Performance Evaluation of Community Based Solar PV System

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Abstract. Building an energy system for an individual household can require high capital and also the replacement and maintenance of such system can be a tedious work. To reduce such kind of stress on an individual, we propose a small power production system for a community. In doing so we will be able to limit the power dependency on the grid. This kind of system is heavily depended on the Battery as the solar panel that generate the power will be in a central place that belongs to the whole group of people. The batteries of individual household will be charged in the central station and the excess of energy will be sent to the grid. A DC system line is also introduced to reduce the system complexity. The Common Solar panel system consist of the Solar Panel, structure, battery charging station and an inverter with grid synchronization. The above-mentioned solar structure products require maintenance and continuous monitoring, thus reducing the initial capital cost that has to invested by an individual. The individual's capital investment will mainly revolve around the batteries and the DC system, which means the invested cost is almost halved from owning an independent solar panel system.

1. Introduction

Construction of a Solar powered PV system can prove to be a high investment with long payback period. Even though this investment will save monthly electricity bills they are a bit tedious work with many monitoring systems as a precaution. As an individual maintaining and monitoring such system will be a tedious work. In this proposed system we will be efficiently using the power produce by the solar PV system with minimum. For this we will be conditioning the DC supply from the system into a usable DC line for the DC appliances and battery charging. To reduce the individuals stress on the monitoring and maintaining solar panel structure. We are proposing a common structure of solar panel for a group of people. The common solar panel system will have a DC outlet apart from the Grid input AC outlet, which the individuals can plug in their Inverter batteries at their house for charging. Then these batteries power the individual's house DC system which can be used as a small backup Consisting of low power consuming DC appliances. An inverter is used in the individual's system to make it more compatible to the conventional AC appliances.

2. Working of the System

The Common Solar panel system consist of the Solar Panel, structure, battery charging station and an inverter with grid synchronization. The above-mentioned products are the priciest, requires maintenance and continuous monitoring, thus by sharing this resource, the initial capital cost that has to invested by an individual is reduced. The individual's capital investment will mainly revolve around the batteries and the DC system. The below line diagram (Figure 1) represents the proposed system (5.25 KW) with DC load line.
The common system is being shared a colony of 5 houses with a daily usage of 2.7KW peaking at 5KW. The initial package of batteries allotted for each house is 4.68 KW. As we can see the solar system is capable of producing 26.25KW per day (5 hrs. sunshine per day), the individual has a flexibility of battery. The Common solar structure is connected to the MPPT charge controller for maximum power adjustment and the DC supply is sent to the battery charging station which has to option of Direct DC supply to the Individual’s houses. The excess of power produced is then sent to the Grid via an inverter fitted at the solar Panel Structure.

![Figure 1. Communal solar Panel structure.](image)

The Grid-tie inverter is connected to the common solar panel, as it assists in various scenarios:

- Panel to Battery (via the inbuilt MPPT charge controller)
- Panel to grid AC conversion
- Grid synchronisation.
- Monitoring the in and out power
- Helps in the charging of batteries when there is no solar power

A DC-DC converter is attached to the DC battery charging line to convert it to right DC loads. The LiFePo4 batteries are connected in the proper order to match this load.

3. Technological Challenges in the Proposed System

The eye of the project Centralized solar power production. The solar panel sharing on paper is one of the best ideas but when it comes to practicality in a society runs into many ethical problems in sharing and conflicts. The construction ground should be common and the usable area of the community should not be restricted. Thus, making it only suitable for rural communities and large-scale apartments. This system has a new generation of battery types which are not widely adopted in the present, which raises the limited rate of production. But as this LiFePo4 battery Technology is much lighter in weight with high energy density and better life then the present led acid tubular batteries. The availability of these batteries might vary from city to city but the future of solar batteries lies in this technology making it the perfect for investment. The light weight and the smaller aspect of the battery is a huge advantage in this case. This makes easier recharge runs even for physically weak individuals.
The system also uses a lot of DC power supply products whose availability also varies in places due to the limited awareness of the product, but is easily overcome with the help of online shopping. Laying DC supply line in most of the existing structure is a bit more tedious than installing in a new structure. Even though it might cost a bit more in laying a backup DC system in an existing structure the savings in the monthly bills can be seen immediately in the next electricity bill as the DC products have longer life and consume less than 60% of the power consumed by the conventional alternative. The need to convert the power supply is also eliminated thus utilizing the maximum available power much more efficiently.

The proposed system has the following advantages over the conventional system:

- Communal solar structure to reduce capital investment and to include individuals into renewable solar power family.
- Usage of low power consumption DC appliances which is less known fact in the solar power system
- Replacing the conventional Lead acid battery power storage system with a much more manageable and lighter LiFePo⁴ battery power bank.
- Integrating the DC load line will help in the backup line in the system will improve the reliability and the elimination of the inverter improves the overall efficiency of the system.
- Modularity and the scalability of the proposed system is much more simpler and user friendly.

4. Techno-Economic and Market Sustainability of the System

4.1 Cost of the System
The approximate bill of the materials (Table1,2) required for a Communal Solar structure of 5.25 kW for 5 households with each household consuming 2.7 kW per day peaking at 5 kW. The system being solar powered will work for 5-7 hrs per day depending upon the sunshine hours of that day. The batteries we will be using is LiFePo⁴. Even though the batteries are a bit pricy they are light and highly dense thus making it great for this project and as a next generation energy storage battery.

| S. No | Parts                             | Spec   | Number | Price (₹)      |
|-------|-----------------------------------|--------|--------|----------------|
| 1     | PV Modules                        | 375    | 14     | 1,40,625       |
| 2     | Charge controllers &MPPT           |        | 1      | 7,000          |
| 3     | Inverter                          | 5 KW   | 1      | 1,40,000       |
| 5     | Net Meter                         | -      | 1      | -              |
| 6     | Knife Breaker                     | 50A    | 2      | 5,000          |
| 7     | Panel Structure                   | Metal  | 1      | 15,000         |
| 8     |Wirings and other miscellaneous parts | As req | 12,375   |

**Total** ₹3,20,000

| S. No | Parts                              | Spec  | Number | Price (₹) |
|-------|------------------------------------|-------|--------|-----------|
| 1     | Battery                            | 48V 100Ah | 1     | 80,000    |
| 2     | Battery bank structure             |       | 1      | 6,000     |
| 3     | DC wiring                          | As req |        | 7,000     |
| 4     | Inverter for emergency             | 1KW   | 1      | 10,000    |
| 5     | Knife breaker                      | 50A   | 1      | 2,000     |

**Total** ₹1,05,000
4.2 Market Sustainability

Before starting any prototyping of a project, conducting an initial feasibility study is a must. So, we conducted a small survey using Google forums to ask 50 random individuals of middle-class income streams at South India. The questions involved were mostly targeted towards the individual’s awareness about alternative energy resources and their willingness to switch to Solar energy. Individuals need for a new low LCOE and low maintenance system is at the peak due to the reducing reliability of the grid systems. The following small-scale study helps us to better understand the need for the proposed projects in urban areas too.

The results are as follows:

![Monthly Power usage](image)

**Figure 2.** Monthly Power Usage of each residence.

From the pie charts above (Figure 2) and the spreadsheet responses we can see the diverse range of houses and their power consumption. 80% of the users consume less than 500 units per month and have flat roof for a room mounted system. Though 20% of the individual have sloped appropriate adjustment to the quantity of solar panel will also benefit them. Families consuming greater than 500 units per month all have flat roof (according to the survey) which opens up the opportunity to lay on more panels on the roof top with ground mounting structure and also aesthetically pleasing sloped structure. Enquiring further about their interest in using power storage and generating solutions (figure 3). We found out that 42% are already using an inverter system and are also interested in laying a solar system. Which opens up the opportunity for the proposed system to be laid with much less capital investment. About 72% are also interested in laying completed system. With only 10% of the people opting generator usage. With proper explanation about the Lifetime Saving and the low maintenance savings. We are confident our product will be much more appealing to 95% of the consumers.

To determine the specific usage of power in the household we asked the individuals about the loads that will be connected to the system. Only 38% of the individual are opting for medium loads which is also in line with the proposed system where all DC Powered appliance can be used. The remaining 62% of them are interested in complete anonymity by hooking their entire household system including heavy loads like Air conditioner to the solar panel. 58% of the members were willing to go full on by installing the system for their entire household. This gives us the flexibility to install DC lines in for maximum savings. Even though they cost a bit more than regular AC appliance they consume very less current thus reducing power consumed. We also asked them if they would be interested in switching some appliance to DC components of less power consumption.
Most of the response associated with Negative response were a part of Backup system for medium loads. This helps us understand that the individual does not want to close the option of AC usage from the grid. Our proposal tackles this problem also by the usage of Hybrid inverter to provide power for the DC appliances in the absence of Solar. We proceed further by asking the individuals about their preferred type of solar system.

On-Grid, OFF-Grid and Hybrid System 74% of the people opted for Hybrid system followed by 18% who opted for on-grid system. This question was also followed by a short answer for their answer about the reason for their preference. There was a mixed response of concerned citizen to individual who just wanted to reduce the long-term stress on their pockets. There were also some concerns about the cost between the systems. All the above concerns are also addressed in the part 1 of the cover sheet attached above. coming to the financial side of things the individuals were posted some Queries about their stand on the capital investment (Figure 4, 5 & 6). The respondent was asked about his/her preference in capital investment and their stance in buying the suggested modular solar power system. Around 76% of the people were more inclined due to the subsidy provided for a Solar Power System and 95.9% of the participants were interested in the Modular solar system. The Participants were also asked about their opinion on the Cost of the Modular system. Around 63.3% of the responder were comfortable with 1-4 lakh per system. Which coincides with the proposed system (altering it to 100-500 units per month).
4.1% opted for Above 4 lakhs which was family with above 500 units per month consumption. 32% who opted for below one lakh were mostly comprised of the people with below 500 units per month and only required a backup system.

![Figure 5. Interest in upgradable PV package.](image)

As this study consist of random individuals (mostly consumers). We have decided to further improve the quality by including more expert and segregating their opinions. We are also in the process of improving the questionnaire for accurate result for the proposed project.

### 4.3 LCOE Calculation

For calculating the LCOE we first need to make some basic assumptions:

- 5 hours of sunshine hours
- 300 days of sunshine approx.
- 15 years of panel life time
- Subsidy of 30% provided by the government.
- ₹2 Per unit provided by the government and 6₹ is charged.

**Note:** The Assumption provide above is heavily undercut to simulate the worst possible scenario.

Solar power produced:

\[
\text{Solar power produced:} \quad 5.6 \text{ kWh} \times 5 \text{ hrs per day} = 28 \text{ kW/Day} \\
28 \text{ kW/Day} \times 300 \text{ days} = 8,437.5 \text{ kW/year} \\
8,437.5 \times 15 \text{ years} = 1,26,562.5 \text{ kW} \\
8,437.5 \times 25 \text{ years} = 2,10,937.5 \text{ kW}
\]

**Table 3:** LCOE calculation with and without subsidy.

| Without Subsidy         | With Subsidy         |
|-------------------------|----------------------|
| Material cost           | ₹ 1,05,000           |
| Maintenance cost per year | ₹ 10,000          |
| Shared cost of str.     | ₹ 64,000             |
| Total cost              | ₹ 1,79,000           |
| Loan amount             | - ₹                   |
| Subsidy                 | - ₹ 53,700           |
| Individual’s payment (initial) | ₹ 1,79,000  |

**With Subsidy:**

| Material cost | ₹ 1,05,000 |
|---------------|------------|
| Maintenance cost per year | ₹ 10,000 |
| Shared cost of str. | ₹ 64,000 |
| Total cost | ₹ 1,79,000 |
| Loan amount | - ₹       |
| Subsidy | ₹ 53,700 |
| Individual’s payment (initial) | ₹ 1,25,300 |
Table 4: LCOE calculation at 10 and 20 years

| LCOE: | 10 years | 20 years | LCOE: | 10 years | 20 years |
|-------|----------|----------|-------|----------|----------|
| 0% sent to grid | 2.19 | 3.714286 | 0% sent to grid | 1.533 | 3.057 |

Note: LCOE for 20 years is greater than 10 years because the battery might be needed to be replaced after 10 years.

| Power and cost gained by the government | Cost saved from EB per house |
|----------------------------------------|-------------------------------|
| % to grid | Power produced | Cost saved | daily watt | Cost Saved/year | Cost Saved/month |
| 20 | 16,87,500 | ₹ 33,75,000 | 2,000 | ₹ 4,380 | ₹ 365 |
| 50 | 42,18,750 | ₹ 84,37,500 | 3,500 | ₹ 7,665 | ₹ 639 |
| 80 | 67,50,000 | ₹ 1,35,00,000 | 5,000 | ₹ 10,950 | ₹ 913 |

Figure 6. Cost gained by the government and saved per household

5. Performance Results from PVsys 7.0

PV Syst 7.017 is a non-commercial Simulation software for Solar system with various types of Photovoltaic panels including the Latest Bifacial panel and CPV panels. The software also has inbuilt Meteorological data and tracking software for various orientation. Under the system configuration various other components are all pre-configured. Choosing the apt components was an important step in the study. The following Table 5,6 provides the system details of the chosen components.

Table 5: Common Solar structure.

| Name | Brand | Spec | Model |
|------|-------|------|-------|
| PV Module*14 | Longi- solar | Si-Mono (375) | LR4-60 H1H 75 M G2 |
| Arrangement | | 14 modules | |
| Inverter*1 | Generic | 4.20KWac | |
| Battery*5 | Generic | Li-Ion | 26V 180Ah parallel |

Table 6: Individual Solar structure.

| Name | Brand | Spec | Model |
|------|-------|------|-------|
| PV Module*3 | Longi- solar | Si-Mono (375) | LR4-60 H1H 75 M G2 |
| Arrangement | | 3 modules | |
| Inverter*1 | Generic | 1.50KWac | CSI-1.5KTL1P-GI-FL |
| Battery*1 | Generic | Li-Ion | 26V 180Ah |
5.1 Common Solar Panel Structure

Inputting these values (Table 5) and choosing the location Kattankulathur @ 12.82°N 80.04°E. The orientation is specified as 13° tilt with no shading, south faced and self-consumption as per the user’s needs (12.9 KW/day). The simulations run for an entire year using the NREL met data available in the software. The panels are arranged in 7 in series of 2 strings thus a total of 14 panels of 375 Wp. The users need are specified hourly and the software calculates it for the entire year. The needs are specified hourly and seasonally to simulate much more accurate results. Here all the 5 houses needs are combined into a single load profile.

Grid connected 5 houses as load (self) with battery

| GridHor kWh/m² | DiffHor kWh/m² | T_Amb °C | GlobInc kWh/m² | GlobEff kWh/m² | EArray MWh | E_User MWh | E_Solar MWh | E/Grid MWh | EfrGrid MWh |
|---------------|---------------|---------|----------------|----------------|------------|------------|-------------|------------|------------|
| January 162.0 | 62.41         | 25.28   | 159.3          | 155.9          | 0.719      | 0.378      | 0.378       | 0.285      | 0.000      |
| February 170.3 | 57.25         | 27.83   | 168.5          | 165.5          | 0.742      | 0.341      | 0.341       | 0.351      | 0.000      |
| March 207.4   | 69.52         | 29.77   | 204.6          | 201.3          | 0.882      | 0.345      | 0.345       | 0.482      | 0.000      |
| April 205.8   | 68.55         | 30.07   | 203.5          | 200.5          | 0.887      | 0.334      | 0.334       | 0.500      | 0.000      |
| May 197.3     | 80.73         | 31.51   | 195.1          | 192.3          | 0.853      | 0.345      | 0.345       | 0.456      | 0.000      |
| June 179.0    | 79.82         | 30.30   | 176.9          | 174.3          | 0.783      | 0.309      | 0.433       | 0.299      | 0.076      |
| July 177.1    | 81.08         | 30.66   | 174.4          | 171.7          | 0.770      | 0.325      | 0.447       | 0.270      | 0.078      |
| August 174.2  | 77.70         | 28.96   | 170.0          | 167.2          | 0.758      | 0.326      | 0.440       | 0.263      | 0.086      |
| September 177.7 | 67.66   | 28.07   | 175.8          | 173.1          | 0.785      | 0.334      | 0.334       | 0.402      | 0.000      |
| October 154.4 | 66.16         | 27.69   | 150.1          | 147.2          | 0.674      | 0.345      | 0.345       | 0.281      | 0.000      |
| November 137.5 | 63.94   | 26.25   | 134.6          | 131.4          | 0.611      | 0.334      | 0.334       | 0.232      | 0.000      |
| December 137.9 | 64.95         | 25.38   | 134.2          | 130.8          | 0.611      | 0.379      | 0.373       | 0.194      | 0.005      |

Year 2080.5 941.68 28.50 2047.0 2011.2 9.074 4.697 4.451 4.016 0.246

Figure 7. Simulation results for common solar str.

From the tabular column above (Figure 7) we can see that the system output is around 9.074 MWh at the end of the panel and the user only uses 4.697 MWh. Which means more than 50 % of the power is sent to the grid, which is a really option for the government as they will get more power for less investment. We should also note that the user also consumes around 0.1% of the power from the grid. This brings the Grid injected power to 43.0% of the total power at the end of panel. After the simulation the system provides a complete report of the performance (Figure 8). From the report we can conclude that the common solar panel structure provides a total of 8.76MWh/year with a performance ratio of 78.82%.
Figure 8. Energy produced each month for common solar str.

5.2 Individual house solar structure:

Inputting these values (Table 6) and choosing the location Kattankulathur @ 12.82°N 80.04°E. The orientation is specified as 13° tilt with no shading, south faced and self-consumption as per the user’s needs (2.9 KW/day). The simulations run for an entire year using the NREL met data available in the software. The panels are arranged in 3 in series panels of 375 Wp. The users need are specified hourly and the software calculates it for the entire year.

Figure 9. Simulation results for individual’s solar str.
From the report we can conclude that the common solar panel structure provides a total of 1.86MWh/year with a performance ratio of 75.13%. From the tabular column (Figure 9, 10) we can see that the system output is around 1.94 MWh at the end of the panel and the user only uses 0.978 MWh. Which means more than 35 % of the power is sent to the grid, which is lower than the Community common solar power by 23.5%. We should also note that the user also consumes around 1.9KWh more than the common solar power solution.

![Performance Ratio PR](image)

**Figure 10.** Energy produced each month for individual's solar str.

6. Conclusion
To compare the results of Common solar structure and a singular individual solar str. we have to multiple the individual's value by five to match the load on the solar communal solar power system. From the figure 7 and 9 we can see that there is a sufficient increase in the production of power and the power in injected to the grid. If this concept is utilised by the government, it would be able to save a lot of cost just by investing in the common solar str. It also encourages the consumers to go renewable energy as they only have to connect their inverter system to the setup. Which almost reduces their investment cost around 40%. The consumers also do not have to maintain and monitor the solar power produced by the structure. Thus, reducing the investment cost and maintenance cost for the individuals and increasing the power injected to the grid, saving money for the government [18].

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