Economic Viability Improvement of Solar Powered Indian Rural Banks through DC Grids

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Abstract — Power shortages result in power outages for period of 8 to 10 Hrs. a day in rural areas due to significant gap between electricity demand and supply. Rural banking is one of the sectors severely affected by power. Majority of population in emerging markets like India live in rural areas. Therefore, reliability and operational efficiency of rural banking is of utmost importance to include rural population into national mainstream. To overcome the problem, solar hybrid power system with battery backup is gaining popularity. However, expensive components like solar array, battery in the system hindering its wide adaptation.

In this paper, efficient DC electrical distribution is proposed to reduce the sizes of expensive solar and battery components. Economic analysis is performed for a typical core banking rural bank. It is shown that by adopting DC grid, Rs. 1.22 lakh can be saved per rural bank. The saving will be Rs. 1.83 billion, if DC grid is implemented across all the 15,000 branches of rural banks.

Keywords: distributed generation, DC grid, renewable energy, hybrid power system, power autonomy and energy efficiency

I. INTRODUCTION

In recent years, India’s electrical energy consumption has been increasing due to population growth, economic development and rural electrification. According to McKinsey report [1], at average GDP growth of 8%, India’s demand for power is likely to touch 335 GW by 2017 from present 140 GW. Power shortage results in power outage for period of 8 to 10 Hrs. a day in rural areas due to load shedding by the distribution companies. Rural banking usually operates from 9 AM to 5 PM and is one of the sectors severely affected due to power crisis. Majority of population in emerging markets like India live in rural areas. Therefore reliability and operational efficiency of rural banking is of utmost importance for including rural population into national mainstream. The erratic power supply interrupts the banking operations and corrupts data storage. In total, there are more than 15,000 branches of rural banks at the end of March 2010 [2]. As a policy decision [3] it has decided by “Working group on technology up-gradation of rural regional banks” to move towards core banking for all banks irrespective of their operational size.

The concept of distributed generation or power backups offers an attractive solution to overcome chronic power outages. Distributed power systems (DPS) are more efficient due to lower transmission losses as they are installed near consumer sites. Most popular DPS are inverters with storage system i.e., battery bank or diesel generator (DG) sets. Diesel generator sets are not economically viable and require regular maintenance. The poor quality of power from DG set necessitates the use of online UPS. Each rural branch uses two 3 KVA inverter/ UPS to meet power outages. In recent times, there is a general trend for green DPS based on renewable energy sources [4]. Among renewable energy sources, solar photovoltaic generators (PV) are very popular in India due to abundant irradiation (on an average 300 sunny days in a year) [5], low maintenance and ease of scalability and decreasing prices for PV components in recent years.

Standalone PV system with power backup is considered for off-grid applications. However, if utility grid is available, PV hybrid power system (i.e., PV tied to utility grid) is preferred over standalone PV system because of lower system cost and higher availability of power. Traditionally, most of the loads are AC driven and hence AC grid is preferred in power distribution. With the technological advancements in the last decade, more & more non-sinusoidal or DC loads like computers, printers, LED lighting are being used. In conventional PV hybrid power system, DC power generated by PV system is fed to AC grid by grid fed inverter and is again converted back to DC inside majority of appliances. This results in double conversion of power, because of losses at each stage. In addition to losses, the reliability of inverter coupled PV hybrid system depends heavily on the reliability of PV inverters [6]. The solar electricity generation and its storage in battery-bank are completely processed as DC and also nowadays most of the end utilization is also in DC. Therefore, distribution of electricity through DC grid will result in increase in overall energy efficiency [7]. Further benefits such as economic savings and improvement in system reliability will be realized due to elimination of PV inverters.

PV hybrid power system is integrated with storage system (i.e., battery bank) to take care of unpredictable AC grid and also fluctuation & variation in solar energy. 48 V battery bank is more efficient in terms of cell equalization, safer (Safety Extra-Low Voltage ‘SELV’ for human body is 60V DC) and widely used voltage level in backup systems, traditionally since early telecommunication age. Therefore, 48 V DC is recommended for distribution systems in rural...
banks. In the present case study, rural banking segment with core banking operation i.e. network based operation has been undertaken. The typical load of a rural bank with core banking is given in Table-1.

<table>
<thead>
<tr>
<th>Type of load</th>
<th>Power, W</th>
<th>Quantity</th>
<th>Total power, W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computers</td>
<td>200</td>
<td>3</td>
<td>600</td>
</tr>
<tr>
<td>Printers</td>
<td>150</td>
<td>2</td>
<td>300</td>
</tr>
<tr>
<td>Ceiling fans</td>
<td>80</td>
<td>2</td>
<td>160</td>
</tr>
<tr>
<td>LED lamps</td>
<td>10</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>Server</td>
<td>500</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>Scanner</td>
<td>100</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td><strong>Total power</strong></td>
<td></td>
<td></td>
<td><strong>1700</strong></td>
</tr>
</tbody>
</table>

Table-1. Typical load of a rural bank branch

The system operation of various distribution systems are explained in Section II. Section III gives the design of system components. The economic analysis and comparison is done in Section IV. Finally conclusions are given in Section V.

II. PROPOSED DISTRIBUTION SYSTEMS

The conventional solar hybrid power system [8] with battery back-up is shown in Fig. 1. The major component in the system is power conditioning unit (PCU) comprising inverter, rectifier and battery charger units. The operation of the system is as follows:

(a) whenever solar energy is available, complete load is fed from the solar and surplus solar power is used to charge the battery bank;
(b) when solar power is not available, grid power is fed directly to the load through a static switch;
(c) when solar power is inadequate for battery charging, grid power is used to charge the battery bank through rectifier-inverter unit;
(d) when both solar power and grid power are not available, battery bank supports the load.

The complete system operation involves multiple rectification (AC-DC) and inversion (DC-AC) process leading to losses in each stage of conversion. Also, at the utilization end, the AC power is converted back to DC inside majority of appliances. The additional power loss due to double conversion of power has to be compensated with increase in battery and/or solar capacity resulting in higher initial investment.

Figure 1. Conventional 230V AC solar hybrid distribution system for Indian rural banks

The hybrid distribution system [9] proposed by famous solar power converter manufacturing company “SMA” is shown in Fig. 2. The system consists of an Inverter ‘SMA SunnyBoy’ and a bidirectional converter ‘SMA SunnyBackup’. Most of the solar power is directly fed to load without storage i.e., single stage conversion and the surplus solar power is stored in the battery bank. The indirect solar energy (stored in the battery) is used during low insolation period which involves three conversion stages (DC-AC-DC-AC). The drawback of multiple conversion loss still holds. These kind of systems are mostly suited for large solar installations with grid in power feed facilities. The system also requires sophisticated inverter and bidirectional units to synchronize with grid supply, which makes the system costlier than the conventional solution (Fig. 1.).

Figure 2. 230V AC solar hybrid distribution system for Indian rural banks using SMA Sunny Backup

The proposed DC electrical distribution system for rural banks is shown in Fig. 3. The system operates in the similar way to conventional system (Fig. 1.), with high priority to solar power then to the grid power and finally the battery power. The proposed system avoids inversion stage at the source and rectification stage in the end use appliances. This results in improvement in overall system efficiency. Due to improvement of system efficiency, solar and battery capacities are reduced leading to savings in system cost.

Figure 3. 48V DC solar hybrid distribution system for Indian rural banks

The proposed system employs centralized AC-DC rectifier which also performs unity power factor correction (UPF). This eliminates the need of power factor circuitry and AC-DC converter in each appliance. Generally electrical wiring in building is rated for 5A, as most of the appliances are typically lower than 200 W; therefore for such loads there is no need of changing the cables. But, for heavy loads, 48 V system results in higher cable loss which can be compensated by running thicker cables in the distribution system. The adaptors of all the appliances (computers, printers etc.) have to be changed and fans, lamps have to be replaced with their DC versions. All these modifications results in compact,
efficient and more reliable power adapters for end appliances. Nowadays, such appliances are available off-the-shelf. The capacity and rating of various components of hybrid PV system for rural bank are derived in next section.

III. DESIGN OF SYSTEM COMPONENTS

The efficiency and performance indices considered while designing the system are given in Table-2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter efficiency (Ieff) at rated power</td>
<td>93%</td>
</tr>
<tr>
<td>PV charge controller efficiency (Ceff) at rated current</td>
<td>95%</td>
</tr>
<tr>
<td>Central AC-DC rectifier efficiency (Reff) at rated power</td>
<td>95%</td>
</tr>
<tr>
<td>Average solar generation constant (energy per day per kWp, E_{avg})</td>
<td>4.5</td>
</tr>
<tr>
<td>Safety factor of solar capacity for low insolation and losses (SF_{loss})</td>
<td>1.2</td>
</tr>
<tr>
<td>Battery nominal voltage (V_{bat})</td>
<td>48 V</td>
</tr>
<tr>
<td>Depth of discharge of battery bank (DoD)</td>
<td>80%</td>
</tr>
</tbody>
</table>

Table-2. Efficiency and performance indices

In this section, the sizes of the system components (primarily solar PV capacity and the battery bank capacity) are calculated for the three distribution systems discussed in Section II. Backup power for rural banks is needed for 8 hours operation and storage i.e. battery bank should cater to 2-day autonomy. Servers are usually operated for at least 12 hours a day while all other loads are operated for 8 hours.

(A) Conventional PV System:

Load per day = server load × 12 + loads excluding server × 8 = 15.6 kWh

Considering no-load current of UPS as 2%, the additional load per day for 5 KVA UPS will be 1200 W per day. The total load per day (L_d) = 16.8 kWh

Required solar energy per day (E_{day}) = L_d/(Ieff×Ceff) = 19 kWh

(i) Solar capacity = (E_{day} × SF_{loss})/ E_{avg} = 5.07 kWp

(ii) Battery bank capacity = L_d/(V_{bat}×DoD) × 2 = 940 AH, 48 V

(B) SMA Sunny Backup System:

The total load per day (L_d) = 15.6 kWh

Assuming 30% of the generated solar power is used directly without storage and the remaining 70% with intermediate storage.

(i) Solar capacity for direct feeding the load (involves one conversion) = (0.3 × L_d × SF_{loss})/(Ieff × E_{avg}) = 1.34 kWp

Solar capacity for indirect feeding the load (involves three conversions) = (0.7 × L_d × SF_{loss})/(Ieff × E_{avg}) = 3.62 kWp

Total required solar capacity = 4.96 kWp

(ii) Battery bank capacity = L_d/(V_{bat}×DoD) × 2 = 873 AH, 48 V

(C) Proposed System:

The total load per day (L_d) = 15.6 kWh

Required solar energy per day (E_{day}) = L_d/C_{eff} = 16.42 kWh

(i) Solar capacity = (E_{day} × SF_{loss})/ E_{avg} = 4.37 kWp

(ii) Battery bank capacity = L_d/(V_{bat}×DoD) × 2 = 812 AH, 48 V

Based on the above calculated system component sizes, the power rating of various power processing units are chosen as follows.

Online solar UPS: 5 KVA
Solar charge controller: 5 kW
SMA sunny boy: 5000 W
SMA sunny backup unit: 2200 W
Central AC-DC rectifier: 2 kW

Based on system ratings in this section, economic benefits of the proposed DC grid system over conventional AC systems have been calculated in the next section.

IV. ECONOMIC ANALYSIS AND COMPARISON

To conduct comparative economic analysis of the proposed system with respect to conventional and SMA PV systems, the cost of solar power including installation (without subsidies) is taken as Rs. 100/Wp and the cost of battery is chosen as Rs. 10000 for 12V, 160 AH capacity. The per-unit costs of various power processing units as per the market trend are given in Table-3. To keep the distribution loss comparable to AC system, electrical wiring is replaced with thicker cables. From the Table-3, it is observed that initial investment in SMA sunny backup system is 13.6% higher than conventional PV system even though the solar array and battery capacities are slightly lower. This is due to the requirement of expensive complex and sophisticated inverter and bidirectional units in SMA system.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional system</th>
<th>SMA system</th>
<th>Proposed system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total load per day (kWh)</td>
<td>16.8</td>
<td>15.6</td>
<td>15.6</td>
</tr>
<tr>
<td>Solar capacity (kWp)</td>
<td>5.07</td>
<td>4.96</td>
<td>4.37</td>
</tr>
<tr>
<td>Battery bank capacity (AH) @ 48V</td>
<td>940</td>
<td>873</td>
<td>812</td>
</tr>
<tr>
<td>Cost (Rs. In thousands)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar panels</td>
<td>507</td>
<td>496</td>
<td>437</td>
</tr>
<tr>
<td>Battery bank</td>
<td>235</td>
<td>218.25</td>
<td>203</td>
</tr>
<tr>
<td>Inverter / UPS</td>
<td>80</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Solar charge controller</td>
<td>120</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Central AC-DC rectifier</td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Rewiring expenses</td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>822</td>
<td>934.25</td>
<td>700</td>
</tr>
<tr>
<td>% of Saving</td>
<td>-13.66</td>
<td></td>
<td>14.84</td>
</tr>
<tr>
<td>Saving</td>
<td>122</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table-3. Comparison of solar capacity, battery bank capacities and cost savings for 48 V DC grid against conventional 230 V AC solar hybrid system and SMA sunny backup system

DC grids in Table-3 show savings of 15% over AC grids. In absolute terms there will be saving of Rs. 1.22 lakhs for single rural bank and Rs. 1.83 billion if DC grid is incorporated across 15,000 rural banks. The gain will be
higher if efficiency improvement in individual appliances is also considered. In Table-3, the grid power is only for emergency backup as the system is designed to run on solar power alone and thus power generation by solar matches power consumption in the bank i.e., \( k=1 \). But where grid power complements solar power to meet load power requirements \( k \) will vary from ‘1’ to ‘0’. \( k=0 \) corresponds to a situation where complete power is drawn from grid without any solar power contribution and \( k=1 \) represents vice-versa situation.

Figure 4 shows the variation in energy cost and savings with percentage of solar power in total power consumption. The life cycle cost is calculated in our study for 5 years period. Similarly, Fig. 5 shows the cost savings with the proposed system for 5, 10, 15 and 20 year life cycle periods respectively. The life of the battery is considered for 5 years whereas the life for the power processing units is taken as 10 years. The cost of these components is included during calculation and the cost of grid power is taken as Rs. 6 per unit with conservative inflation coefficient of 0.8.

V. CONCLUSIONS

In this paper, the advantage of electric power distribution through DC grid over AC grid is analytically demonstrated. In present study, case study of rural banking with core banking operation has been undertaken. The analytical results clearly show that there is reduction of 15% in initial investment if electrical power is distributed over DC grid in place of AC grid. In absolute terms, the saving is Rs. 1.22 lakh per each rural bank branch. For 15,000 banks, the cost saving is huge to the tune of Rs. 1.83 billion. If the efficiency gains in the end-equipment is included the cost saving will further improve.

There is further need of study on life cycle cost reduction due to improvement in reliability of appliances under DC operation.

REFERENCES