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Economical Benefits of Integrating Solar Energy Based DG units on an Existing Low Voltage Distribution Network in Pakistan

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ABSTRACT

Availability of electrical energy plays a dynamic role in the social and economic development of any country. The energy mix in Pakistan is majorly dependent on the non-renewable energy sources which are imported, which results a short of electricity production while the consumers are facing a load shedding of 10-12h/day. This technological revolution, regulatory environment and changing economic conditions increase the importance of Distributed Generation. Distributed Generation not only meets the energy requirements of any country but also improves the various issues such as saving in cost, reduction in technical losses, improvement in the power quality, reliability and security, reduction in power losses and environmental concerns to decrease the greenhouse gases. This paper presents the comparison of the energy utilization and its price between the existing low voltage system and the proposed solar PV system integration. It is seen that with the integration of an optimized PV system we will not only meet the energy requirement of our existing system but also inject some amount of energy in access to the national grid. Also a cost to benefit ratio of 2.63 is calculated which means the cost of this modification can be reversed in a time less than 3 years while the normal life of a PV system is taken as 25 years.

Key words : Distributed Generation, PV System, PV Integration, Renewable Energy, Energy Crisis.

1. INTRODUCTION

A substantial role of electricity is seen in social and economic development of any country. Due to extensive increase in population, use of modern technologies etc. a continuous increase in the electricity usage is seen around the world [1]-[3]. For the viable economic evolution a continuous and reliable accessibility of electricity is the need of the day [4]. Energy security is now acknowledged as an integral part of any country's national power [5]. A rise in the demand of electricity and its belief on traditional sources as oil, gas, coal is the major concern which is faced by the world nowadays. These non-renewable energy sources are the major cause of environmental pollution and add a significant amount of CO_2 to atmosphere [6], [7]. Since last two decades the peoples of Pakistan are facing a 10-12h/day load shedding due to the short fall of electricity even though a population of around 43% population lives without electricity and around 50,000 small villages do not have access to the national grid [8], [9]. Pakistan is the country whose major electricity production is based on the non-renewable imported fuels which are very costly and pollutant hence the electricity production cost has direct relation with the increase and decrease in the cost of imported fuel in the international market [10]-[12]. Also due to unplanned extension of the low voltage distribution networks the distribution companies of Pakistan are facing a great loss of electrical power in the shape of technical loss [13]. In order to accomplish the environmental challenges, reduction in technical losses and decline the reliance on non-renewable energy sources, it is essential to transform these non-renewable energy sources to renewable energy sources for the production of electricity [14]. Due to its cleanness, simplicity, durable and environmental pleasantness the SPV system is catching world's concentration around the globe. Many countries around the world have increased their solar photovoltaic generation capacity from kW to MW in recent past [15], [16]. In order to overwhelmed this electricity deficiency and generate electricity from renewable energy sources in Pakistan the best choice is the utilization of PV systems as it requires negligible running cost, harmless and do not contain any moving parts [17], [18]. A study on optimum size of a solar photovoltaic inverter for 3kW PV system is carried at QUEST Nawabshah Sindh Pakistan in [19] and is suggested to be integrated at low voltage distribution network.

This research article is organized as under. Section 2 describes the study of the existing distribution network under study. Study of the proposed solar energy based DG integration and solar irradiance, ambient temperature and AC power injected to national grid is described in Section 3. Section 4 compares existing and proposed distribution system and cost to benefit ratio is explained in Section 5 while Section 6 concludes the paper.

2. STUDY OF EXISTING LV DISTRIBUTION NETWORK

The objective of this research work is to design a low voltage distribution network which is effective, reliable, environmental friendly with minimum price. For this purpose a class of Electrical Engineering Department is chosen as a model. The total load of the class is determined and is shown in Table 1. If whole load of the class works from 8a.m to 4p.m thus for 8 hours a day, the per month and annual electricity consumed by the class and their respective cost based on the current tariff rate in Pakistan is shown in Table 2 while Table 3 shows the current tariff rate of electricity in Pakistan [20] for a installed load below 5kW according to National Electric Power Regulating Authority (NEPRA). Table 2 shows that 7300kWh of electricity consumed by the class annually while a cost of Rs.101840 occurred on it. This cost of electricity is calculated without considering the various taxes imposed on the electricity in Pakistan.

Table 1: Load Demand of the Class

S. No	Load name and its power rating in Kw	Quantity of each load	Total power of load in kW
1	Tube light (0.040)	16	0.640
2	Fan (0.080)	12	0.960
3	Multimedia and speakers (0.900)	01	0.900
Total load demand			2.50

Table 2: Monthly and Annual Electricity Consumed by the Class and its Respective Cost

S. No.	Month	Units of energy consumed (kWh)	Cost of electricity (Rs)
1	January	620	8692
2	February	560	7636
3	March	620	8692
4	April	600	8340
5	May	620	8692
6	June	600	8340
7	July	620	8692
8	August	620	8692
9	September	600	8340
10	October	620	8692
11	November	600	8340
12	December	620	8692
Annual electricity consumed		7300	101840

Table 3 Current Tariff Rate of Electricity in Pakistan

S. No	Units of energy consumed (kWh)	Cost of electricity (Rs)
1	Up to 50	2
2	1 to 100	5.79
3	101 to 200	8.11
4	201 to 300	10.2
5	301 to 700	17.6
6	Above 700	20.7

3. STUDY OF THE PROPOSED SOLAR ENERGY BASED DG UNITS INTEGRATION

After calculating the load requirement of the class a 3kW solar energy based PV system is optimized in [19]. Using the factual time data of irradiance and ambient temperature the PV to inverter sizing ratio of 1.4664 with an annual conversion efficiency of 95.8727% is determined for Nawabshah Sindh Pakistan. The proposed single line diagram with the integration of solar energy based DG units with real time data modeled in DIgSILENT power factory software is shown in Figure 1.

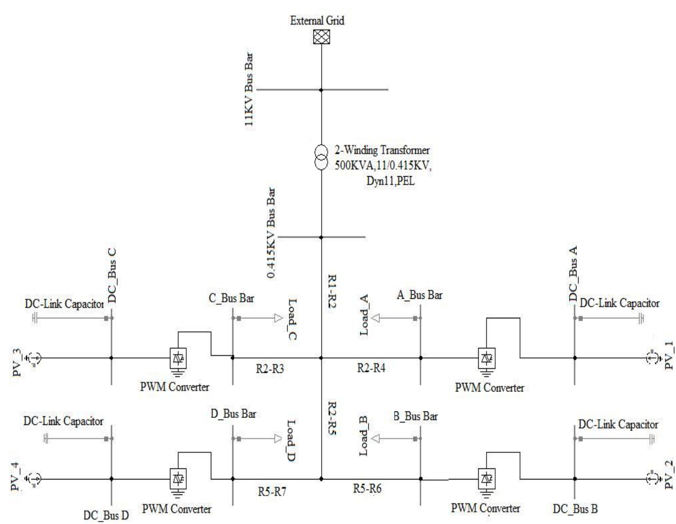

Figure 1: Proposed Single Line Diagram with the Integration of Solar Energy Based DG Units

3.1 Solar Irradiance, Ambient Temperature and AC Power Injected to LV Grid

The metrological data values of irradiance and ambient temperature are site, time and day of the year dependent. The data values of irradiance and ambient temperature of the site based on annual hourly average [21] are shown in Figure 2 and 3 respectively.

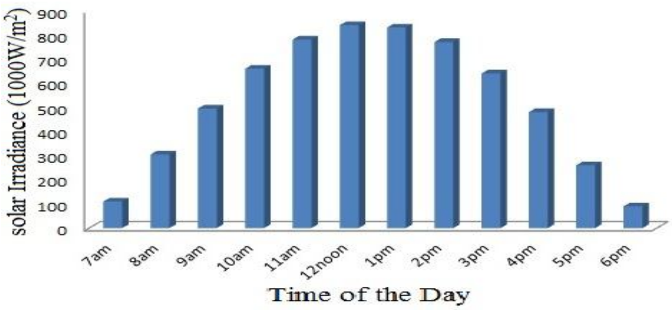

Figure 2: Solar Irradiance Data Values of the Site

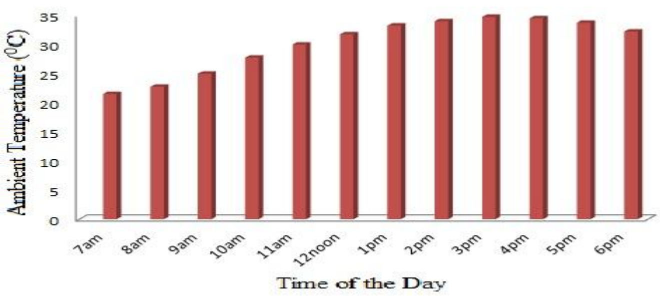

Figure 3: Ambient Temperature Data Values of the Site

The dc electrical power generated by the solar PV generator is irradiance and cell temperature dependent. Beyond the standard test conditions there is a direct relationship between the solar PV generated dc electrical power and irradiance while with the cell temperature there is a non-linear relationship [22]. The dc electrical power [19] at the output terminals of a PV generator is determined by using the model shown in (1),

$$P_{dc(out)(t)} = P_{rated}\left(\frac{G(t)}{G_{standard}}\right)\left[1 - \alpha(T_c - 25)\right] \qquad (1)$$

Where,

$P_{dc(out)(t)}$ = instantaneous dc power generated by PV system,

P_{rated} = installed PV system capacity at STC i.e. (1000W/m^2) irradiance and 25^{0}C cell temperature,

$G(t)$ = instantaneous solar irradiance of the site,

$G_{standard}$ = standard solar irradiance i.e. 1kW/m^2,

α = temperature coefficient of power equal to -0.41%/^{0}C

T_c = instantaneous cell temperate of the PV generator

The photovoltaic cell temperature can be calculated by using model shown in (2),

$$T_c = T_a + \left[(NOCT - 20)/800\right] * G(t) \qquad (2)$$

Where T_a and $G(t)$ are the instantaneous data of the ambient temperature and solar irradiance of the site and $NOCT$ is the normal operating cell temperature i.e. 46^{o}C given in the PV generator data sheet. Based on the metrological data of the site, Using (2) and (1) cell temperature and extracted power of a 3kW optimized solar PV system is simulated in MATLAB. Figure 4 and 5 shows instantaneous cell temperature and dc power generated by the solar PV system installed at the site respectively. While Table 4 shows the monthly and annual dc and ac energy generated by PV system and delivered to low voltage grid through the inverter respectively based on the annual average inverter efficiency presented in [19].

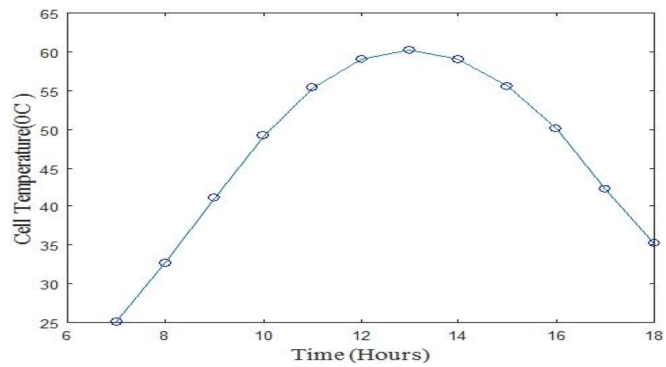

Figure 4: Instantaneous Cell Temperature Data Values of the Site

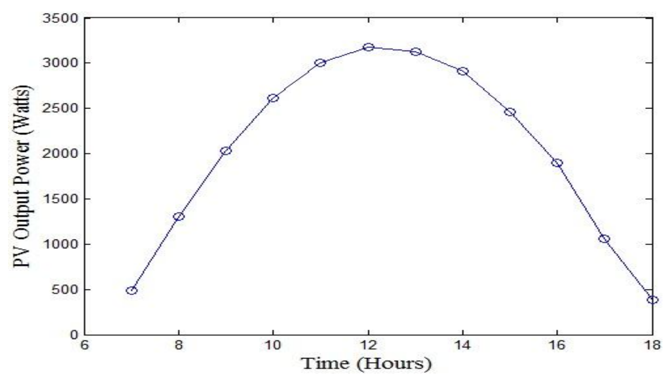

Figure 5: Instantaneous DC Generated Power Data Values of the Site

4. COMPARISON BETWEEN EXISTING AND PROPOSED DISTRIBUTION NETWORK

Table 5 shows the comparison between the monthly and annual electricity demand of the class taken as a model and the electricity generated by the optimized PV system proposed to be integrated at the LV distribution system. Also the Figure 6 shows the graphical representation of the existing energy demand and proposed energy injected to LV grid.

Table 5 shows that an integration of 3kW optimized PV system to the existing low voltage distribution network not only meet the electricity demand of the class but also inject some amount of electricity in access to the low voltage distribution grid.

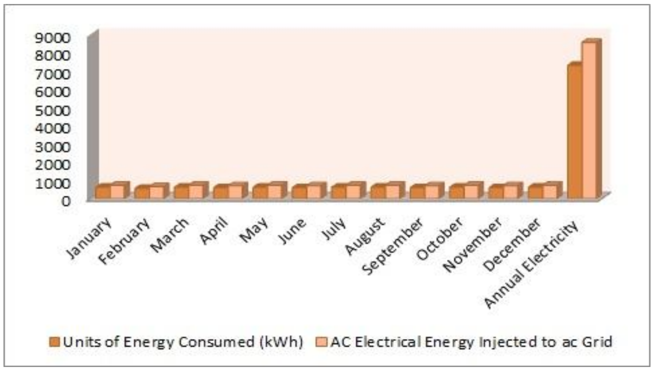

Figure 6: Graphical Representation of the Existing Energy Demand and Proposed Energy Injected to LV Grid

Table 4: Monthly and Annual Electricity Generated by the PV System and AC Electricity Injected to LV Grid

S. No.	Month	Generated DC electrical energy by PV system	Injected AC electrical energy to LV grid
1	January	758.26	726.96
2	February	684.88	656.61
3	March	758.26	726.96
4	April	733.8	703.51
5	May	758.26	726.96
6	June	733.8	703.51
7	July	758.26	726.96
8	August	758.26	726.96
9	September	733.8	703.51
10	October	758.26	726.96
11	November	733.8	703.51
12	December	758.26	726.96
Annual electricity generated/ injected		8927.9	8559.37

Table 5: Monthly and Annual Energy Demand of the Class and Injected to LV Grid

S. No.	Month	Energy demand (kWh)	Energy injected to LV grid
1	January	620	726.96
2	February	560	656.61
3	March	620	726.96
4	April	600	703.51
5	May	620	726.96
6	June	600	703.51
7	July	620	726.96
8	August	620	726.96
9	September	600	703.51
10	October	620	726.96
11	November	600	703.51
12	December	620	726.96
Annual electricity consumed/injected		7300	8559.37

5. COST TO BENEFIT RATIO

Based on the market price in Pakistan a total of Rs.392000/- expenditure occurred on the installation of an optimized 3kW PV system. In general the life of a PV system is approximately 25 years thus the expected electricity generated by the PV system in 25 years will be 213984kWh.

Based on the current tariff of electricity in Pakistan as in Table 2 the total cost of electricity injected to LV distribution grid in a single year will be Rs. 149050/- .

Thus the cost to benefit ratio will be=2.63

The cost-to-benefit ratio indicates that the entire price incurred on this transformation will yield in a time period of less than 3 years.

6. CONCLUSION

It is summarized that an integration of an optimized 3kW solar energy based PV system injects an electricity of 8559.37 kWh annually in the LV distribution grid. Thus this integration not only meets the electricity requirement of the class without affecting the environment but also injects some additional amount of electricity in the national grid which reduces the dependence of fossil fuels generated electricity and overcome energy crisis.

The aim of this research work is to study the economic benefits of integrating a PV system to the low voltage distribution network, as the huge initial cost of the PV system is the major concern of the utilizers. Therefore the study of a distribution network is carried out which shows that an electricity of 7300kWh is consumed annually by the class while the integration of an optimized 3kW PV system generates 8559.37kWh of electricity annually.

The total expenditure occurred on this modification based on the current price in Pakistan will be Rs.392000/- while the annual electricity price of the existing and proposed system will be Rs.101840 and Rs.149050 respectively. Based on the expenditure occurred on PV system integration and expected annual revenue collected from the electricity injected to the grid a cost to benefit ratio of 2.63 is calculated which indicates that the entire price incurred on this transformation will yield in a time period of less than 3 years while the expected life of a PV system is considered as 25 years.

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