.

[7] Saudi Electricity Company. Available from: https://www.se.com.sa/enus/customers/Pages/TariffRates.aspx
[8] Surface meteorology and Solar Energy. Available from: https://eosweb.larc.nasa.gov/sse

[9] NREL. Renewable Resource Data Center – Solar Resource Information. Available from: https://www.nrel.gov/rredc/solar_resource.html

[10] Best price 1kw_2kw_3kw_4kw_5kw_10kw home solar systems for Saudi Arabia, View home solar systems, TF solar panel home system Product Details from Foshan Tanfon Energy Technology Co., Ltd. on Alibaba.com, Putra Jaya, Malaysia. Available from: http://solarsupplier.en.alibaba.com/product/1802008103-218330625/Best_price_1kw_2kw_3kw_4kw_5kw_10kw_home_solar_systems_for_Saudi_Arabia.html

[11] Imdadullah M, Ashraf I. Estimation of CO₂ mitigation potential through renewable energy generation. 2006 IEEE International Power and Energy Conference, (pp. 24–29); IEEE; 2006.

[12] Chandel SS, Nagaraju Naik M, Chandel R. Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. Renewable Sustainable Energy Rev. 2015;49:1084–1099.

[13] Singh B, Sharma U, Kumar S. Standalone photovoltaic water pumping system using induction motor drive with reduced sensors. IEEE Trans Sustain Energy. 2018 July–Aug;54(4):3645–3655.

[14] Maleki A, Pourfayaz F, Hafeznia H, et al. A novel framework for optimal photovoltaic size and location in remote areas using a hybrid method: a case study of eastern Iran. Energy Convers Manag. 2017;153:129–143.

[15] Quansah DA, Adaramola MS, Appiah GK, et al. Performance analysis of different grid-connected solar photovoltaic (PV) system technologies with combined capacity of 20 kW located in humid tropical climate. Int J Hydrogen Energy. 2017;42(7):4626–4635.

[16] Omar AM, Mahmoud MM. Grid connected PV-home systems in Palestine: a review on technical performance, effects and economic feasibility. Renewable Sustainable Energy Rev. 2018;82(Part 3):2490–2497.

[17] Adaramola MS, Vagnes EET. Preliminary assessment of a small-scale rooftop PV-grid tied in Norwegian climatic conditions. Energy Convers Manag. 2015;90:458–465.

[18] Adaramola MS. Techno-economic analysis of a 2.1kW rooftop photovoltaic-grid-tied system based on actual performance. Energy Convers Manag. 2015;101:85–93.

[19] Dobaria B, Pandya M, Aware M. Analytical assessment of 5.05 kWp grid tied photovoltaic plant performance on the system level in a composite climate of western India. Energy. 2016;111:47–51.

[20] Elgendy MA, Zahawi B, Atkinson DJ. Operating characteristics of the P&O algorithm at high perturbation frequencies for standalone PV systems. IEEE Trans Energy Convers. 2015;30(1):189–198.

[21] Elgendy MA, Zahawi B, Atkinson DJ. Assessment of perturb and observe MPPT algorithm implementation techniques for PV pumping applications. IEEE Trans Sustainable Energy. 2012;3(1):21–33.

[22] Ashraf I, Chandra A. Techno economic viability of a rooftop hybridized solar PV-AC grid assisted power system for peak load management. In: Power Electronics, Machines and Drives, 2004. (PEMD 2004). Second International Conference on (Conf. Publ. No. 498), (Vol.1, pp. 442–446); IET; 2004, Edinburgh, UK.

[23] Jain S, Agarwal V. A single-stage grid connected inverter topology for solar PV systems with maximum power point tracking. IEEE Trans Power Electron. 2007;22(5):1928–1940.

[24] Pervaz S, Khan HA, Qureshi MA. A practical perspective on grid-tied PV systems in low reliability grids. In: 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC), (pp. 1969–1972); IEEE; 2014, Denver, CO, USA.

[25] Klaic Z, Fekete K, Šljivac D. Demand side management in the distribution system with photovoltaic generation. Tech Gaz. 2015;22(4):989–995.

[26] Tabish S, Ashraf I. Simulation of partial shading on solar photovoltaic modules with experimental verification. Int J Ambient Energy. 2015;38 (2):161–170.

[27] Al-Mofeez IA. Electrical energy consumption pre and post energy conservation measures: a case study of one-story house in Dahran, Saudi Arabia. J. King Saud Univ., Vol. 19. Arch. & Plann. (2), pp. 1-12, Riyadh (1427H./2007).

[28] Lashway C, Elsayed AT, Mohammed OA. Design and control of a grid-tied PV system for medium-sized household in South Florida. Presented for the 12th Latin American and Caribbean Consortium of Engineering Institutions (LACCEI), 22–24; Guayaquil, Ecuador; 2014.

[29] Anwari M, Hiendro A. Performance analysis of PV energy system in western region of Saudi Arabia. Engineering. 2013;5(01):62–65.

[30] Alaidroos, A., He, L., Krarti, M., 2012. Feasibility of renewable energy based distributed generations in Yanbu, Saudi Arabia. In: Solar 2012. ASES Conference, Denver, Colorado, 13–17 May.

[31] Taleb HM, Sharples S. Developing sustainable residential buildings in Saudi Arabia: a case study. Appl Energy. 2011;88(1):383–391.

[32] Imdadullah M, Ashraf I, Ali ML. Renewable energy technologies for the developing and developed countries power sector and assessment of CO₂ mitigation potential. In: 2006 International Conference on Electrical and Computer Engineering, (pp. 225–228); IEEE; 2006, Dhaka, Bangladesh.