DESIGN AND OPERATING PHOTOVOLTAIC POWER SYSTEM-INTERACTIVE THE ELECTRIC UTILITY TO SUPPLY RESIDENTIAL LOADS IN EGYPT

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ABSTRACT

Conservation and independent on conventional fuel for electric power generation is the main target of Ministry of Electricity and Energy (MEE) in Egypt. So, different types of renewable energy sources (RESs) are used with the bulk power supply in Egypt. Solar energy is the main type of these RESs pertaining the metrological conditions of Egypt. This is due to the sunrise is 3000 – 4000 hours per year with an average insolation of 5-7 kWh / m^2 at different regions of Egypt. Therefore, this work aims to design and operate solar photovoltaic (PV) power system with the electric utility to supply residential loads. An approach is presented here to design and operate PV system to supply these loads during the sunshine hours, while the electric utility is used through the other periods of the day. This approach has been applied for designing this power system at different regions of Egypt. Also, this power system has been operated to develop its impact on the conventional fuel conservation, environment pollution and utility bill of the owner of this PV system at the considered sites of Egypt.

Introduction

Due to the prices of conventional fuel (petrol) are high and limited, in addition to the impact of using this fuel for power generation on the environment, many of world countries and in Egypt are used RESs as primary materials for electricity generation[1]. The main types of RESs pertaining the meteorological conditions of Egypt are wind and solar energies. Also, solar energy is the most type of these RESs. This is due to the sunrise from 3000-4000 hours with an average insolation of 2000 kWh/m^2/year received on solar collector in all regions of Egypt [2]. Photovoltaic (PV) power system is the most one of the technologies used for convertion solar energy into electricity [3]. Also, this system has many advantages. These are; it can be designed for variety of applications and operation requirement, easily expandable and even transportable in some cases, in addition to the (sunrise) is free, require minimal maintance, have long service life-time and very reliable. Also, no noise or pollution is created from operating PV systems. PV systems are used for variety of remote area applications in Egypt, including water pumping and rural residential [4,5]. Grid-connected PV systems applications are now deployed in great numbers for residential, commercial and utility grid-support application of many of world countries [6,7]. Two modes of PV system-interconnecting the electric utility are used [8]. These are centralization or decentralization of PV systems on the electric utility grid feeders. Also, a bi-directional interface is made between the PV system output circuit and the electric utility network.

In this work, centralization mode of PV systems are planned to interactive the electric utility to supply residential loads. So, a proposed approach had been introduced to design these systems to supply residences through the sunshine hour, while the electric utility grid is used through the cloud and night periods. Also, the impact of these systems on the energy conservation, environment and the electric utility bill of the owner of PV system are evaluated through the sunshine hour, while the electric utility grid is used through the cloud and night periods. Also, the impact of these systems on the energy conservation, environment and the electric utility bill of the owner of PV system are evaluated.

2. PROPOSED APPROACH:

The proposed approach includes the calculation of the energy requirements for the residential load, design PV system to supply diurnal load, conventional energy conservation due to the generation of PV systems, and the economy of PV system and the electric utility bill of the owner of this system are considered.

2.1 Load Calculation:

The average daily or monthly daily load curve of a residence can be obtained by the load elements and their expected operation hours.

2.2 Design of PV System

PV system design depends on the load value, the insolation at the installation site, the operation mode and the method of design. So, in Refs. [9, 10], six design methods are suggested, modeled, studied and optimized for residential load applications. The 6 th design method (the total annual load demand and insolation) is defined as the optimal one of the study design methods. This method is modeled in Ref. [9] and used here for PV system-interactive the electric utility as following:

$$S_v = E_{ld}(a) / (H_t(a) * h_c * h_{pc}) \quad (1)$$

Where ηc and ηpc are the efficiencies of PV array and power conditions, $E_l(a)$ is the annual energy demand of the study residences through the diurnal periods and given by :

$$E_{ld}(a) = \sum_{m=1}^{12} \sum_{i=1}^{t_s} P_{(i,m)} \quad (2)$$

P(i,m) is the load demand during the i th hour of the month m and t_s is the sunshine hours of the month m, and $H_t(a)$ is the annual solar radiation received on the unit area of PV array and computed by :

$$H_t(a) = \sum_{m=1}^{12} \sum_{i=1}^{t_s} H_{(i,m)} \quad (3)$$

Where $H_{(i,m)}$ is the solar radiation received on the unit area of PV array through the i th hours of the month m. Considering the characteristics of the PV module used for constructed PV array (S_v), the number of these modules, N (m), and peak power of the designed PV system, P_{vp}, are developed and given by:

$$N(m) = S_v / S_{vm} \quad (4)$$

, and $$P_{vp} = N(m) * P_{vp}(m) \quad (5)$$

$P_{vp}(m)$ is the peak power of the PV module used and S_{vm} is the net area of this module.

2.3 Conventional Energy Displacement and Environment:

The annual energy displacement of conventional power supply (CPS) operated on an electric utility with PV systems depends on the annual energy generated of PV systems, Ev(a). This energy is given by:

$$E_v(a) = N(m) * S_{vm} * H_t(a) * h_c * h_{pc} \quad (6)$$

The amount of conventional fuel, F_c , and the savings of its costs, C_F, due to the generated energy $E_v(a)$ is also given by:

$$F_C = E_V(a) / (H_F * h_o) \quad (7)$$

$$C_F = c_f * F_C \quad (8)$$

Where H_F is the heat value of the conventional fuel used, η_o is the overall efficiency of the conventional power generation (thermal station) and C_F is the cost of 1 ton of conventional fuel.

CO_2 and SO_2 are the main gases affecting the environment at the installation site of conventional power stations. The amount of pollution of these gases (POL) and the savings in its elimination costs, C_{pol} and assessed by:

$$C_{pol} = c_{pol} * POL \quad (9)$$

$$POL = (e_c + e_s) F_C \quad (10)$$

Where e_c and e_s are the emission rate of CO_2 & SO_2 respectively, and c_{pol} is the cost of 1 ton of *POL* elimination.

2.4 Economy of PV System and Electric Utility Bill.

The economy of PV system includes the capital, operation and unit energy cost. The capital cost is developed as a function of the peak power of PV system and the cost per $1kW_p$. Thus, the capital, CC_v, and the annual capital ACC_v, cost of a PV system are given as:

$$CC_v = c_c * P_{vp} \quad (11)$$

and, $$ACC_V = DR * CC_V \quad (12)$$

Where c_v is the cost per $1kW_p$ and DR is the annual discount rate and given by [11]:

$$DR = r(1+r)^n / [(1+r)^n - 1] \quad (13)$$

Where r is the interest rate and n is the life-time. The total annual, TAC_v , and unit energy , UEC_v ,costs of this system are :

$$TAC_V = ACC_v + AOC_v \quad (14)$$

$$UEC_V = TAC_V / E_V(a) \quad (15)$$

Where AOC_v is the annual operation cost and developed as a function of the operation cost of 1kWh of Ev (a) [11].

The unit energy cost of complimentary conventional –PV generation on the electric utility, UECcv , can be modeled as :

$$UEC_{cv} = [c_u(E_l(a) - E_v(a)) + UEC_v * E_v(a)] / E_L(a) \quad (16)$$

Considering the savings in conventional fuel, C_F, and pollution elimination, C_{pol}, costs due to PV generation, UEC_v and UEC_{CV} are modified to UEC'_v and UEC'_{cv} and given as:

$$UEC'_v = (TAC_v - C_F - C_{pol}) / E_v(a) \quad (17)$$

$$UEC'_{cv} = [c_u(E_L(a) - E_v(a)) + UEC'_v * E_v(a)] / E_L(a) \quad (18)$$

Where c_u is the cost per 1 kWh supplied by the electric utility, E_L (a) is the annual energy required for the study utility.

3. CASE STUDY

The electric utility (EU) at Menoufiya Governorate (MG), Egtpt, is used to interactive PV systems. These systems are assumed to be concentrated on the residential feeders of this utility. Also, PV systems are used to supply the diurnal loads, while the EU supplies the loads through the other periods of the day. The proposed model in section 2 is applied to design and asses the operation of this system on the study electric utility.

3.1 Load Calculation:

Figure 1 shows the electric network of Mobarak Industrial city (MIC). Also, this figure illustrates the residential and industrial feeders, substations and their capacities. Two PV system plants are assumed to be concentrated and interactive 11 kV busbar of the two substations which are used to supply residential feeders of the study electric utility.

The electrification Authority of MG recorded the number of consumers on the residential feeders of MIC network, Figure 1, and the annual energy consumption in the year 2007 as:

	Residential feeder I	Residential feeder II
Number of consumers	25747	13301
Annual Energy,GWh.	61.458	31.750
Diurnal Energy,GWh.	21.51	11.112

3.2 Design PV System:

The solar data recorded by meteorological Authority of Egypt at the considered site [2] are used with the conversion factor model in reference [8] to estimate the solar insolation received on PV array installed at MIC (30º 27′ N and 31º 15′ E), and shown in Figure 2. This figure gives the monthly solar radiation of different year months. This figure concluded the annual solar radiation received on the PV array at Mobarak city site as 1961 kWh /m^2.

The annual diurnal energy demand and solar radiation are used with the proposed model, section 2.2, to estimate the PV array size for PVSI and PVSII and given as 121878 and 62963 m^2 respectively. A module of 50 W_p [12] is used for constructing this array. Number of modules and peak power of the designed PV systems are determined and given as: 196578 & 101553 and 9.8 & 5.1 MW_p.

3.3 Impact of Operating PV System on Electric Utility:

The impact of operating the deigned PV systems in section 3.2 is determined here in terms of the conventional energy displacement and its impact on the environment, and PV generation and its impact on the electric utility bill.

The proposed model in section 2.3 is applied numerically to estimate C_F and C_{pol} considering C_F is 261 $/ton, C_{pol} is 100 $/ ton [13]. Also, the model in section 2.4 is applied using these results to determine UEC_v, UEC'_v, UEC_{cv}, UEC'_{cv} considering UEC_u as 4.2 ¢ / kWh [14], c_v is 0.05 ¢ /W_p, AOC is 0.1 ¢ /kWh , r is 10% and n is 25 years [11], and shown in Figure 3. The results of this figure concluded that UEC_{cv} is (12.9 ¢/ kWh) Also, this cost is (10.9 ¢/ kWh) when savings in convention fuel and pollution elimination costs are taken into consideration. Thus, the annual increase in the utility bill of a consumer used 2387 kWh /year is $ 60 . To reduce this increase, the interest rate of the capital investment is assumed to be varied from 2% to 10 %. Figure 4 shows the impact of this variation on the EU bill. This figure concluded that UEC'_{cv} is 6.1 ¢/ kWh at interest rate of 2%.

4-CONCLUSION:

A proposed approach has been introduced in this paper. This approach includes a model to design PV system to supply residential loads interactive the electric utility. This model is applied numerically to design concentrated PV systems to supply the diurnal residential loads of Mobarak Industrial city in Egypt. The remarkable results of this application are:

1-The annual solar radiation received on PV array is 1961 kWh /m^2.

2-The peak power of PV systems to supply the annual diurnal residential load of 32.622 GWh is 14.9 MW_p.

3-The annual savings of conventional fuel and its costs due to the PV systems generation are 6412 ton and 1.676 million dollar. Also, the reduction of pollution is 16362 ton, and the corresponding elimination cost is 0.162 million dollar.

4- The increase of the utility bill of residential loads is 60% at interest rate of 10 %. This bill will be decreased at interest of 2% of the capital investment to 18 %.

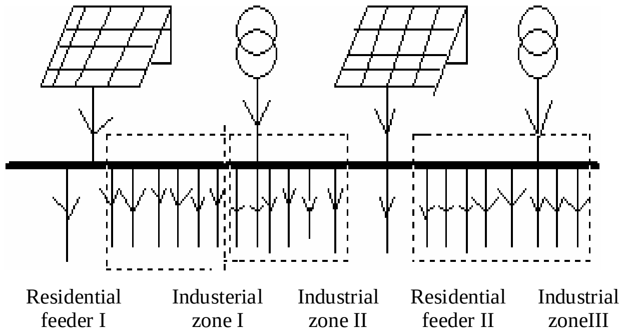

Figure 1 The line diagram of Mobarak Industrial city electric utility network [14].

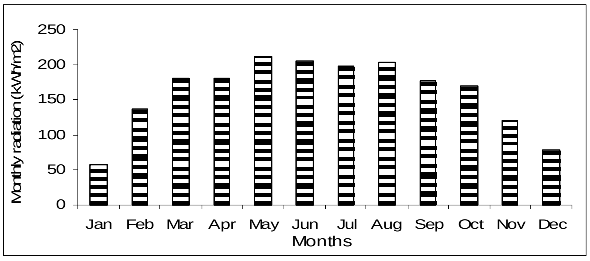

Figure 2. The monthly solar radiation received on 1 m2 of PV array at MIC.

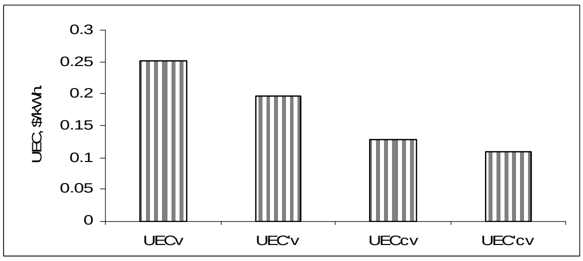

Figure 3. The UEC of the PVPs and electric utility bill with and without the savings of fuel and pollution elimination costs.

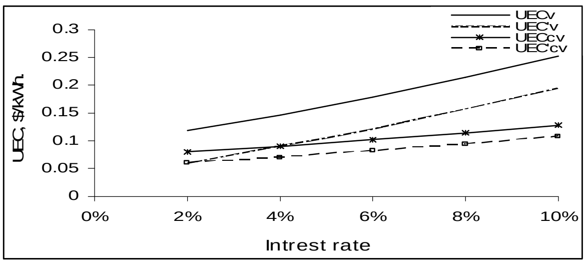

Fig4. The relation between cost and interest rate.

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Atef El-zeftawy

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Abla Gado

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