Energy management of a SPV System for ICT Application – A Case Study

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Abstract—Information and Communication Technology (ICT) operations needs uninterrupted power supply due to over dependency on ICT. Due to large gap between energy demand and supply, load shedding is very common phenomenon in northern grid. This uncertainty in power availability forces telecom company to depend on non-renewable fuels for continuous supply. Non renewable fuels increasing cost and emission of green house gases has severe issues with its use. Environment ministry encouraging to curb carbon emissions and rising fuel cost reducing the operating margin. Several alternate energy sources like solar photo voltaic (SPV) provide best solution where wind velocity is not sufficient to run wind turbines. The paper presents the detailed design of SPV system for a grid connected communication tower. For this, a case study of the grid connected site is carried out at Masoodabad site in Aligarh, India and comparative study of diesel and SPV system is achieved. The payback period is also calculated for the same site. From the design calculation it is found that solar SPV system is more economical and pollution free. SPV system curb approximately 70-80% of the fuel cost, in addition to this it also reduces carbon dioxide and other harmful gases emissions.

Keywords— *Case study; Information and Communication Technology (ICT); Solar photo voltaic (SPV).*

I. INTRODUCTION

Around the world about 600 TWh energy is being supplied to the nformation communication technology. This shares around 3% of the total energy produced. Therefore it is need of the hour to find some solution to curb the energy consumption. Also it is desirable to introduce some greener energy alternative during load shedding period that lead to reduction in use of nonrenewable resources and curve the pollution [1].

The main energy consumer in the cellular network is the base station which consume more than 50% of the total energy consumed by the network [2]. To curve the energy consumption by the base station it is necessary to have precise knowledge of the base station. There is little difference in the power consumption during the peak load and the lean load period. During load shedding period it is necessary to use clean fuel. Out of 4.4 lacs telecom towers in India less than 1% towers is powered by clean fuel [3]. The policy set by government needs telecom operators to migrate 20 % of all mobile towers in urban areas and 50% in rural areas to run on hybrid power by 2015. In India tower network consume 11 billion KWh energy annually. According to survey by economic times around 10,000 cr rupees were spent on diesel in 2013 and uses 2 billion liters of diesel in the same year that leads to CO2 emission of 11 million ton. 33% of total energy consumed were supplied by grid and remaining by liquid fuel. There is huge difference in cost per unit in operation by diesel and grid supply. Grid power supply cost telecom operators at a rate of Rs 6-8 per unit, where diesel cost Rs 15-16 per unit. Considering all these facts it is essential to install renewable energy sources to curb the pollution and reduce operating cost. Although capital investment in installing such system cost more. Sometimes it is advantageous to use hybridsystem to supply energy to BTS to provide uninterruptible supply [4]. For regions like north India where solar insolation is not sufficient during winter season it is necessary to use battery backup during that period. If I consider autonomy period for the region more than three days in that case it is advantageous to supply power during that period by diesel generator to reduce capital investment and payback period will also reduces [5].

Several other techniques to reduce power consumption is dynamic management of network resources, energy efficiency evaluation framework (E3F), and dimming cellular networks. Furthermore some initiatives are based on the mutual sharing between competing operators who provides service in the same locality.

II. SPV SYSTEM FOR ICT

A. SPV Application in ICT

Enabling ICT with distributed generations (DGs) and pollution free indicates SPV technology best available alternative for backup power. However, the SPV system suffers with the constraint of sunshine and space requirement of approx. 10 square meters for a 1KWp panel. Recently two types of systems being used at telecom tower sites are namely stand-alone SPV technology and hybrid SPV technology. The choice between these two is made as per the load profile, unavailability of grid, space availability at the site and other configuration aspects including average peak sunshine available throughout the trial and the energy storage system for non-sunshine hours. The illustration in Fig. 1 describes the stand-alone system and Fig. 2 details the hybrid application using SPV technology. Hybrid applications can be designed by combining solar photovoltaic technology with various other energy sources such as wind turbines, biomass gasifiers, fuel cells and diesel generators. Using an augmented battery bank is not considered to be a hybrid solution; instead it is a part of the SPV solution.

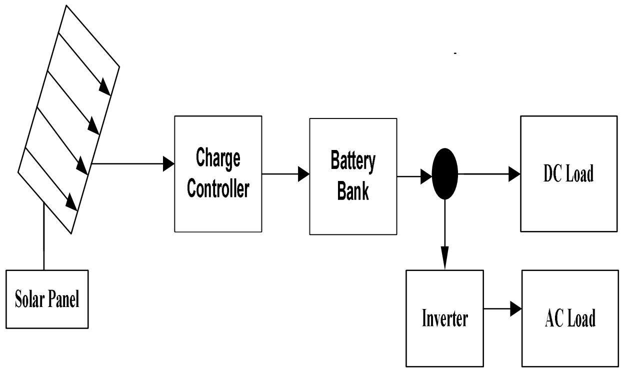

Fig. 1 Stand-alone SPV application.

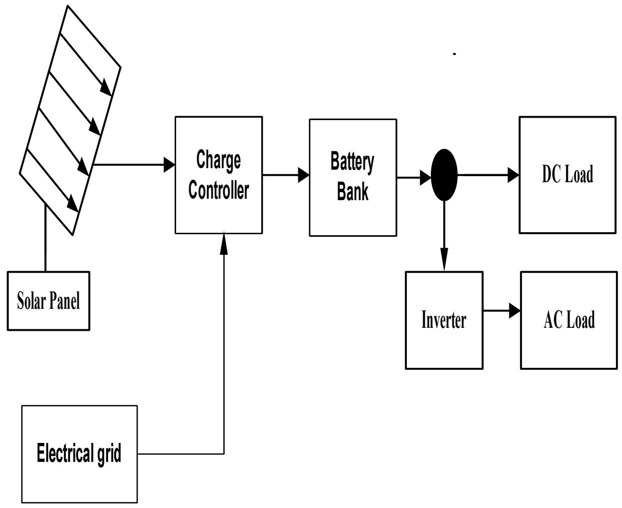

Fig. 2 Hybrid SPV application.

B. SPV Design Consideration for ICT

Four major issues are considered while designing a grid connected SPV system for ICT:

1. The load profile is quite variable in nature in a period of one day.
2. The per day energy consumption is varies over the year.
3. The energy generation from SPV system is variable in nature from time to time according to climatic condition.
4. The energy generated from the SPV array will vary from day to day during the year.

Since the load is being met by the SPV modules, then a comparative study should be done between the available energy from the SPV and actual load profile. The worst situation is that when the ratio between the generation and demand is smallest.

III. Case Study

The case study below provides an overview about the usage and economics of a SPV technology implementation by considering actual data at the Aligarh site. The study includes details of the solution parameter and economic comparison between before and after installation of SPV system at the site [6].

A. Abbreviations and Acronyms *Site location*

The site location is given in Table I.

TABLE I. SITE LOCATION

Site name	Masoodabad
Geographic location	District : Aligarh Latitude 27.880N,longitude 78.0800E
Distance from Delhi	100 km
Temperature	25°C

B. Site description

The description of site is given in Table II.

TABLE II. SITE DESCRIPTION

Site description	Units	Values
Type	-	Outdoor
Base transceiver station(BTS)	-	Outdoor
No. of BTS	-	1
BTS load	kW	5
Grid connection	KVA	16
Grid power available	hrs/day	16
Battery storage	Ah	400
DG set	KVA	15

C. Energy management before SPV hybrid installation

Since the grid supply is available only for 16 hours so before the installation of SPV system 8 hours of mismatch was backed by running 15 KVA DG set and rest 3 hour by a 600 Ah battery. Fig. 3 explains the power supply schematics at the site.

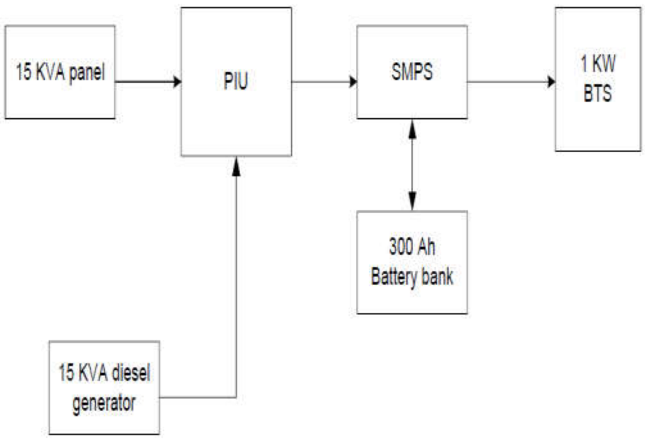

Fig. 3 Power supply schematic of backup power with DGs prior to the SPV hybrid installation.

D. Energy management after SPV hybrid installation

The CCU (central controlling unit controls and observe solar power consumption, grid power consumption and battery usage as well as charging and discharging of the battery. The CCU is programmed to give priority to the solar photovoltaic technology as a primary power source over all the other available energy sources [7]. Thus , solar energy is used when sunshine is available even though the grid power is available. The schematic has an inbuilt data transfer unit (DTU) to store and send data for remote monitoring. It does so by sending SMS alerts through GPRS when service is required. Since at this installation DGs set has not been utilized. Fig. 4 explains the power supply system at the site.

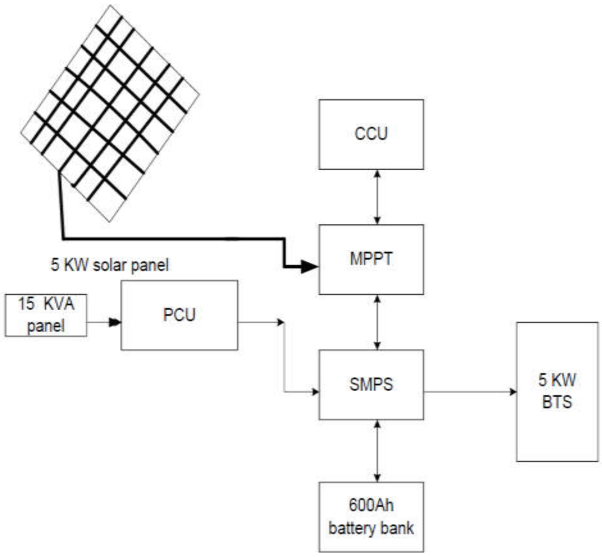

Fig. 4 Power supply schematic diagram with SPV installation.

TABLE III. SOLUTION CONFIGURATION

Components	**Units**	**Values**
Solar panel capacity	kWp	5
MPPT	kW	5
PCU	KVA	15
SMPS	kW	10
Battery capacity	Ah	600

Table III shows the solution configuration of the site.

E. Cost Calculation without SPV

Grid supply to the system = 3-phase, 440 V, 50 Hz.

Per day consumption by BTS= 50 unit for 16 hours of operation from grid.

Cost of Grid connected electricity at rate of INR 5 = 50 × 5 = INR 250.

1) Cost of diesel

Generator rating = 15 KVA

Fuel consumption = 2 litre/hour

For 5 hour generator operation per day fuel consumed = 2 × 5 = 10 litre.

Cost of diesel per day at the rate of INR 60/liter = 60 × 10 = INR 600.

Total running cost of one day operation = Grid supply cost + Fuel cost = 250 + 600 = INR 850.

For one month operation running expenses of the system = 30 × 850 = INR 25,500.

Operator salary = INR 5,000 /month

Maintenance cost = INR 1,000 /month

Total expenditure excluding capital investment of generator/month = INR 25,500 + INR 5,000 + INR 1,000 = INR 31500 /month.

2) Capital investment

15 KVA Diesel Generator cost = INR 3,00,000

Battery cost of 48 V, 400Ah (VRLA type) Koyosonic Electronics = INR 86,400.

Total capital investment = INR 3,00,000 + INR 8,6400 = INR 3,86,400.

F. Design of SPV system

Electrical power is supplied to the base transceiver from the batteries or via an converter. We generally use 48 volt system. Generally electricity consumption is expressed in watt hours Whs or kWhs. To calculate the daily energy usage. We need to calculate the electrical energy usage by the telecom tower. From the observation it is found that average load is around 70 Amp, so power supplied by 48 volt battery is 70 × 48 = 3360 Watts.

For supplying power for 5 hours = 3360 × 5 = 16.8 kWh.

Let the converter efficiency is 93%, then energy supplied by the battery is = 16.8 /0.93 = 18.06 kWh.

1) Battery selection

a) Determination of System Voltage

For BTS system voltages is generally considered to be 12, 24 or 48 volts. The actual voltage to be considered is determined by the requirements of the system. For example, if the energy storage and the converter are a long way from the energy source then a higher voltage may be required to minimize losses in the cables. For large systems 120V or 240V DC is considered, but these are not typical household systems. As a general rule, the recommended system voltage increases as the total load increases. For small loads, a 12V system voltage can be used. For intermediate loads, 24V is sufficient and for larger loads 48V system is employed as shown in Fig. 5.

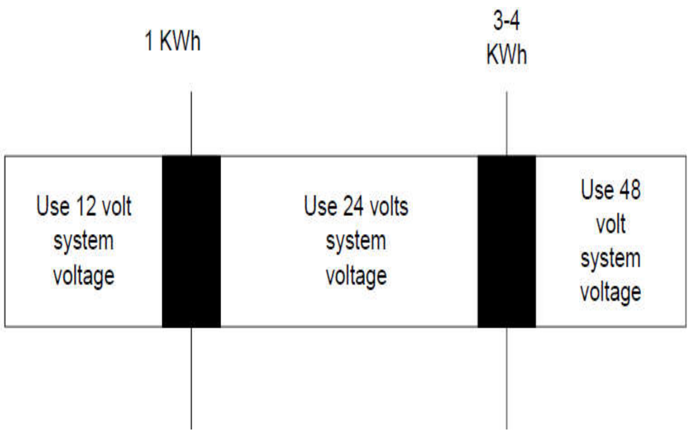

Fig. 5 Battery selection according to energy requirement.

The change over in voltage level roughly depends at loads of 1 KWh and 3-4 KWh but this will be dependent on the actual load profile of the site. One very important constraint is that the maximum continuous current being drawn from the battery storage should not exceeds 150A. Thus, system voltage is of 48 Volt.

b) **Battery Sizing**

In SPV system capacity of the battery is determined by whichever is the greater of the following two requirements[2]:

1) The ability of the energy storage system to meet the energy demand of the system during the autonomy period which is often for few days during the rainy season; or
2) The ability of the energy storage system during peak load..

The critical design parameters include:

1) Parameters relating to the energy requirements of the battery:

a) Daily energy consumption
b) Maximum depth of discharge
c) Autonomy days

2) Parameters relating to current of the battery:

a) Maximum power consumption
b) Surge demand

3) Parameters relating to the charging of energy storage system.

On the basis of above parameter several factors that will increase the capacity of the energy storage to improve the performance. Correction factor must be included to improve the performance.

Days of Autonomy

More batteries would be require if we have to design the PV system for some autonomy during completely cloudy condition. Here our system is connected to the grid so we will not design the system for autonomy period. The autonomy is defined as the number of days the battery should be able to supply the energy to load even for those days there is no sun shine.

Battery Capacity (adjusted) = X + nX

Maximum Depth of Discharge

Often energy storage manufacturers recommend a maximum depth of discharge (DOD). During the operation if the DOD exceeds the prescribed value the battery life is severely effected. The energy that needs to be supplied by the battery is 18.06 KWh and our system voltage is 48Volt. Dividing the energy to be supplied by the system voltage would give us the required charge capacity (Ah) of the battery.

Required charge capacity = 18.06 × 103 /48= 376.25 Ah

Take DOD of 70% = 376.25 /0.7 = 537.5 Ah

Battery Discharge Rate

The discharge rate selected depends on the usage power rates of concerned loads. Several appliances operate only for short duration, drawing power only for short intervals. This practice badly affects the life of the battery selected, as battery capacity varies with the rate of current drawn by the system information such as a power usage profile over the period of an average day is required for calculation of the appropriate discharge rate.

For small systems this is often impractical.

Where the average rates of power usage are low, the battery capacity for 5 days autonomy is often selected at the 100hr rate of discharge for the battery.

For the worked example

Battery Capacity (adjusted) = 529 Ah (@ C100)

Where the average power usage rates are high, generally 5 dys autonomy period is chosen for the calculation of battery capacity at a higher discharge rate. eg. the 10 (C10) or 20hr (C20) rate.

Battery Temperature derating

The capacity of the battery is badly affected by the temperature as depicted in Fig. 6. As the battery temperature goes down, the capacity of the battery reduces. The graph below gives a battery correction factor for low temperature operation of the battery. It is noted that the temperature correction factor is 1 at 25°C since this is the Temperature at which the capacity of the battery is specified In the tropics it is often still 20°C in the evening so unless the system is situated in the hilly region that does get cold then ignore the temperature derating. If you want to be conservative add 5% to the capacity to allow for this factor.

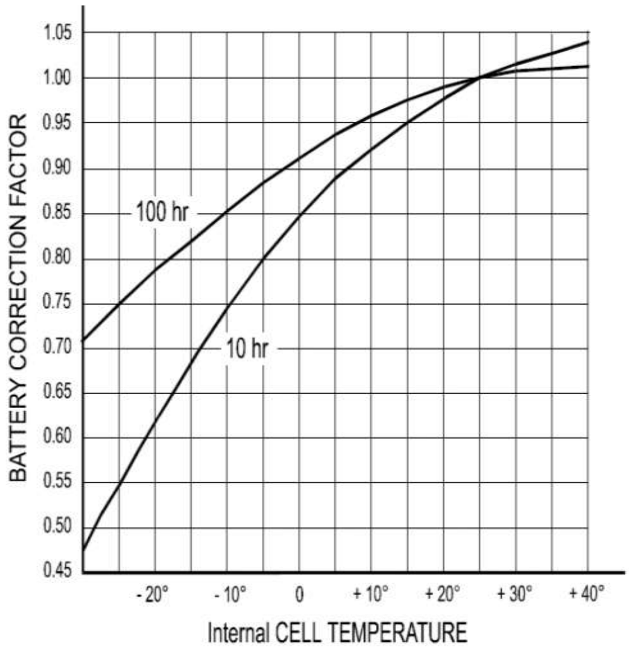

Fig. 6 Battery correction factor with cell temperature.

In case of deep discharge type batteries per cells should be selected for the required system voltage and capacity in a single series string of battery cells. Where parallel strings of batteries are not recommended. Where this is necessary that each string must be separately fused. For example a battery of at least 529 Ah (@C100) is recommended.

Considering all the above factors we will design for 600 Ah.

In order to achieve target voltage of 48 volt, 24 number of 2 volt batteries will be connected in series.

2) Sizing of SPV array - Standard switched controllers

The size of the array depends upon the controller used in the system. Generally standard switched controllers were the most commonly used controllers. Now a days a number of maximum power point trackers (MPPT) have become available for this purpose. This section determines how to size the PV array based on switched controllers based on the PV array that can meet the daily load requirements throughout the year. The size of the PV array should be selected considering following points:

- Variation in solar irradiance with different climatic condition
- Variation in the daily energy usage
- Efficiency of the battery
- Tolerance provided by the manufacturer
- Dirt on the array
- Temperature of array (the effective cell temperature)

Solar insolation data is available from various sources[8]. Some countries have data available from their respective meteorological department. Most important source for solar insolation data is the RETSCREEN, NASA website: http:/eosweb.larc.nasa.gov/sse/ a program available from Canada, incorporates the NASA data and it is simple to take data. Please note that the NASA data has, in some instances, had higher insolation values than that recorded by ground collection data in some location. But if there is no other data available it is data that can be used. Solar insolation is typically given by kWh/m^2 however it can be stated as peak Sun Hours (PSH). This is the equivalent number of hours of solar insolation of 1kW/ m^2 .The variation in both the solar insolation and the load energy requirement should be estimated. If there is no change in daily load profile of the various times in the year then the system should be designed on the basis of the month with the lowest insolation that is peak sun hours (PSH) for lowest insolation month.

a) **Daily Energy Requirement From The Array**

In order to achieve the y required energy from the PV array, it is essential to increase the energy from the energy storage device to account for battery efficiency. The average columbic efficiency (in terms of Ah) of a new lithium ion battery is 85% (variations in battery voltage are not considered). For the explained example the daily energy requirement expressed in Ah from the battery is 74 Ah.

Allowing for the battery efficiency, the solar array then needs to produce 18.06 /0.85 = 21.24 kWh.

The energy to the input terminals of the battery bank is supplied through controller electronic charge controller and MPPT.

b) Consideration of controller efficiency

The efficiency of the controller circuitry is generally high. Let us consider the controller efficiency to be about 90%. The energy should be supplied by the PV panels at the input of the controller circuit is 21.24 /0.90 = 23.6 kWh.

Thus about 23.6 kWh energy should be generated by SPV panel every day.

c) Solar radiation capacity and number of panels

In order to charge batteries the PV panel need to supply the energy to the battery bank at 48 volt. Therefore total Ah generated by the PV panel should be 23.6 /48 = 491.66 Ah.

d) Derating Module Performance

The rating of the PV array is derated due to following factors:

1) Tolerance limit provided by the manufacturer: Many manufacturers rate their modules ± a percentage (e.g. ±3%) or wattage (e.g. ±2W). it is required that every module is tested and its actual rating is known then the modules will be derated by the manufacturer’s tolerance.
2) Dust: as time passes the dirt or salt (if located near the coast) can accumulate up on the array and reduce the output of the module. The output of the module should therefore be derated to reflect this soiling. The actual rating will be very much depends on the site but this can vary from 0.9 to 1 (i.e. up to 10% decrease due to dirt).
3) Temperature: output power of the Module’s decreases with temperature above 25°C and increases with temperatures below 25°C. The average cell temperature re will be higher than the ambient temperature because of the glass envelop on the front of the module and the fact that the module absorbs some heat from the sun. The output power of the module must be based on the resultant temperature of the cell. This is determined by the following formula:

Tcell-eff = Ta day + 25°C
Where,
Tcell-eff = the average daily effective cell temperature in degrees Celsius (°C)
Ta day = the daytime average ambient temperature for the month that the sizing is being considered.
Since the modules are used for battery charging, the current at 14 Volts (a good battery charging voltage) at the effective cell temperature should be used for calculation purpose. If standard values are unavailable to determine the current at effective cell temperature then use the Normal Operating Cell temperature (NOCT) provided by the manufacturer is considered.
Therefore the derated module output current is calculated as follows:
The Current of the module at 14V and effective cell temperature (or NOCT current) derating due to manufacturers tolerance derating due to dirt.
$I_{(NOCT)} \times f_{man} \times f_{dirt}$
If a module has a 3% (0.03) manufacturer's tolerance, then the module current is derated by multiplying by 0.97 (1-0.03).
If a module has a 5% (0.05) loss due to dirt then the module current is derated by multiplying by 0.95 (1-0.05).
Let us consider that the location where PV system need to be installed have 6 hours equivalent peak sun shine hours.
Now by dividing the Ah capacity that is required to produce by SPV is 491.66Ah /6 hour = 81.94 A.
Now it is time to decide the peak power capacity of PV module, for this purpose PV module of various power capacities can be used. Let us consider module has a peak rating of 240 W_P
The manufacturer's data sheet will provide us the current and voltage of the module at maximum power point is provided in Table. IV.

TABLE IV. 240W MODULE DATA (EMMVEE CRYSTAL ESC240 P60SGAW50WB4)

Rated Power	240 W
NOCT	47 ± 2 °C
Power Tolerance	± 3 %
Maximum Power Voltage V_{pm}	30.08 V
Maximum Power Current, I_{pm}	7.98 A
Open Circuit Voltage, V_{oc}	37.20 V
Short Circuit Current, I_{sc}	8.40 A
Permissible system voltage	1000 VDC
Maximum reverse current	12.5 A

Here power = 240 W_p
V_{pm}= 30.08V
I_{pm}= 7.98 A
We need to estimate how many module will be required to produce 81.94 A.
Since one module can provide us 7.98 A of current, so to get 81.94 A we need 81.94 /7.98 = 10.26 Modules ~ 11 Modules.
These 11 PV modules should be connected in parallel.

e) Number Of Module Required In Array

We need to put two modules in series to get voltage higher than 48 V required for charge the batteries.
Thus we require 11× 2 = 22 Module each of 240 Wp.
Each row containing two such module in series and there would be 11 rows in parallel.

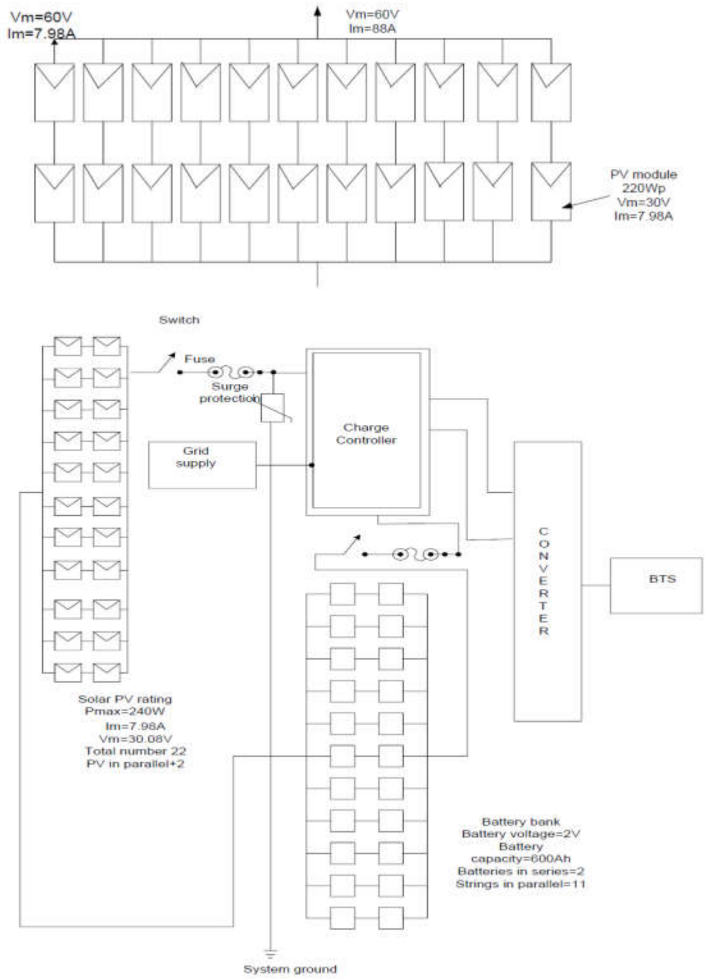

Fig. 7 Design of SPV Module.

G. Cost Calculation with SPV

Grid supply to the system = 3 phase, 440 V, 50 Hz.

Per day consumption by BTS = 40 unit for 12 hours of operation from grid.

Cost of grid connected electricity at rate of INR 5 = 40 × 5 = INR 200.

Monthly expenditure 200 × 30 = INR 6,000.

Maintenance cost for one month = INR 1,000.

Total monthly expenditure = INR 6,000 + INR 1,000 = INR 7,000.

1) SPV Installation Cost

Solar panel capacity = 5 kWp.

Cost of 240 W module = INR 12,000.

Cost of panel consisting of 24 module = 24 × 12,000 = INR 2,88,000 ≡ INR 3,00,000.

Cost of battery i.e. 2V, VRLA battery TAICO make cost = INR 4,500.

For 24 batteries bank = 4500 × 24 = INR 1,08,000 ≡ INR 1,20,000.

Total cost = INR 3,00,000 + INR 1,20,000 = INR 4,20,000.

Cost of solar charge controller for 3 sets =

Cost of MPPT 2 sets =

Total cost of solar PV installation = INR 13,00,000.

H. Site Economics

1) Operating expenditure (OPEX) comparison

Table V shows the monthly savings over the traditional diesel solution for backup power for the telecom tower after the solar photovoltaic solution was installed. Evaluated in the comparison are cost of the grid, cost of fuel for the diesel generator and operation and maintenance of the hybrid.

TABLE V. OPEX COMPARISON TABLE FOR THE SITE

Components	**Units**	**Before solar hybrid**	**After solar hybrid**
Rate of grid consumption	INR/day	250	200
Cost of Diesel	INR/day	600	0
Maintenance cost	INR/day	200	35
Total OPEX	INR/day	1,050	235
Per unit OPEX	INR/kwh	44	10

Saving per KWh is calculated to = INR 44 – INR 10 = INR 34.

2) Simple Payback Period Calculations

Simple payback period = Initial investment cost ÷ Cost of energy saving

The solution costs = INR 13,00,000.

Cost of energy saving /day = INR 1,050 – INR 235 = INR 815 /day.

Annual saving = 815 × 30 × 12 = INR 2,93,400.

Payback period = 13,00,000 ÷ 2,93,400 = 4.43 years.

If the cost of diesel is = INR 65 /litre.

Then cost of diesel = 65 × 2 × 5 = INR 650 /day.

Total expenditure = INR 250 + INR 650 + INR 200 = INR 1,100.

Cost of energy saving = 1100 – 235 = INR 865 /day.

Annual saving = 865 × 30 × 12 = INR 3,11,400.

Simple payback period = 13,00,000 / 3,11,400 = 4.17 years.

Similarly if the cost of diesel is = INR 70 /liter.

Then payback period is 3.94 years ~ 4 years.

3) Payback Period Analysis

The graph summarizes the time frame of the realized return on investment for the installation of SPV solution in comparison with the yearly expenditure for the non-renewable solution. Considering the plausible price points of diesel at INR 52.25 per litre28, INR 60 per liter and INR 70 per litre, the respective calculated payback periods, including capital expenditure investment. The calculation explains that, at INR 52.25 per litre of diesel, the return on investment on SPV can be realized after approximately two and half years of deployment. When the price is at INR 60 or 70 per litre for the fuel, the return on investment of solar photovoltaic technology will be much earlier, and will be approximately 4 years. In this case, for every INR 10 increase in diesel price the time frame of the return on investment for the SPV solution is reduced by approximately half year. The savings resulting from the deployment of the solar photovoltaic system will result in an increase in free cash flow of INR 4,81,737 on an annual basis. In other words, the investment in the system will yield an INR of 33% which is significantly higher than cost of capital (14%) and implies viability of the solution. Site has not received any capital subsidies for SPV systems and hence such subsidies have not been used in the calculation.

IV. CONCLUSION

The paper discussed a case study for a grid connected BTS communication tower along with power management strategy and economical solution for Masoodabad site at Aligarh location in India. The performance of the power system comprising of solar photovoltaic array, battery bank and 16 hours of grid supply considering different representative days of season of a climatic cycle has been presented. From the design analysis presented in the paper, it is found that 24 hour supply with diesel generator and grid available for 16 hours is not economical. Thus a 22 photovoltaic module in two rows and two in series and 11 rows in parallel each of 240 Wp along with 22 batteries connected in series each of 2 V and 600 Ah, grid can meet the power requirement of a 5 kWp BTS station for 24 hours in all days of climatic seasons. It reduced approximately seventy to eighty percent of fuel cost over conventional diesel generator and also reduced the emission of carbon dioxide and other harmful gases in environments. Further, the payback period is around 4 years and for every INR 10 increase in diesel price the payback period for the solar photovoltaic solution is reduced by approximately 6 months.

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