Optimization of Hybrid PV/Diesel Power System for Remote Telecom Station

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ABSTRACT

Photovoltaic system is an important topic that can be researched and studied in Iraq because a solar energy potential is available. This paper deals with the design of PV system for electrification of remote communication towers in a mobile company in Iraq, design of solar hybrid power generation system connected to the tower loads. This hybrid system consists of photovoltaic system, diesel generator, power flow controller, power electronic converter and the tower loads. The main strategy of the system will be if there is enough energy from the sun, the load demands can be supplied from these sources. Whenever there is excess supply from the renewable energy sources, the energy will storage in special batteries. If either the available power from the solar panels cannot satisfy the load demand, the generator can meet the excess power demand. The main objective is to estimate the economical and environmental impact of using solar PV hybrid system instead of diesel generators, estimated for both running and fixed costs. The related environmental impacts are discussed from the sustainable development point of view, the using of PV solar energy systems in two mentioned locations it can be saved around 27,000 kg CO₂, which is emphasize on the future role of renewable energy sources in Iraq.

Keywords: Solar, Photovoltaic, Diesel, Communication Towers, Mobile

1. INTRODUCTION

In recent years, a considerable growth in using renewable energy resources has been observed. Specially, solar energy is infinite, site-dependent, non-polluting, and high potential source for alternative energy production. For remote systems such as radio telecommunications, satellite earth stations, or at sites far from a conventional power system, the hybrid energy systems is referable. Such system is usually equipped with diesel generators to meet the peak load demand during short periods, when the available energy is deficit. Hybrid energy systems are best suited to reduce dependence on fossil fuel using available solar radiations. A configuration of a hybrid energy system is shown in Fig. 1. It includes PV panels and diesel generator and batteries. These energy systems are considered as one of the cost effective solutions to meet energy requirements of remote areas.

Fig. 1. Schematic of a hybrid solar- diesel power system

This uncertainty in availability of grid connected electricity compels telecom operators in Iraq to the use of diesel generator for proving uninterrupted power supply to the telecom equipment. Annually, more than 500 million liters of diesel are consumed by telecom sites in Iraq, resulting in CO₂ emission of about 1.3 million metric tones. The utilization of diesel generators as the main power generation for off-grid and back-up for grid connected telecom tower sites comes with its implicit disadvantage in terms of high cost of diesel based power generation as well as having a negative environmental impact due to high CO₂ emission per kWh consumed. Renewable technologies offer clean, sustainable, green and reliable power generation as well as low operating and maintenance cost of power supply. Both solar and wind are ubiquitously available sources of clean energy, bring power generation to where it is needed and thus being suitable for the telecom industry. However, independent solar photovoltaic (PV) and wind turbine generator alone cannot provide reliable power supply due to the intermittent nature of the resources (variation in solar irradiation, wind speed) because of changes in atmospheric conditions. The combination of different energy resources allows improving the overall system efficiency, reliability of the power supply.
and reduces the energy storage requirements compared to the systems comprising only one renewable energy source [6].

This paper presents the results of technical and economic feasibility studies of employing hybrid renewable energy system (HRES) to power a remote location mobile telecom base transceiver station (BTS) in Iraq. The stand-alone solar with diesel backup hybrid system is an economically attractive alternative for mobile telecom sector over the conventional diesel generator standalone system [7]. A hybrid renewable energy system with diesel generator offers several advantages which include reduction in operating cost by decreasing operating time of the generator, reduction of environmental pollution and lower maintenance costs, etc. The inclusion of battery storage reduces the number of start/stop cycle of the generator and thus minimizes oil consumption considerably. The complementary nature of solar and resources combined with a storage system significantly increases the reliability of system [8]. Figure (2) shows the average monthly solar energy on horizontal Surface.

![Figure (2): Average monthly solar energy on horizontal surface](image2)

The following Figure (3) shows the daily solar radiation.

![Figure (3): Daily solar radiation of typical summer day (20/8/2015)](image3)

It's obvious that we have enough potential for solar radiation in the interval period from 10 to 14, it's more than 900 W/m² also we can obtain electric energy in morning and evening period because the solar radiation is more than 130 W/m².

Figure (4) shows the daily curve of the ambient temperature drawn below. It shows that the maximum temperature occurs around noon time (32°C), and the minimum temperature occurs in the early morning (21°C).

![Figure (4): The daily ambient temperature 20-8-2015](image4)
1.1 Hybrid System Components and Control Parameters:
In this study, PV-diesel-battery system is proposed for the site. The solar PV and diesel generator components are integrated together to harness the output power of the system as well as to compensate for the unpredictable variations in the climate. The converter is added to maintain the flow of energy between the AC and DC components, while the battery is employed as a backup in order to ensure uninterrupted power and to maintain the desired power quality at the load point. The use of these two energy sources in parallel with battery storage provides a smooth and uninterrupted output which makes the hybrid system more reliable and efficient.

i) PV/diesel/battery Hybrid System:
The cost of energy (COE) for a hybrid system consisting of 8 kW PV, 5.5 kW diesel generator with 64 batteries is I.D. 500/kWh. The total annual diesel consumption is 1,050L and total net present cost reaches I.D. 86 million. The initial capital cost of a 8 kW PV system is around 60% of the total initial capital cost, whereas it is 4% and 26% for generator and batteries respectively. With regard to annual O&M cost for PV, it is negligible compared with the O&M cost of the diesel

ii) PV/diesel Hybrid System:
The hybrid system consisting of 8 kW PV panel and 5.5 KW diesel generator, the COE from this hybrid system is I.D. 795 kWh$^{-1}$. The total annual diesel consumption is increased to I.D. 136 million. The renewable fraction is 0.19 and the excess electricity is 44% (10,554 kWh).

iii) Diesel/battery Hybrid System:
The COE for a hybrid system consisting of 5.5 kW diesel generator with total number of 32 batteries is I.D. 798/kWh. For this system, the total annual diesel consumption is 5,902L and the total net present cost (NPC) reaches I.D. 136 million.

iv) Traditional Diesel Generator:
The traditional diesel generation system consisting of 5.5 KW diesel generator, the COE is I.D. 874/kWh. The total annual diesel consumption is increased to 7,804L. NPC is increased to I.D. 150 million. The excess electricity is 15.4% (2,441 kWh).

The following figure (5) shows the main components of PV cell and how it works [11].

1.2 Analysis of Electrical Loads in Each Site:
Actually, the electrical load in each of the telecom tower site is mainly concentrated air conditioner system, since the telecom equipment must be under low temperature to protect it from possible damage. Also there is constant load (telecom equipments) works for 24 hours in a day. As a result of my visit to these telecom sites, We noticed that all of sites are similar to each other, the same shelter, have the same design, the same area, and approximately the same loads.

Figure (6) shows the average monthly Energy output from PV system and the monthly saving in Money.
2. DESIGN AND CALCULATIONS:

2.1 The Electrical Loads of Telecom Tower shelter at Algazalia Site:

The electrical loads inside 4m² shelter at this site is shown in table 1. The average Energy consumption per one day is 32.25 KWh/day and the total max demand is 2.288 KW.

Table (1): The electrical load for Algazalia telecom tower site

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Power (W)</th>
<th>Quantity</th>
<th>Time working (h)</th>
<th>Energy consumption (Wh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFL lamp</td>
<td>13W</td>
<td>2</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>Modem</td>
<td>15W</td>
<td>1</td>
<td>24</td>
<td>360</td>
</tr>
<tr>
<td>Fan unit</td>
<td>180W</td>
<td>1</td>
<td>24</td>
<td>4320</td>
</tr>
<tr>
<td>Microwave cell equipment (RBS2206)</td>
<td>230 W</td>
<td>1</td>
<td>24</td>
<td>5520</td>
</tr>
<tr>
<td>Microwave cell equipment (RBS2206)</td>
<td>230 W</td>
<td>1</td>
<td>24</td>
<td>5520</td>
</tr>
<tr>
<td>Microwave cell equipment (RBS2206)</td>
<td>230 W</td>
<td>1</td>
<td>24</td>
<td>5520</td>
</tr>
<tr>
<td>Air conditioner</td>
<td>1690W</td>
<td>1</td>
<td>6.5</td>
<td>10985</td>
</tr>
<tr>
<td>Total</td>
<td>2288 W</td>
<td></td>
<td></td>
<td>32.25 KWh</td>
</tr>
</tbody>
</table>

2.2 Design of PV System for Algazalia Telecom Tower Site:

2.2.1 Selection of PV Generator Sizing:

To determine the PV sizing, we should calculate the necessary output energy from the PV modules, and its can be calculated by using equation (1) [14].

\[
E_{PV \text{ output}} = \frac{E \text{ consumption per day}}{\eta_{\text{ln}} \times \eta_{\text{cont}}} \tag{1}
\]

Where Energy consumption from table (1) equal 32.25 KWh,

\[
\eta_{\text{ln}} = 0.90, \quad \eta_{\text{cont}} = 0.92
\]

\[
E_{PV \text{ output}} = \frac{32.25}{0.9 \times 0.92} = 38.95 \text{ KWh}
\]

The peak power (Wp) of the PV generator can be calculated by using equation (2) [14].

\[
W_{p} = (PV \text{ Energy} / \text{day}) \times \text{Safety factor} / \text{Peak Sun Hours} \tag{2}
\]

PSH (average peak sun hours in Iraq) = 5.4, the safety factor for compensation of resistive and PV-cell temperature losses = 1.15.

The power peak necessary for Algazalia tower.

\[
W_{p} = \frac{38.95 \times 1.15}{5.4} = 8.3 \text{ KW}
\]

To obtain this peak value, we select to install 135W high efficiency multi-crystal photovoltaic modules for example Kyocera-135, Rectangular cells module type 135 W of a 1.002 m² area, rated at 12VDC, and P_{mpp} = 135 W the specific
of this module shown in we selected the module of Kyocera-135W for our analysis, because it has a good performance and suitable for our environmental conditions.

The number of necessary PV modules (No. of PV) can be calculated by using equation (3):

\[
\text{No. of PV modules} = \frac{W_p}{\text{power for one module}} \quad \text{…………..……..(3)}
\]

No. of PV modules = \(8.3 \times 1000/135 = 61.5\) PV modules

and, we take 63 modules for this site, in order to install it in symmetrical-arrays, each array will include 21 modules, also to be sure we will get the needed \(W_p\) value.

We can select the voltage of the DC equal 48 V, so the number of modules in series can be obtained by using equation (3).

We can calculate the number of strings can be also calculated.

We can select No. of arrays to be three arrays with seven strings in each array. We can calculate the total area needed for PV generator at Algazalia site. Total minimum area needed for PV generator = no. of modules x area for one module.

Total minimum area needed to install PV generator = 63x1.002 =63.126 \(m^2\) which is available in this place.

The configuration of distribution PV modules will be shown in Figure (7)

For these arrays, the actual maximum open circuit voltage is:

\[
V_{oc} = 3\times22.1 = 66.3 \text{ VDC}
\]

The actual maximum short circuit current is:

\[
I_{sc} = 21\times8.37 = 175.77 \text{ A}
\]

Accordingly, the maximum power point of this array will be in the IV curve at the coordinates of 53.1 VDC and \(I_{mpp}\) of 160.23 A. The actual maximum power obtained from:

\[
\text{PV} = 53.1\times160.23 = 8.508 \text{ kW}_{p}, \text{ which is enough to supply the tower energy.}
\]

2.3 Selection of Battery Block Sizing for Algazalia tower:

Since the necessary storage capacity for this system is considerably large, so we have to select a special lead-acid battery cell (block type) which are of long life (more than 8 years), high cycling stability (more than 1100 times) and standing very deep discharge [3].

\[
\text{Ampere hour capacity} = 2 \times E_{\text{load}} / \text{DOD} \times \eta_{\text{Battery}} \times \eta_{\text{Inverter}} \quad \text{………..(4)}
\]

Where DOD is the depth of Discharge = 0.75

\[
C_{Ah} = 2 \times 32250 / 0.75 \times 0.85 \times 48 \times 0.9 = 2342 \text{ Ah}
\]

And the Watt hour capacity \((C_{Wh})\) is obtained from equation (5)

\[
C_{Wh} = C_{Ah} \times V_{\text{Battery}} \quad \text{…………………………………………………..(5)}
\]

\[
C_{Wh} = 2342 \times 48 = 112.42 \text{ KWh}
\]

To install this capacity, we need 24 batteries in series, (each battery rated at 2 V / 2500 Ah) as shown in figure (8) to build a battery block of an output rated at 48 V DC /2500 Ah (2V/2500Ah block battery has been selected).
2.4 Selection of Charge Controller Sizing for Algazalia Site

It's a DC/DC converter, used to regulate the output current of PV generator going to the inverter, and to protect the battery block against 61 deep discharge and over charge, the input/output rating of CR are fixed by the output of the PV array and the voltage of batteries (VB) [14]

- The range of the V input equal: $V_{oc}(PV) = (3 \times 12) / (3 \times 22.1) = (36 / 66.3) \text{ VDC}$
- The range of the V output equal: $V_{nom(al)}(PV) = (48 \times 0.875) \text{ W (48x1.2)} = (42 / 57.6) \text{ VDC}$
- $I_{CC} = 8.37 \times 21 \times 1.25 \times 210 \text{ Ampere}$.
- The power of C.C., $P = 48 \times 210 = 10080 \text{ Watt}$, we choose the rated power $=10 \text{ KW}$ It's recommended that the CC should have a maximum power control unit.

We select three (70A / 48V) charge controller for Algazalia site, as shown before

2.5 Selection of Inverter Sizing for Algazalia Site

For the selection of the suitable inverter, we should determine the following data.

- $V_{input}$, has to be matched with battery block voltage, $V_{CC}$ output $= (42 / 57.6) \text{ V DC}$
- $V_{output}$, should fulfill the specification of the Diesel generator of the site specified as: $230V \text{ AC } \pm 5\%$, single phase $50 \text{ Hz}$, (sinusoidal wave voltage) [15].
- Power of inverter:
  - we can calculate $P_{nominal}$ for the inverter $P_{nominal} = P_{max\;load}P_{load} = 2288 \text{ Watt}$ So $P_{nominal} = 3 \text{ KW}$
  - The efficiency must not be less than $90 \%$
  - *(3 KW inverters have been selected for Algazalia site, as shown before).*

2.6 Design of PV System for all Remote telecom tower sites

2.6.1 Selection of PV Generator Sizing for All Sites

Rectangular cells module type 135 W of a 1.002 m$^2$ area, rated at $12\text{ VDC}$, and $P_{mpp} = 135 \text{ W}$, $V_{mpp} = 17.7 \text{ Volt}$, $I_{mpp} = 7.63 \text{ Ampere}$. 

2.6.2 Selection of Battery Block Sizing for All Sites

- Battery system Voltage = $48\text{ V}$
- Efficiency of Battery = $85\%$
- Efficiency of Inverter $=90\%$
- Depth of Discharge $=75 \%$
- Autonomy days $=2$

2.6.3 Selection of Charge Controller Sizing for All Sites

- $80 \text{ A} – 48\text{ V}$ charge controller have been selected.
- $70\text{ A} – 48\text{ V}$ charge controller have been selected.
- $90\text{ A} – 48\text{ V}$ charge controller have been selected.

2.6.4 Selection of Inverter Sizing for All Sites:

3 kW inverter have been selected for all sites [17]

2.7 The Configuration of PV system for All Remote Locations

The configuration of PV system for all locations can be presented below. In each configuration illustrated the connections of all elements with cables and protective devices.

Fig.(9 ) PV system with all components for each site. [18]
3. ECONOMIC ANALYSIS OF USING PV SOLAR SYSTEMS INSTEAD OF DIESEL GENERATORS

In each Telecom tower site of these above four sites which we are studying in our analysis in each location, there are two diesel generators working 24 hours all day throughout the year, each one works for 12 hours a day, so they require very high operating costs, which can be summarized in the following points:

- High maintenance cost
- High diesel consumption
- Prices of oils and filters for the diesel generators
- Cost of transporting diesel to these sites

We noticed that the diesel generators consume high amounts of diesel, despite the load is small compared with fuel consumption, maybe it is because the high capacity of the diesel generator, and the load factor is very small in these generators less than 30%.

The price of the diesel consumption in I.D. for each telecom site is equal the quantity of diesel in litter multiplied by the price of one litter diesel in I.D. as shown below.

Price if the diesel consumption I.D = Quantity of diesel (litter) x price of one litter in I.D.

Note that the average price per one litter of diesel = 2000 I.D.

3.1 Analysis of Unit Energy Cost from Diesel Generators:

The running cost per one KWh for each site can be calculated as the following:
Running cost per KWh= Total running cost/Total annual Energy consumption …. (6)

= 1380 I.D./KWh which is very huge

Fixed cost per KWh = Total investment cost x D.F/Total annual Energy consumption ……… (7)

Where D.F is depreciation factor and its equal = 0.1

Fixed cost per KWh =120 I.D. /KWh [18]

4. CONCLUSIONS

From this research it was shown that it is possible to supply the communication towers in remote areas by using PV systems as a hybrid with existing diesel generators. Furthermore, it was shown that it is possible to design and select the size of PV models which are applicable to supply the tower loads during 24 hours/day.

Upon achieving this, techno-economical analysis for specific locations was performed. The analysis was justified by looking at different measured values over the collection period, such as: variation of solar radiation in Baghdad, variation of electrical loads, and output energy vs. solar radiations. This analysis gave an appropriate justification for the PV sizes as the optimum design for electrification of these towers by using solar energy. In addition to all these, the PV solar hybrid systems like the one analyzed for specific towers and specific locations mentioned in this research, can be used very effectively and efficiently as well during all days in a year, specially in these rural areas, where the connection from the grid is not possible for the next five years, it is show that the installation of these PV systems usually are an economically and cost saving viable idea. Also, it is highly recommended to implement the design suggested in this research in oil companies to achieve these economical and environmental savings mentioned in this research.

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