



Peak reduction in the qeshm island with photovoltaic farms

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Abstract. Recently, renewable resources, are increasingly used for power generation in most countries. Qeshm Island, has significant solar radiation and its required power can be provided by solar power plants. In this paper a technical and economic study is performed and the possibility of providing some required power of Qeshm Island by photovoltaic farms. Due to the variation in the solar radiation, their power generation depends on the solar radiation. In this paper three types of the photovoltaic farms, including fixed panel farms, farms equipped with single and double axis tracker are investigated. The real economical and technical data is used in 2011. The investment, installation and operation costs of photovoltaic farms as well as the penalty of CO₂ producing thorough power plants with fossil fuels are considered. After economic evaluation, it is deduced that single axis photovoltaic power plant, is suitable for power providing of Qeshm Island.

Keywords: Economic Analysis, Electrical Peak Reduction, Photovoltaic Farms

1. INTRODUCTION

Recently, the use of renewable resources, especially wind and solar, for electric power generation, has been increased. Being classified in the group of clean and ecofriendly energies, having free and unlimited resources, are the main reasons for extensive development of renewable energies. Development in the solar farm technologies leads to the decrease in the prices of generating electric power from these power plants and so construction of very large scale photovoltaic farms around the world. For example, a 250 MW Agua Caliente Solar plant in USA, 214 megawatt Charanaka power plant in India and a 200 megawatt Yuma county in the United States has been operating in 2012. Although development in photovoltaic farm technologies has considerably reduced the total price of producing electricity, but it still hasn't reached to such an amount to be replaced instead of the common thermal power plants in countries with large fossil fuel resources such as Iran. Moreover, the generated power of photovoltaic plants depends on the amount of the solar radiation and so the photovoltaic farms installed in the region with the highest solar radiation, the higher electric power can be produced.

During the day and also the different seasons, as the sun position in the sky changes, the angle of sun radiation on the area that the panels are installed, is changing too. Therefore, to attract the maximum amount of the sun radiation of the panels, some photovoltaic plants is equipped to the sun tracker. The mentioned systems increase the productive power of these plants in comparison with the power plant with fixed panels. However, in comparing to the fixed panel photovoltaic farms, the sun trackers cause higher costs and also to move the panels they consume part of the produced power of the plants.

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Regarding the mentioned points, in order to install a photovoltaic plant in a certain area, an economic investigation has to be done based on the amount of the sun radiation, investment and operation costs as well as in regard to pollution reduction. After these studies, according to the acquired results, the planners and the decision makers of the power system can decide about the type and capacity of the required generation units. Numerous researches have been done all over the world to use the photovoltaic systems for electricity power generation.

Many efforts have been devoted to the economic evaluation of the standalone photovoltaic systems. In [1] a hybrid system, including wind turbines and photovoltaic systems is proposed for power generation of home usage in remote areas. In the paper based on the annual total cost of the hybrid system optimal combination of wind turbines and photovoltaic systems is determined using the genetic algorithm. In [2] the stand alone photovoltaic systems are used for power generation of the typical household in Malaysia. In the paper using of the RETScreen software the cost of 1 kilowatt per hour of generating power over a period of 25 years is calculated. In [3] photovoltaic systems connected to energy storage batteries are investigated for power generation of remote areas. Using of the Matlab software, the reliability criteria as well as the economic studies of the photovoltaic systems are performed and the optimal sizing of the photovoltaic systems and the connected batteries is determined. In [4] an economic analysis conducted to estimate the total costs of producing 1 kw/h electricity power by photovoltaic system in Riodejaniro, Brazil and Chicago, USA. In the analysis the cost of preliminary investment based on the interest rate regarding the system useful life times, operation and maintenance costs are considered. In [5] an economic investigation has been done to determine the number of optimum solar panels for a photovoltaic system which can be used in a hybrid system connected to the power network and diesel generators. This economic analysis has considered the useful lifetimes of the hybrid system, high fuel costs of diesel power plants and utilized from the solar data in northern areas in Brazil. In [6] an economic investigation is done to produce electricity power by photovoltaic system in eastern European countries such as Bulgaria, the Czech Republic, Lithuania, Hungary, Poland, Romania, Estonia and Slovakia. In these countries, the government policies tried to install and extend the photovoltaic systems. In [7] three scenarios, including wind turbines, photovoltaic systems and hybrid wind/PV systems are considered for power generation of remote areas in Montana. Minimization of the customer total cost, the size of these systems and also the battery storage are determined. In [8-9] the reliability and economic evaluation of standalone photovoltaic systems are performed and the optimum size of these resources is determined based on the results. In [1-9], an average amount of solar radiation is considered and the evaluation is performed based on this value. As we know, during the day and also different seasons, the solar radiation varies and so the generated power fluctuation of photovoltaic farms is not considered in the previous works. Besides, the effect of solar trackers in increasing the generated power of photovoltaic systems hasn't been considered. This paper in a complementary manner tries to investigate the utilization of photovoltaic farms connected to the power grid, to provide some required electric power of Qeshm Island from technical and economic point of view. The investment, installation, operation costs of photovoltaic farms, as well as the penalty of diffusion carbon dioxide from present thermal power plants has been taken into account. Moreover, to investigate the impact of sun trackers on the efficiency of the photovoltaic farms, three types of photovoltaic farms, including fixed panel farms, farms with single axis tracker and also farms with double axis tracker is studied. In this study, it is utilized from the hourly solar radiation value and angle data and also electric power price data on Qeshm Island in 2011. This paper is organized as below: In section 2, different types of photovoltaic systems are introduced and associated received radiations are obtained. In section 3, different costs of a photovoltaic farm are determined and in section 4, providing the required power of Qeshm Island by different cases is compared with each other. The conclusion and results of the paper are given in section 5.

2. DIFFERENT TYPES OF PHOTOVOLTAÏC SYSTEMS

A solar cell is a p-n junction which produces DC electrical power with absorption the sunlight. Since, the produced voltage and current of this cell is low, a number of these cells are connected to each other in series and parallel manner which formed the solar panel. A DC to DC converter named maximum power point tracker (MPPT) is connected to panels and the voltage and current are varied so that the panels can work at this point. In order to connect photovoltaic systems to AC power network, an inverter can be used. An array is made of several parallel sub-arrays connected to an inverter. A photovoltaic farm is the parallel connection of several arrays. The generated power of a photovoltaic farm depends on the amount of the solar radiation. Since the sun radiation angle, during the day and also during the various seasons of the year is different, a tracker system can be utilized by some power plants. Therefore the direction of the panels can move by this tracker so that the sun radiation is perpendicular to the panel. The location of the sun in the sky is determined based on two angles named Zenith and Azimuth angles. The Zenith angle is an angle between the sun direction and the axis which is vertical to the related point and extends upward. The Azimuth angle is an angle between the North Pole and the direction of the sun image on the earth. Generally, the geographical position of a point on the earth is recognized by two geographical quantities named longitude and latitude. The longitude recognizes the specific position in the direction of east to west and the latitude recognizes that position in the direction of north to west. In an area with definite geographical longitude and latitude, the Zenith and Azimuth angles of the sun during different times of the year, from astronomical relations can be simply determined. In this study, the Zenith and Azimuth angles related to Qeshm Island in 2011 is utilized in the simulations. Generally, there are three types of photovoltaic systems as follow:

- A photovoltaic system without tracker; while in the northern hemisphere, the panels with an appropriate tilt angle have been located to the south.
- A photovoltaic system equipped to single axis tracker; while during the day, the panels can move in one direction which is usually east to west.
- A photovoltaic system equipped to double axis tracker; while the panels can move in two directions of east to west and also north to south. They are always located vertical to the solar radiation.

At this stage the solar radiation is considered to be A_t and so the amount of the received radiation related to each photovoltaic system can be determined from the following relations.

$$A_{double\ axis} = A_t \tag{1}$$

$$A_{fixed\ panel} = A_t(\sin(z)\cos(a)\sin(\gamma) - \cos(z)\cos(\gamma)) \tag{2}$$

$$A_{single\ axis} = A_t\sqrt{(\sin(z)\sin(a))^2 + (\sin(z)\cos(a)\cos(\gamma) - \cos(z)\sin(\gamma))^2} \tag{3}$$

Where z , a and γ are respectively, the Zenith, Azimuth and the tilt angles.

3. DIFFERENT COSTS OF THE PHOTOVOLTAÏC POWER PLANTS

The investment cost, including the costs of related equipment and the land of power plant, installation cost and operating costs, including human costs, maintenance cost and the cost of cleaning the solar panels is the main costs of a photovoltaic power plant. In this study, a photovoltaic power plant consisted of n solar arrays installed in the Gavazrin region of Qeshm Island is considered. The area of each panel is $1 \times 1.60 = 1.60m^2$ and the efficiency of the plant is 17.36% (considering the converter losses). Therefore, in solar radiation $900\text{ watt}/m^2$, the output power has been 250watt. In this study the photovoltaic system lifetime is considered to be 25 years while 0.5% of its rated power is being reduced yearly. The MPPT is connected to four

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panels which made a sub-array with the capacity of 1000 watt. Besides, the arrays involve three sub-arrays and an inverter to power of 3 kW. In the photovoltaic systems equipped with mechanical trackers, the costs of the trackers should also be taken into account. In Tables 1(a) and 1(b) the related equipment characteristics in photovoltaic power plant and their costs have been illustrated.

Table 1: (a)The characteristics of photovoltaic systems equipment(b) The costs of sun trackers

(a)

Components	Price (Rial)
Optical sensors	1200000
Tracker stand	2000000
Motor	4000000
Control system	2500000

(b)

Components	Company	Price (Rial)
Solar panel 250w, mono	LG	8250000
Charger (MPPT) 45 A	PRBNF	7000000
Inverter 3000w-25 A	FARAN	20500000

Each of the trackers is able to move 4 panels (1 sub-arrays), while their motor consumes 25 watt power. In a solar farm with n arrays equipped with single axis trackers, one optic sensor and $3n$ number of other equipment is required. However, in a system equipped to double axis tracker with the same number of arrays, a pair of optical sensors and $2 \times 3n = 6n$ number of other equipment is required. Since the motor associated with the north to south tracker moves less, the consumed power of each tracker which is associated with each sub- array is 30 watt. The installation and operation costs of photovoltaic system are considered to be 1% of investment cost yearly. In this paper, the power plant is located in Gorzin, Qeshm Island and so the price of the land is 3000000 Rials per meter. In order to prevent shading of panels on each, a certain distance is required between the panels. In the worst case in summer, the sun radiation angle is almost 50° (the geographical latitude in Qeshm Island plus the angle 23.45°). The distance between the panels is calculated as

$$b = \frac{a}{\cos(\alpha)} = \frac{a}{\cos(50)} = 1.5a \quad (4)$$

The cost associated with each array during 25 years for three types of photovoltaic systems is shown in Table 2. In this study the cost of optic sensors which in comparison with other costs is not significant, is ignored. In the sensor less trackers operated based on the predetermined sun position, the optical sensors are not required. In a region with defined latitude and longitude, the data associated to the sun radiation angle have been achieved based on astronomical relations along with the sun position in the sky.

Table 2. The cost associated with each array in different photovoltaic systems

Type of photovoltaic system	Price (Rial)
Fixed panel	186300000

Equipped to single axis tracker	222210000
Equipped to double axis tracker	258120000

4. ECONOMIC INVESTIGATION OF DIFFERENT CASES

In this section, different cases which supply required loads in Qeshm Island are investigated from economic and technical points of view. These cases are as below:

Case I: The required loads are supplied by Iran power network and no photovoltaic farm is installed.

Case II: The required loads are supplied by photovoltaic power plants without sun tracker connected to the power grid

Case III: The required loads are supplied by photovoltaic power plants equipped to the single axis sun tracker connected to the power grid

Case IV: The required loads are supplied by photovoltaic power plants equipped to the double axis sun tracker connected to the power grid

4.1. Cost function

Very low diffusion of carbon dioxide is one of the important advantages of photovoltaic systems in comparing to thermal power plants and so this factor is considered in the cost function. In this study a penalty term has been considered for carbon dioxide diffusion through thermal power plants of the power grid. In Table 3, the penetration level of each type of electrical power plant in power generation of Iran network in 2011 is shown. In Iran, the main fuel for thermal power plants is steam, gas and for combined cycle plants is natural gas. When these fuels are not available, the gasoline or crude oil can be used. The Diesel power plant also uses gasoline to produce electricity. In Table 4 the amount of different fuels in electricity production in 2011 is illustrated.

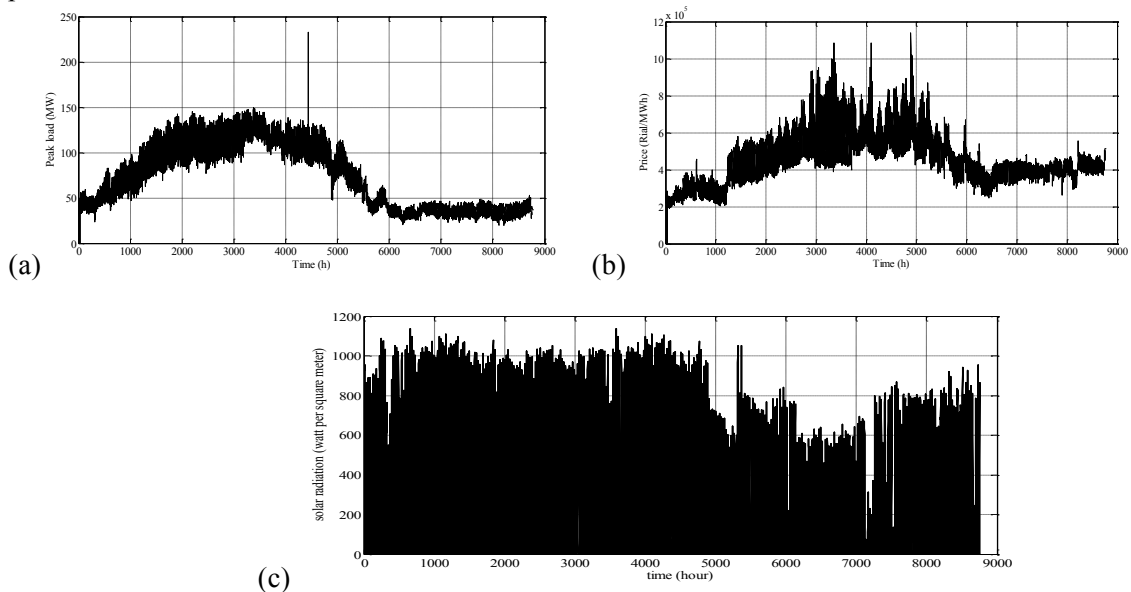


Figure 1. (a) Hourly peak load associated to Qeshm Island (b) Hourly electricity price associated to Qeshm Island (c) Sun radiation data on Qeshm Island

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Table 3. The penetration level of different types of power plants in 2011.

Kind of power plant	Capacity (MW)	Penetration level (percent)
Thermal	15821	24.3
Gas power plant	24342	37.3
Combined cycle	14780	22.7
Hydropower	8745	13.4
Diesel, wind and renewable	504	0.8
Nuclear	1020	1.6

Table 4. The amount of consuming fuel associated with different power plants

Kind of fuel	Amount of consumption (million m ³)	Percent of consumption
Natural gas	38901	63.9
Gasoil	9406	15.3
Fuel oil	12019	20.8

It is deduced from Table 4, 85% of generating power is produced by the power plants, including steam, gas, combined cycle and diesel plants which used fossil fuels for power generation. These power plants use 63.9% from natural gases and 36.1% diesel fuel. In Table 5, the amount of diffused carbon dioxide produced due to the burning diesel fuels and natural gas is illustrated. In the third column of this table the output power of the plants and in the fourth one, the amounts of produced carbon dioxide arisen from each megawatt/h electricity production through burning these fuels have been shown [11]. Therefore, for each megawatt electricity production in Iran power plants 0.598 ton carbon dioxide have been diffused. In this study, 20 dollar penalty or 400000Rialshave been considered for each ton of diffused carbon dioxide. Therefore, producing 1 megawatt/h electricity through Iran power grid has a 239200 Rials penalty which has to be regarded in the cost function. The diffusion of carbon dioxide in photovoltaic power plants has not been so much and has been ignored in this study. Thus, cost function consists of two terms, firstly, the costs of power plants, secondly the penalty for carbon dioxide diffusion. At this stage, to investigate different states, the total costs to provide Qeshm Island required loads during 25 years have been regarded as the comparison criteria. In most of the previous studies, The comparison criteria have been the total costs associated to produce one kilowatt/h electricity from different items. However, the mentioned investigation needs to consider the present value of the costs use of the economic factors such as interest rate, benefit rate, fluctuation rate and so on. It is difficult to estimate these factors and so the total costs of producing the required power of the Qeshm Island during 25 years is considered in the comparison. Thus the cost function associated with different cases has been investigated.

Table 5. The amount of carbon dioxide gas produced from different fuels

Kind of fuel	Produced gas (ton per Mw/h)	Plant efficiency	Produced gas (ton per Mw/h generated power)
Diesel	0.26676	0.38	0.78
Natural gas	0.20196	0.34	0.66

4.1.1. Cost function associated to case I

In this case, the Qeshm island load is provided through Iran power network. In Figure 1(a), the hourly peak load of Qeshm Island in 2011 has been shown. The peak load is a summation of peak loads associated with different feeders including Dargahan1, Dargahan2, Dargahan3, Kave1, Kave2, Suza1, Suza2, Setareye Qeshm1, Stareye Qeshm 2, Tab11, Tab12, Laft, Qeshm1, Qeshm2, Tola1, Tola2 and Basaeedu. The distribution network losses in Qeshm Island are 7.92% and thus total required power is calculated. The hourly electricity price is determined according to Iran electricity power market and is shown in Figure 1(b). The average price of electricity in 2011 was 462Rials per kw/h. Since the government pays subsidies for electricity, so this price is different from the real price which is 1200 Rials. Therefore, in order to make the prices real, the hourly prices of electricity in Figure 1(b) are multiplied in 2.6. The cost function associated to case I is consisted of the cost of purchasing electricity from power network for 25 years along with gas diffusion penalty produced by thermal power plants as (5).

$$obj\ func = 25 \times \sum_{k=1}^{8760} (L_k C_k + L_k \times 239200) \text{ rials} \tag{5}$$

Where L_k and C_k are respectively the peak load and electricity price associated to hour k .

Based on the present value for electricity price, the total cost and average cost per kw/h of providing the required power of the Qeshm Island are respectively 13241.75 billion Rials and 591.11 Rials. However, considering the real price of electricity power, 27564.55 billion and 1536.88 Rials are respectively the total cost and average cost per kw/h of providing the required power of the Qeshm Island. It is deduced from the figures in the peak load situation when the electricity is expensive, the consumed power is higher and it is not economical.

4.1.2. Cost function associated to case II

In this case, some of the Qeshm Island required power is provided from the photovoltaic power plant connected to the Iran power grid and it is considered that the photovoltaic farms are fixed panel. The objective function of this case is consisted of costs of photovoltaic power plants, costs of purchasing electricity from Iran network thermal power plants and the carbon dioxide diffusion penalty. The sun radiation data associated to Qeshm Island in 2011 is shown 1(c). The received sun radiation is measured by a spherical sensor and so these data are the maximum sun radiation associated with the photovoltaic farm equipped to the double axis sun tracker.

The sun radiation data associated with the photovoltaic systems which don't have any tracker and also for ones equipped to single axis tracker are calculated by (1) and (2). The produced power of a photovoltaic system with n arrays can be achieved by (6).

$$PV_k = [(1 - (h - 1) \times \frac{0.5}{100}) \times n \times \frac{S_k}{900} \times 0.003] \text{ MW} \tag{6}$$

Where, S_k , PV_k and h are respectively the received sun radiation by fixed panels, generated power by the photovoltaic farm and year of operation.

The objective function associated with this case is illustrated in (7). At this stage, it is considered that photovoltaic system cannot sell its extra electricity to the network.

$$obj\ func = 186300000 \times n + \begin{cases} \sum_{h=1}^{25} \sum_{k=1}^{8760} [(L_k - PV_k) \times (C_k + 239200)] & L_k \geq PV_k \\ 0 & , L_k < PV_k \end{cases} \tag{7}$$

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For determining the optimum capacity of the photovoltaic farm an optimization is done by MATLAB software and the optimum number of required arrays is calculated. It is deduced from the results, if the present power price has been regarded as the comparison criteria, the photovoltaic power plant may not be justifiable. This result can be inferred from Figure 2(a). It is clearly deduced from the figure that as the capacity of photovoltaic power plant increases the costs increase too. However, considering the real price of the electricity power resulted in the optimum 51 megawatt photovoltaic power plant as shown in Figure 2(b). Therefore, the total cost of providing electricity in Qeshm Island is reduced to 27533 billion Rials, the price of each kw/h of electricity will be 1534.96 Rials and the average cost of photovoltaic electricity for each kw/his 1549.4 Rials. Although, the cost of the photovoltaic power plant of this case is not less than network but by providing some of the required power of Qeshm Island, the total cost during the peak time is reduced. In Figures 3(a) and 3(b), the impact of photovoltaic system for peak reduction of Qeshm Island in winter and summer are shown.

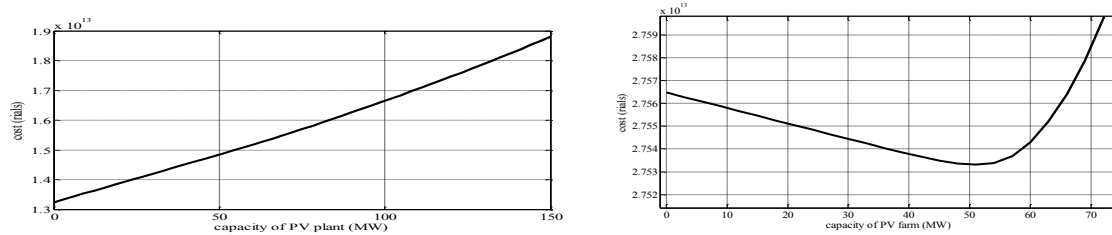


Figure 2. (a) Objective function value considering capacity of photovoltaic farm (case II with present price of electricity) (b)Objective function value considering capacity of photovoltaic farm (case II with real price of electricity)

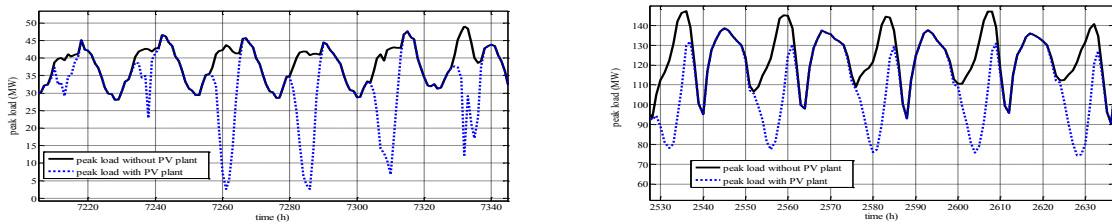


Figure 3. (a) Peak reduction by photovoltaic farm (case II) in winter (b)Peak reduction by photovoltaic farm (case II) in summer

4.1.3. Cost function associated to case III

In this case a photovoltaic power plant equipped to east to west single axis tracker connected to the power network provides the required loads of the island. The generated power of this plant and its objective function are illustrated in (8) and (9). In these equations S_{sk} is the received sun radiation density through a panel equipped to single axis tracker in hour k . When the generated power in each sub- array be less than 25 watt, the solar farm cannot inject any power to the load (or to the power network). Besides, S_h is the value of the sun radiation in year h , so that it can produce 25 watt power in each sub-array.

$$PV_k = \begin{cases} [(1 - (h-1) \times \frac{0.5}{100}) \times n \times \frac{S_{sk}}{900} \times 0.003 - 3n \times 0.000025], & S_{sk} \geq S_h \\ 0, & S_{sk} < S_h \end{cases} \quad (8)$$

$$obj \ func = 222210000 \times n + \sum_{h=1}^{25} \sum_{k=1}^{8760} (C_k + 239200) \times (L_k - PV_k) \quad (9)$$

As shown in Figure 4, optimization of the objective function results in the optimum 60 MW photovoltaic power plant. Thus, the total cost of producing electricity during 25 years and the average price of each kw/h power respectively are 27307 billion and 1522.52 Rials. The cost of photovoltaic electricity in this case is 1518.10 Rials in each kwatt/h. In Figures 5(a) and 5(b), the impact of photovoltaic system equipped to single axis tracker on peak reduction of the power grid in summer and winter are illustrated.

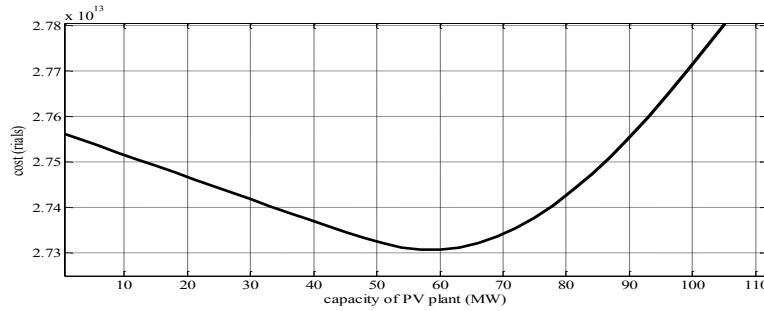


Figure 4: Objective function value considering capacity of photovoltaic farm (case III with real price of electricity)

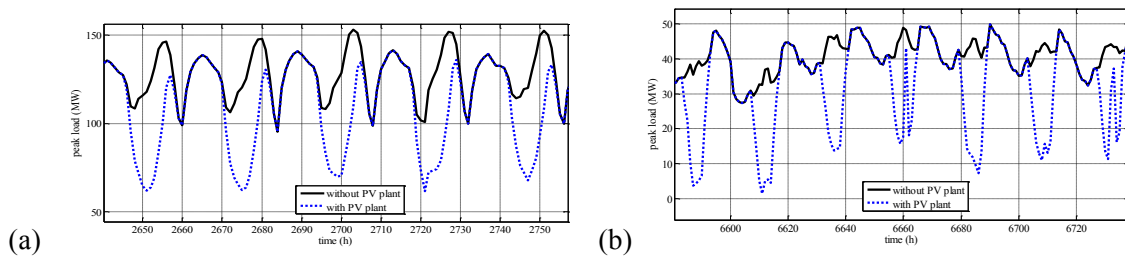


Figure 5 (a). Peak reduction by photovoltaic farm(case III) in winter (b)Peak reduction by photovoltaic farm (case III) in summer

4.1.4. Cost function associated with case IV

In this case a photovoltaic power plant equipped to double axis tracker provides the required loads of the island. The generated power of this plant and its objective function are as (10) and (11). In these equations Sd_k is the received sun radiation through panels equipped to double axis trackers and S_h is the value of the sun radiation in year h so that it produces 30 watt power in each sub-array. As it is obvious in the equation, when the produced power in each sub- array is more than 30 watt, the solar farm can give power to the load (or to the network).

$$PV_k = \begin{cases} [(1-(h-1) \times \frac{0.5}{100}) \times n \times \frac{Sd_k}{900} \times 0.003] - (3n \times 0.00003) & , Sd_k \geq S_h \\ 0 & , Sd_k < S_h \end{cases} \quad (10)$$

$$obj \ func = 258120000 \times n + \sum_{h=1}^{25} \sum_{k=1}^{8760} (C_k + 239200) \times (L_k - PV_k) \quad (11)$$

In this case, an optimization is done to determine the optimum capacity of photovoltaic power plant. However, as can be seen from Figure 6, photovoltaic system equipped to double axis tracker is not economic.

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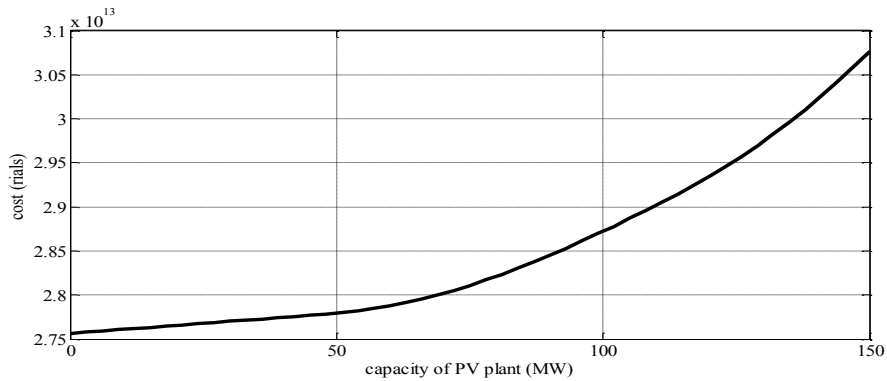


Figure 6. Objective function value considering capacity of photovoltaic farm (case IV with real price of electricity)

5. CONCLUSION

This study attempted to conduct an economic investigation on providing some of the required power of Qeshm Island by photovoltaic farms. For this purpose various costs, including photovoltaic power plant costs as well as a penalty of diffused carbon dioxide produced from fossil fuels by thermal power plants are taken into account. As it can be deduced from Figure 7 and Table 6, a 60 MW photovoltaic power plant equipped to single axis tracker connected to the power network is the most economic option for this purpose. In this case, during 25 years, the distribution company will benefit from 258 billion Rials cost reduction. In the other word, it can dedicate 10.28 billion Rials of its yearly income from investing in other parts. Besides, if this company can provide some of its required power by installing 51-MW photovoltaic power plant without tracker, 32 billion Rials during 25 years and 1280 million Rials during a year will benefit from cost reduction. However, the photovoltaic power plant equipped to double axis tracker won't be economically justified.

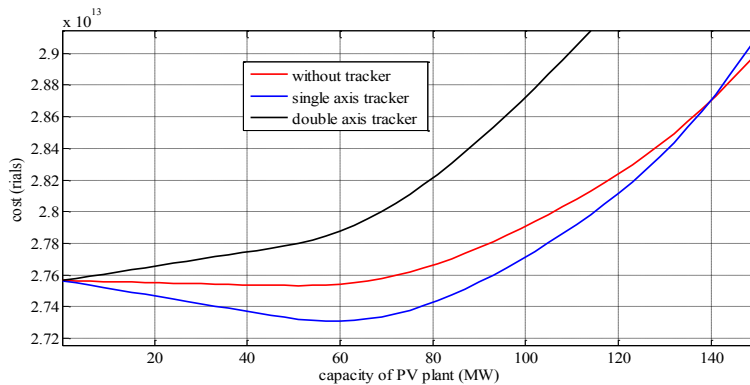


Figure 7. Comparison of different options for power providing of Qeshm Island (versus capacity of photovoltaic farms)

Table 6. Costs (Billion Rials) of different options for power providing of Qeshm Island

Options	Case I	Case II	Case III	Case IV
Present price	13242	No economy	No economy	No economy
Real price	27565	27533	27307	No economy

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