Journal of Student Research
Fourth Middle East College Student Research Conference, Muscat, Sultanate of Oman

Distributed Generation and µ-Grid to Enhance use of Solar Energy in Oman

Haya Said Matar Al Sakiti College of Applied Sciences
Shamsa Abdullah Ali Al Belushi College of Applied Sciences
Wafaa Mohammed Hamed Al Shilla College of Applied Sciences
Bayan Khalifa Ahmed Al Qassabi College of Applied Sciences
Parmal Singh Solanki College of Applied Sciences

This paper has presented the concept of distributed generation to endorse microgrid in Oman to enhance utilization of solar energy. The various components of a 3 kW solar photovoltaic based distributed generation system have designed to meet the lighting load of a laboratory. The HOMER Pro software has used to model and simulate the output power of PV system and per unit energy cost. The optimized energy cost determined under sensitivity scenario becomes US$0.17per kWh. During off peak duration, the microgrid can export 740 kWh surplus powers to the grid annually. Paper has also discussed the benefits and challenges of distributed generation and microgrid

Introduction

In recent years the concept of distributed generation (DG) based microgrid (µ-grid) has been widely used and is expected to be essential component of electrical power system in future for harnessing power from distributed energy resources. The term DG more commonly referred to as one of the demand side management activity deployed by electric utilities to connect the renewable or small conventional power sources at low voltage distribution networks. Many scholars in their literature have defined the DG but there is no consensus on single definition. Some scholars define based on voltage level where as others considering dispersed generation units connected to distributed networks near to the load (Solanki, 2012; Sherif et al., 2019**)**. The international energy agency (IEA) has considered distributed generation as units producing power on a customers' site or within local distribution network without specifying or limiting the generating capacity while European Commission define as "*A source of electric power connected to the distribution network or the customer side*". Due to rising concern of environment, socio-economic, technological innovations, and electricity market liberalization, the renewable based DG has gained the popularity. The DG is broadly classified in two categories like conventional rotating machines based and static power converter type respectively. The later one is able to produce DC as well as AC power in the range of 10W<100kW.

Nowadays the structure of conventional power system is reforming itself to decentralize, decarbonize and democratize due to various driving factors like to curb in transmission and distribution losses, improve flexibility and reliability, reduction in carbon emissions and to exploit the DG system. Though the weight of driving factors and a particular solution may differ from place to place, microgrids have emerged as a flexible architecture for utilizing distributed energy resources. The µ-grid and its functional classification have defined by many authors in their literature (Adam et al., 2018; Martin et al., 2016**)**. The definition used by the United States Department of Energy in their project states that "*It is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode*" (Ton and Smith, 2012**)**. The major renewable resources for which the technological developments are on the way across the Arabian Peninsula are solar, wind and tidal energy**.**

The tidal energy is available along the Arabian Sea cost but adequate information on tidal waves and its complete atlas not available. Also the energy density is relatively low and technology is still in its experimental stage hence tidal based DG is economically not viable. The Oman is very rich in terms of solar and wind energy. The solar insolation varies from year to year and location to location, therefore to estimate the long term average solar energy potential, it is important to use the data of past several years. A study on renewable energy resources (Cowi and Partners, 2008) has collected the solar radiation data from 1987 to 1992 for six different locations across the country, had revealed that Sultanate of Oman is blessed with abundant direct solar radiation. The most parts of country bear clear sky (except some part of southern Oman) with annual average sunshine duration of 3708 hours per year (Cowi and Partners, 2008). The monthly average solar radiation incident in Suhar region of Oman is shown in Figure 1. It can be depicted from Figure 1, the potential of solar energy at Suhar ranging from 4. 31 to 7.25 kWh/m^2 per day with overall average of 5.92 kWh/m^2 per day (Hussein, 2016).

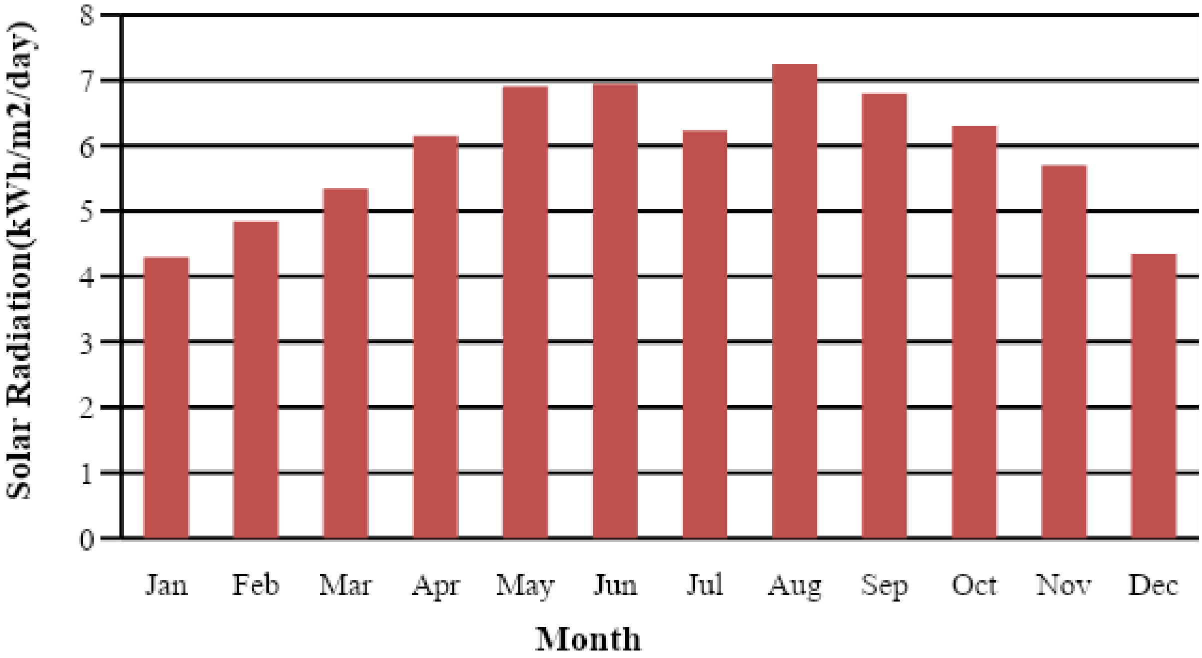

Figure 1. *Average monthly solar radiation at Suhar*

The photovoltaic system is one of renewable energy source in distributed generation which uses PV modules to convert sunlight into electricity. The electricity generated can be stored or used directly, export to grid line or combined with one or more other electricity generators or more renewable energy source to form an islanded small grid.

The PV system is intermittent in nature but clean source of electricity that can suit a wide range of applications such as residence, small scale industries, commercial houses and agriculture etc. In this paper the solar photovoltaic (PV) modules which are also known as PV array or panel are taken into consideration to produce electricity to cater the 3 kW lighting loads of electrical machines laboratory at College of Applied sciences-Suhar. The PV system is consists of various components that should be selected according to its system type, site location and applications. The design of major components of a 3kW photovoltaic system has discussed in next section.

Design of PV System

The layout of a PV system as a source of distributed generation to integrate with µ-grid is shown in Figure 2. It can be depicted from the layout the major components to be design are:

- PV Array;
- Charge controller;
- Battery bank and
- Inverter

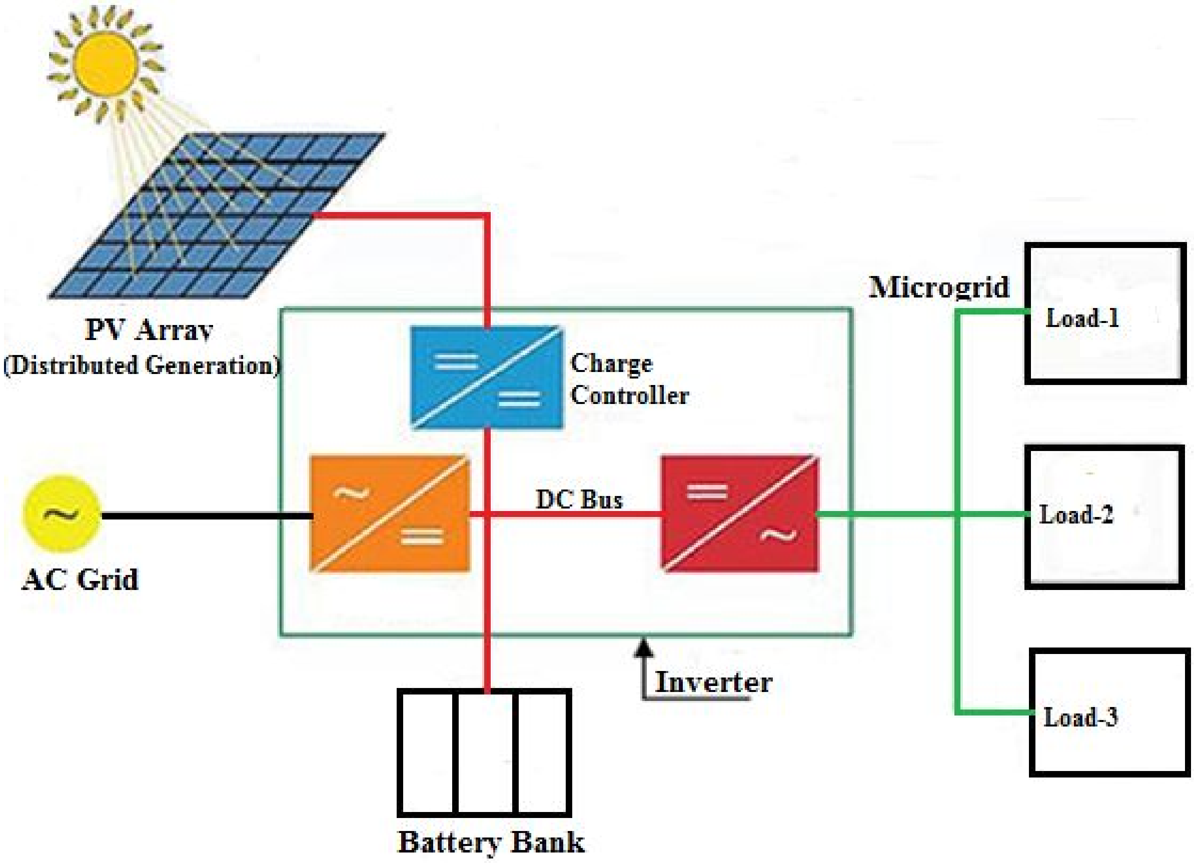

Figure 2. *Layout of PV system as DG to from µ-grid*

Load Data

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system. In this study the load components of electrical machines laboratory is shown in Table 1,

Electrical Load	Number of Units	Operating Hour/day	Rating per unit used (Watts)
Fluorescent Lamp	8 36 72 36 72	16-8 8-10 10-12 12-13 13-15	18 18 18 18 18
SP Light	1	0-23	15
LED Projector	1	10-12 13-14	250 250
Smoke Sensor	2	0-23	10

Table 1. *Daily load data of the Machine Laboratory*

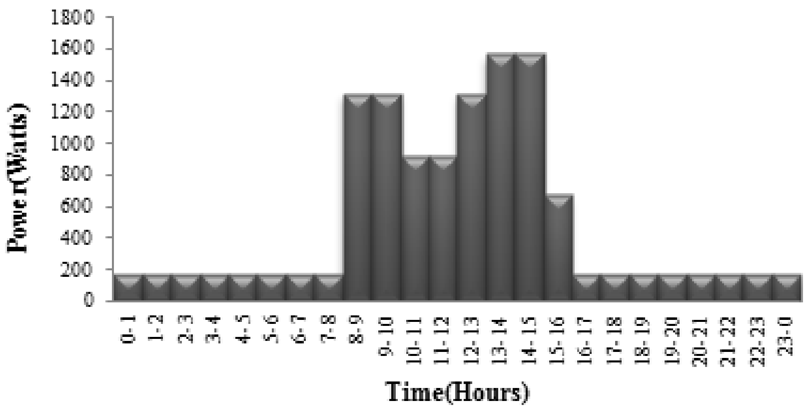

Figure 3. *The working day load profile*

It can be seen that most of the load is on during morning 8 AM till 4 PM which are working hours and 169 W load remains on round the clock. The average daily load demand P_a determined from load profile is 10782 Watt-hour.

PV Array

The polycrystalline photovoltaic cells are making modules which are connected in series and parallel to form a PV array. The area required for PV array calculated using following equation (Abd El-Shafy and Nafeh, 2009; Alamsyah et al., 2003)

Where,

G_a Average solar radiation (kWh/m^2/day);

TCF Temperature correction factor;

η_{PV} Efficiency of PV cell;

η_O $\eta_{Battery}$ $\eta_{Inverter}$

It is assumed that efficiency of PV cell is 17% and it is attaining a maximum temperature up to 60 ^{0} C then the TCF become 0.8(Alamsyah et al., 2003). The battery efficiency is 0.8 and inverter efficiency as 0.9. The average daily solar radiation energy input over the year G_a at Suhar is 5.92 kWh/m^2/day. Thus using equation (1) the PV array area is 17.5m^2. The peak power rating (W_P) of PV panel at Peak Solar Insolation (PSI) of 1kW/m^2 is determine by equation-2

W_P = 17.510000.17 = 2975 watts

The polycrystalline PV module used with the following specifications:

Peak power = 240 W_P, Peak power voltage = 29.6V

Peak power current =10.3A;

Module Dimension = 1524mm 870mm 36mm

Thus 12 PV modules are used to supply the energy required by lighting load of the electrical machines lab. The series and parallel connections of module can be adjusted according to the bus voltage and current. In this study the DC bus voltage is 48V therefore two modules will be connected in series and six strings with each of two modules in series will be connected in parallel to layout the PV array.

Figure 4. *Formation of PV Array*

Battery Bank

The battery bank stores energy for supplying to electrical load when there is a demand. The battery type recommended for using in solar PV system is deep cycle battery. The storage rating of the battery can be determine using the equation-3 (Abd El-Shafy and Nafeh, 2009; Mahmoud and Ibrik, 2006)

Where,

DoD is maximum permissible depth of discharge of battery;

N_C is maximum number of continuously cloudy days.

According to Oman climatic conditions it is worth to assume 4 days as maximum continuously cloudy days. For a deep cycle battery, maximum depth of discharge is 80%. Considering all parameters of equation-3, the rating of battery become 70470 Wh. Since the selected bus voltage is 48V, the required rating of battery become =1468.12 or let us say 1470 Ah in round number. If the available standard rating of single battery is 24V, 250Ah then two batteries should be connected in series and such three strings of batteries should be in parallel. Therefor overall 6 batteries will serve the purpose.

Charge Controller

The solar charge controller is typically rated against Amperage and Voltage capacities. It regulates the voltage and current coming from the PV panels going to battery. It prevents battery overcharging and prolongs the battery life. Charge controller should have the capability to withstand the short circuit current of the PV array. In this study peak current of PV module is 10.3A and six parallel strings are used. Therefore charger controller should handle 61.8A to maintain the DC bus at 48V.

Inverter

An inverter is used in the system where AC power output is needed. The inverter must have the same nominal voltage as battery bank. For grid tie systems or grid connected systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation while for standalone system the inverter size should be 25-30% bigger than total power of appliances. In this study 2kW, $48V_{dc}$, $220V_{ac}$, 50Hz inverter is chosen, which is around 26% higher than the maximum demand as depicted in Table 1

Simulation by HOMER software

The HOMER Pro® (Hybrid Optimization Model for Multiple Energy Resources) software is a widely used for optimizing μ-grid design in all sectors for grid connected or island modes. To simulate the energy output of a PV system and net energy cost, modeling is the first step as shown in Figure 5. The PV system is model for a given load and performance is simulated with HOMER Pro software.

The design of major components has validated with standard components used by manufacturer and PV system commissioning company.

HOMER can accept input data either directly through user interface or through file import. It has its own rich library and facilitated online global data bank in association with NASA. The input data required for the modeling in this study has taken from the various sources like design of PV system, electricity market, default values in software and few parameters are assumed when data is readily not available. The maximum power point tracking system is not taken into consideration. It is assumed that life span of PV system's component (accept battery bank) is 20 years while battery bank should be replaced after every five years. In simulation, all cost calculations with different scenario of sensitivity analysis has converted from local currency Rial Omani into US Dollar (1Baiza =0.259 Cent).

Figure 5. *Model of PV based DG connected to grid*

Results and Discussion

The simulated monthly output energy of PV system as source of DG is shown in Figure 6 which is able to produce annually 5695 kWh. It can be observed from Figure 6, the output is well resembles with amount of solar radiation receive from the Sun. The entire lighting load of the laboratory is taken care by PV system and surplus 740 kWh electricity, shown in red color available during June to August because the college is observing summer vacation. This power can be inject back to grid and sold to the network operator at green energy tariff of US$ 0.094per unit. This will make revenue of US$ 69.5 to compensate other electricity bills.

Further it can be depicted from Figure 6 the maximum power is generated during the month of august when the incidence solar radiation is highest while ambient temperature is lower than its peak. The output of photovoltaic cells has close relation with ambient temperature. It adversely affects the cell performance at higher ambient temperature.

Figure 6. *Simulated energy output of 3 kW PV system*

The optimum cost of energy (unit electrical cost-COE) determined by software is shown in Table 2. It can be seen that cost of energy is US$ 0.17 while the applicable tariff for commercial load by the grid through distribution network operator is about US$ 0.06 in Oman. Some variation in applicable tariff depends on amount of energy used by customer and summer to winter season.

Figure 7. *Simulated energy cost of PV system*

It is clear from the above data; the cost of grid connected electricity is one-third of the cost of power produced by the PV system. Even though power produced by DG is costly but still it is preferable due to many other factors which are discussed as follows:

- The applicable tariffs in Oman are based on substantial subsidies (AERO, 2017) granted by the government at all level of power system and to support the welfare of the citizen in financial modes. The actual cost of electricity generation of a modern power plant operated with subsidized fuel rate had estimated US$ 0.17 per kWh (Solanki, 2012). This is indicating that cost of energy supplied by PV system and grid are closing in the cost parity.

- Geographically Oman is spread in 309501 km^2 with rich solar radiation while the density of electricity consumers is not uniformly distributed across the country. Many off-grid remote villages and town in Dhofar, Masirah and Musandam can adopt the DG to form the µ-grid and to feed the residential load

- The DG based µ-grid is quite encouraging for all consumers to install the PV system and sell their surplus power to network operator at a price much higher than local tariff. This is new government policies to procure green energy from µ-grid at the rate of around US$0.094/kWh.

- The most of power produced in Oman is based on combustion of fossil fuels like liquid natural gas or diesel which are having cumulative emission factor of 0.685 kg CO_2/kWh (Solanki, 2013). But power generated by PV system is free from carbon emission. This is a point of motivation to save the environment and prevent climate change as the energy produced by 3 kW PV system is enable to curb 4.5 metric tons CO_2 per year.

- As of now the per unit energy cost of PV system is relatively more than subsidized applicable tariff due to higher cost and lower efficiency of PV modules. In future due to advancement of technology cost of solar PV module and battery storage will decrease. Some experimental results are indicating that soon in future the efficiency of solar cell will improve from 17% to 50%.

Benefit and Challenges of DG and µ-grid

Due to socio-economic and technological developments energy demand is continuously increasing which is mounting pressure on power system to heavily invest to enhance its capacity. In this scenario, the concept of DG associated with µ-grid can play vital role to meet the future demand. It has its own merits, demerits and challenges which are described in this section.

Benefits

- The DG based on solar or wind energy is geographically dependent which can produce AC or DC voltage. Their power flow can be control using maximum power point tracker and pitch and torque control techniques. The µ-grid deployment in location with electrical grid provides the energy security and clean energy integration. The renewable based DG has zero fuel cost and zero emission.

- The output of DG is intermittent in nature but using power electronic converters it is possible to control the voltage magnitude and frequency while µ-grid are designed to handle variable generation.

- The main power grid nowadays is more relies on advanced information and communication technologies like SCADA. This makes the grid more susceptible against virus and cyber-attacks. On other hand due to decentralize architecture of µ-grid, it is less vulnerable against such threats.

- The DG and µ-grids are generally located near to the load centers and hence avoid the additional investments of grid to expand its infrastructure. It also offers to improve the efficiency by reducing line losses.

- It has the potential to improve the resiliency and reliability of power supply to critical facilities such as traffic control signals and emergency response infrastructure.

- This system provide the opportunity to end-user to import and export electricity.

Challenges

- The output power of DG associated with grid is non- dispatchable without storage capacity. The battery bank used for storage has limited number of charge-discharge cycle.

- Most of μ-grid generating sources not have inertia machines so a buffer is required to reduce the impact of imbalance in electric demand and supply.

- The large amount of DG penetration possess several technical issues in the operation of grid such as steady state and transient voltage at point of common coupling, malfunctioning of protection coordination, variation in fault levels by switching of distributed energy source and increase in power quality problems.

- Though DG based μ-grid customers would like to remain tied with grid but over the period of time it will erode the revenue base of distribution networks operator which is to be paid by customers in lieu of utility infrastructure and investments. This will create a financial plunge to utilities for their business margin.

- As of now the DG and μ-grid are at their initial stage in Oman but with respect to time when it develop further the legal and regulatory issues will impact on it. Therefore it is essential to develop better understanding of the impact of DG and network management procedures to fully exploit its implicit benefits

Conclusion

Even though there is no consensus on single definition of distributed generation but mostly authors are using small scale generation near to the load as DG. The power generated by DG is delivered to the load by a small distribution network known as μ-grid. The 3 kW PV system and its essential components are designed to cater the lighting load of electrical machines laboratory. The modeling and simulation to get the output and cost of energy is tested with HOMER Pro software. It is revealed that PV system is capable to produce 5695 kWh per year at the cost of US$0.17 per unit. The import and export of power is possible by μ-grid associated with DG. During off peak loads, it is possible to export 740 kWh to grid. The developed system can support to protect the environment by reducing 4.5 metric tons CO_2 annually. The major benefits and challenges are also highlighted in bullet points.

Acknowledgements

Authors are acknowledging the technical assistance provided by the management of College of Applied Sciences-Suhar and Nafath Renewable Energy LLC, Muscat.

References

Solanki, Parmal Singh (2012). “Demand Side Management Strategies to Regulate Electricity in Oman”, *Doctoral thesis: Glasgow Caledonian University*, Glasgow (UK), 2011, pp. 121.

Sherif M. Ismael, Shady H.E. Abdel Aleem, Almoataz Y. Abdelaziz, Ahmed F. Zobaa (2019). “State-of-the-are of hosting capacity in modern power systems with distributed generation” *Renewable Energy*, 130(2019), pp. 1002-1020.

Adam Hirsch, Yael Parag, Josep Guerrero (2018). “Microgrids: A review of technologies, key drivers, and outstanding issues”, *Renewable and Sustainable Energy Reviews*, 90(2018), pp. 402-411.

Martin-Martinez F, Sanchez-Miralles A, Rivier M (2016). "A literature review of microgrids: a functional layer based classification." *Renewable Sustainable Energy Review,* 62(2018), pp. 1133-1153.

Ton DT, Smith MA. (2012). "The US department of energy's microgrid initiative." *The Electricity Journal*. 25(8), pp. 84-94.

COWI and Partners LLC (2008). "Study on Renewable Energy Resources, Oman." *Authority for Electricity Regulation,Oman* , May 2008, pp. 57-127.

Hussein, A Kazemiken (2016). "Solar Radiation, Temperature and Humidity Measurement in Sohar-Oman." International Journal of Computation and Applied Sciences, pp.15-20.

Abd El-Shafy, A. Nafeh (2009). "Design and Economic Analysis of a Stand-Alone PV System to Electrify a Remote Area Household in Egypt", The Open Renewable Energy Journal, Vol 2, pp. 33-37

Alamsyah, T.M.I.;Sopain, K.;Shahrir, A. "In Technoeconomics Analysis of a Photovoltaic System to Provide Electricity for a Household in Malaysia", Proceedings of the International Symposium on Renewable Energy: Environment Protection & Energy Solution for Sustainable Development, Kuala Lumpur, Malaysia, 2003, pp. 387-396

Mahmoud, M.M.; Ibrik, I.H (2006). "Techno-economic feasibility of Energy Supply of Remote Villages in Palestine by PV-system, Diesel Generators and Electric Grid." *Renewable Sustainable Energy Review,* 10: 128-138.

AERO, Oman (2017). "Annual Report 2017 of Authority for Electricity Regulation, Oman" Available at: www.aer-oman.org,

Solanki, Parmal Singh (2013). "Estimation and Diminution of CO_2 Emissions by Clean Development Mechanism Option at Power Sector in Oman." *International Jiurnal of Energy and Environment*, Vol. 4(2013), Issue 4, pp.641-652.