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Design of A solar power system for an offshore platform

By

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Abstract:

A solar power system is designed for offshore platform in order to supply power to DC load including emergency lighting, VHF radio, remote terminal unit, well head control panel, multiphase flow meter, fire and gas panel, marine lantern, and fog horn system. In this paper, the main objective is to design, analyze and sizing the solar power system for DC loads at offshore platform. This project will be beneficial for oil and gas industries in installing their offshore platform because by using the solar power system, they can actually reduce the cost of the project in terms of supplying the DC power. A study concerning the economics of solar versus generators as a choice of power was conducted. The study considers all costs involved: modules, mounting structure, pumps, miscellaneous components, installation, operation, maintenance, yearly inspection, component replacement and salvage value. The solar power system will be installed at a new minimum facilities wellhead platform situated approximately 150 km southwest of Hazira in the Gulf of Khambat, offshore Gujarat Province, India.

Keywords:

Photovoltaic system, solar array sizing, battery sizing, mono-crystalline silicon, nickel cadmium battery

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1. Introduction:

Solar energy technology potentially suitable for use in offshore ocean environments includes photovoltaic technology. The hot, high humidity, saline environment, in the middle of the sea is just perfect for installation of solar power system. The solar power system will be installed on the offshore platform situated approximately 150 km southwest of Hazira in the Gulf of Khambat, offshore Gujarat Province, India. This platform is a new minimum facilities wellhead platform (named as MTA Platform) located at the Mid Tapti Field Gas reserves. The MTA wellhead platform shall normally be unmanned. The MTA wellhead platform is designed based on minimum facilities concept. The unmanned minimum facilities wellhead platform shall be designed without the need of AC power .The solar panel will supply the DC power to several DC loads. During normal operation, which is unmanned operation, the only permanent power envisioned will be solar cells. During manned operation, the platform power supply shall be provided by Portable Diesel Engine Generator for the normal loads such as AC lighting system, receptacles, helideck lighting and charger for solar battery system. The solar power system shall be designed to meet the load requirements for MTA platform [1].

The research is focused on the solar panels, battery storage system, and power conditioning unit as the main components in solar power system. The designing stage comprises the size and type of solar panel, and battery storage system. In designing and sizing solar power system, steps involved consists of load estimation, battery sizing, solar energy requirement, and number and size of solar panels. The estimation of loads and load profile are important in designing solar power system since the system will be sized to satisfy the demand of the loads at the platform. The system block diagram of solar power system is shown in Figure 1.

Fig (1) System block diagram.

2. Results and Discussion.

A study was conducted to compare the power choices at MTA platform. There were three options that has been considered, which are:

- Option 1: Solar Power as primary source and back up Diesel Engine Generator.
- Option 2: Micro turbine Generator as primary source and back up Diesel Engine Generator.
- Option 3: Gas Engine Generator as primary source and back up Diesel Engine Generator.

In option 1, the solar power will be the permanent power during unmanned operation and diesel engine generator will supply power to AC loads during manned operation. During unmanned operation, only the DC loads will be operating, hence the solar power will supply power to the DC loads.

In option 2, the micro turbine generator will provide permanent source of power to the loads while diesel engine generator will be a standby source. The micro turbine generator will operate as 1x100% scheme and the diesel engine generator also will operate as 1x100% scheme.

In option 3, gas engine generator will provide primary power source to the loads and diesel engine generator will act as standby power source. The gas engine generator will operate as 1x100% scheme and the back up diesel engine generator also will operate as 1x100% scheme.

All three options were analyzed in terms of costs, reliability, availability, environmental impact, safety, operability, maintainability, and noise emission. The comparisons of three options were summarized in Table 1.

Table(1) Comparisons of Three options of Power Choice [1]

Criteria	**Option 1:**	**Option 2:**	**Option 3:**
Reliability	Solar power supply is considered a very	Quite reliable, but not much information is	Very reliable since the gas engine unit is
Availability	High availability as the sun is always	High availability. Fuel gas is always available	High availability. Fuel gas is always
Min. Env. Impact	Zero emission	Low NOx emissions	Low emission engine type can be specified
Safety	Low personnel risk. Very safe	Medium personnel risk due to less frequent	High personnel risk due to frequent visit
Operability	Very easy to operate	Easy to operate	Easy to operate

Operability	Very easy to operate	Easy to operate	Easy to operate
Maintainability	Very low maintenance -Battery replacement every 20 years	Low maintenance. - 7500hrs between service interval - 40000 hours between overhaul The micro turbine is air-cooled, air-lubricated and has only one moving part. There are no fluids (no oil, no coolant) to change	High maintenance. - 100-500 hrs for service interval - 4000 hours for overhaul interval Requires motor oil for lubricant and glycol/water for coolant
Noise	Zero noise emission	70dBa at 10m	Noisy
Total Cost	Medium cost ~USD753.02k	High cost ~USD818.6k	Low cost ~USD717k

Table 1 shows that in terms of cost, Option 3 has the higher cost and may not be considered as a power choice at MTA Platform. For overall criteria, Option 1 which is solar power with diesel engine generator as back up power source has more advantages especially in terms of maintainability, operability, safety, minimum environmental impact, and noise emission. Therefore, Option 1 is being chosen as the power supply at minimum facilities platform, MTA Platform.

3. Solar Power System.

The continuous DC power at the platform will be supplied by solar power obtained from solar panels. Due to large size of the loads, there were 4 separate systems namely:

- System I : Electrical Emergency Lighting system.
- System: IIA Instrumentation and Telecommunication Power system.
- System IIB : Instrumentation and Telecommunication Power system.
- System III : Marine Navaids system.

Each system has their own loads and will use separate solar panels to power them. The loads for System I consists of emergency lighting; System IIA consists of VHF radio, remote terminal unit and microwave radio, wellhead control panel; System IIB consists of multiphase flow meters, fire and gas panel, and System III consists of navaids lanterns, foghorn and fog detector.

In order to size the solar power system which consists of solar panel and battery storage system, the total load required at the platform has to be determined first. The total load requirement is obtained by referring to the single line diagram. The equations used to calculate the total loads required per day are as follows:

$$P_{tot}\,(\text{watt}) = P \times n \times \eta/100 \quad (1)$$

$$P_{tot}\,(\text{watt-hour}) = P_{tot}\,(\text{watt}) \times D \quad (2)$$

$$P_{tot}\,(\text{ampere-hour}) = P_{tot}\,(\text{watt-hour}) \div V_{supply} \quad (3)$$

where;

P_{tot} = total power

P = power of appliance

n = no. of units

η = efficiency (%)

D = daily duty cycle (hours)

V_{supply} = supply voltage

For System I, the total loads are:

Emergency lighting; P=18, n=11, η=90, D=14;

which total up to be, P_{tot} = 220W, 3080Wh, 128.3Ah

For System IIA, the total loads are:

RTU & microwave radio; P=316, n=1, η=100, D=24

Wellhead control panel; P=8, n=1, η=100, D=24

VHF radio; P=140, n=1, η=100, D=0.857

Which total up to be P_{tot} = 464W, 7896Wh, 329Ah

For System IIB, total loads are:

Multiphase flow meters, P=30, n=6, η=100, D=24

Fire and gas panel; P=175, n=1, η=100, D=24

for this system, design margin at 10% is being applied.

which total up to be P_{tot} = 390.5W, 9372Wh, 390.5Ah

For System III, total loads are:

Navaids lantern; P=2.65, n=4, η=100, D=16

Fog horn; P=37.06, n=1, η=100, D=24

Fog detector; P=5.56, n=1, η=100, D=24

which totals up to be P_{tot} = 53.22W, 1192Wh, 49.69Ah

4. Battery Sizing.

The two most common types of rechargeable batteries in use are lead-acid and alkaline such as nickel cadmium. Lead acid batteries have plates made of lead, mixed with other materials, submerged in a sulphuric acid solution while nickel cadmium batteries have plates made of nickel submerged in a solution of potassium hydroxide [3]. There were several types of batteries in the market that can be used in the industry. The major types of batteries available in the market nowadays are vented/flooded Lead Acid, Valve Regulated Lead Acid (VRLA), Vented/Flooded Nickel Cadmium and Semi-Sealed/Low-Maintenance Nickel Cadmium. Each of these types has it own unique advantages and disadvantages when being considered for a particular application. A comparison of the different types batteries was done.

The battery type chosen was the low-maintenance nickel cadmium battery, due to low maintenance cost and it is suitability for extreme temperatures which happen at offshore platform. The battery will be charged from the surplus power available from the solar panel array when the sunlight is available and provide electricity during the nights or for periods with low or no insolation such as cloudy days.

In sizing the batteries, the autonomy times which is the number of full days that a fully charged battery can supply power to the specified load, without any charging by solar modules [4], had to be determined.

The design criteria for the designing the batteries are as follows:

- Battery configuration per system - 1 x 100%
- Nominal voltage - 24 V DC
- Ageing degradation - 10%

There are a design allowances that has to be followed during the battery sizing and in order to choose the best battery that suits the requirements. The design allowances for battery sizing are as follows:

- 10% allowance for battery ageing effects,
- 20% maximum depth of discharge for daily load cycle,

- 80% maximum depth of discharge during autonomy period (full discharge cycle),
- 7% loss allowances for battery recharge, inefficiency and float charge,
- 0.1% loss allowances for battery self-discharge,

The equations used in sizing the battery are as follows:

$$Q_d = Q_{d1} \div \eta_{vr} \quad (4)$$

$$t_n = 24 - t_d \quad (5)$$

$$Q_s = R_b \div 100 \text{ x } Q_d \quad (6)$$

$$Q_{bs}' = Q_s \text{ x } t_s \quad (7)$$

$$Q_{bc} = Q_{bs}' \div (k_{d3} \div 100) \div k_{age} \div k_T \quad (8)$$

$$Q_{dLn} = Q_d \text{ x } t_n \div 24 \quad (9)$$

$$Q_{bLoss} = 7\% \text{ x } Q_{dLn} \quad (10)$$

$$Q_{bdisch} = 0.1\% \ Q_b \quad (11)$$

$$Q_d'' = Q_d + Q_{bLoss} + Q_{bdisch} \quad (12)$$

$$Q_{bLoss}' = 7\% \text{ x } Q_{bs}' \quad (13)$$

$$Q_{chr} = (Q_{bs}' + Q_{bLoss}') \div T_{ch} \quad (14)$$

$$Q_{tot} = Q_{chr} + Q_d'' \quad (15)$$

where;

Q_d = average daily power consumption
Q_{d1} = average daily load = total power (from load list)
η_{vr} = voltage regulator efficiency
t_n = no. of hours which load is supplied by battery
t_d = assumed daylight hours per day
Q_s = daily load demand on battery without solar array
R_b = battery system capacity (% of total system requirement)
Q_{bs}' = total battery load demand over discharge period
t_s = autonomy period
Q_{bc} = battery size for max depth of discharge from 100% charge
k_{d3} = max % discharge allowed (max depth of discharge)
k_{age} = ageing factor for battery capacity
k_T = temperature correction factor for battery performance
Q_{dLn} = distribution load per night cycle
Q_{bLoss} = battery recharge inefficiency loss (from daily load cycle)

Q_{bdisch} = daily battery self-discharge loss
Q_d" = daily system energy requirements
Q_{bLoss}' = battery recharge inefficiency loss (from full discharge cycle)
Q_{chr} = daily recharge load from full discharge
Q_{tot} = total average solar energy requirements per 24 hour

By using equations above and the design criteria decided, the results for battery sizing are as follows:

- Design Load:
  System I = 128.3Ah
  System IIA = 329Ah
  System IIB = 390.5Ah
  System III = 49.69Ah
- Battery size:
  System I = 213Ah
  System IIA = 4400Ah
  System IIB = 4400Ah
  System III = 645Ah
- Solar energy requirement:
  System I = 21.34Ah/day
  System IIA = 474.4Ah/day
  System IIB = 562.2Ah/day
  System III = 86.25Ah/day

5. Solar Panel Sizing.

The main component of solar power system is the solar panel itself. There are different types of solar panels made using different technologies. Basically, the solar electric panels are made from silicon and are divided into three main category based on how they are manufactured. The technologies used to manufacture mono-crystalline, poly-crystalline and amorphous silicon is differs from each other. The comparison of three types of solar panel is being summarized in table 2.

Table(2) Comparison of three types of solar panels

Type	Mono-crystalline Silicon	Poly-crystalline Silicon	Amorphous Silicon
Efficiency	15 - 18 %	13 – 15 %	5 - 8 %
Performance	Remains fairly constant during the first few months	Remains fairly constant during the first few months	Lose about 25% of their output during the first few months of use
Prices	Higher	Higher	Lower

Based on comparisons of three types of solar panels, it is clear that mono-crystalline silicon is the best choice in designing solar power system that will last for 20 years. Even though the price is higher compared to others, it will give better performance as it has the highest efficiency among others.

The solar panel array is designed based on insolation data at specific location. Hence, the solar radiation data (insolation data) has to be observed first. For this project, the sizing of solar panel is based on the worst insolation data at Mumbai High, which occur on August with value of 3.86 kWh/m²/day.

In the calculations of the solar array, the following design criteria will be applied:

- Solar array per system - 1 x 100%
- Nominal voltage - 12 V
- Worst case insolation - 3.86 kWh/m²/day

The following design allowances will be applied in sizing the solar panel:

- Degradation over life span - 15%
- Alignment/Tilt errors - 2%
- Fouling - 1%
- Cell mismatch - 2%
- Losses (solar controller/cables) - 3%

This design allowance will be used in calculating the size of array. The equations used in sizing the solar panel are:

$$Q_a = (k_T \div 100) \times (T_a - 25) \quad (16)$$
$$N_s = V_r \div V_n \quad (17)$$
$$I_{mod} = [(I_{mpp} \times k_R) + Q_a] \times ESH \quad (18)$$
$$N_{min} = Q_{tot} \div I_{mod} \times N_s \quad (19)$$
$$Q_{A1} = N_{act} \div N_s \times I_{mod} \quad (20)$$

where;
Q_a = additional output due to temperature correction
k_T = temperature performance factor of efficiency
T_a = cell temperature
N_s = no of series module connection per array
V_r = nominal system voltage
V_n = selected module nominal voltage
I_{mod} = single module capability
I_{mpp} = selected module peak power current
k_R = design allowances factor
ESH = equivalent sun hour (insolation/solar radiation data)
N_{min} = min no of modules per array
Q_{tot} = total average solar energy requirements per 24 hour
Q_{A1} = capability of array
N_{act} = selected no of modules per array

The solar array sizing was done based on Shell Powermax^{TM} Ultra SQ85-P solar modules which its rated power is 85 watt. By using equations above and the value of selected solar panel module, the results of solar panel sizing are as follows:

- No of solar panels:
  System I = 4
  System IIA = 62
  System IIB = 74
  System III = 12
- Array capability:
  System I = 30.59 Ah/day
  System IIA = 474.09 Ah/day
  System IIB = 565.85 Ah/day
  System III = 91.76 Ah/day

From the array capability results, it shows that the selected battery and solar panels size is capable of supplying the load demands for this offshore platform.

6. Conclusions.

The solar power system designed is reliable and practical as it is designed with real loads used in offshore platform. The hybrid solar power system is identified to be the most suitable type of solar power system to be installed at offshore platform, specifically MTA Platform. The hybrid solar power system consists of solar panel as a photovoltaic generator, battery as storage system, charge regulator as power conditioning unit and portable diesel generator as back-up power supply. The permanent power during normal operations will be solar panels to supply power to DC loads while during manned operation portable diesel generator will supply power to the AC loads. The solar power system designed meets the DC load requirements at the MTA Platform as the design is based on the real situation of the platform using the real data. The solar panel used in this solar power system is from mono-crystalline type which is higher in efficiency compared to other types of solar panels such as poly-crystalline or amorphous thin film. The storage system for this solar power system use battery from nickel cadmium type. The selected battery capacity is able to provide power to the loads during low insolation for the specified autonomy period.

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