Let There Be Light: Harnessing Solar Energy as a Solution to Erratic Grid Power in Rural India

Dhruv Kulgod

Shri Ram School Aravali

dhruv.kulgod@gmail.com

Abstract —Rural areas in India suffer from erratic power supply. Indian villages in states with a “100% electrification rate” according to the government still only receive 11-17 hours of power a day. The aim of this research study was to develop and evaluate the implementation of a DIY standalone photovoltaic (PV) system to solve the issues caused by power shortages in rural areas through the use of renewable energy, specifically solar power, to supplement the power supply in a village in Haryana. Telephone surveys were conducted with 7 residents of local villages in Haryana to gather data regarding the types of appliances used and the extent of the usage in order to calculate daily power backup requirements for a home in the targeted demographic segment. Once the requirements were established, “Surya”, the DIY standalone PV system was designed and tested in a home in the Chakkarpur village in Haryana to determine the effectiveness of the system in reducing the effects of erratic power over a two-week testing period, as compared to the power situation without Surya over the same period. While this research study has shown that the creation of a targeted system is technologically achievable, there is a need to reduce the financial burden on adopters. Viable methods to reduce this burden include increasing scale and improved technologies.

I. INTRODUCTION

India prides itself in having a national rural electrification rate of 95%; however, the definition of “electrified” is misleading [1]. Based on the official definition, a village is considered electrified when “the number of households electrified [are] at least 10% of the total number of households in a village” [1]. What this translates to is that villages in a state like Andhra Pradesh with a supposed 100% electrification rate only receive 11–17 hours of power per day, about 20 days a month. Their electricity rate exceeds the stipulated government rate of “6-8 hours a day” [1]. Clearly, there is much room for improvement. The population segments that are affected are generally low-income households; despite having to pay for power throughout the year, they receive less than 60% of the power they are paying for [1].

In Haryana, near where I reside, rural villages in Haryana experience up to 80% in energy losses due to energy theft, according to a 2018 study [2]. Residents draw power illegally from overhead cables through the village to power devices, hence circumventing the electricity meter, which means that they do not pay for the additional electricity obtained. The high temperatures in the summer months are one of the major factors associated with power theft, with summer highs in Haryana crossing 42 degrees Celsius [2]. Given that the major occupation of these residents is agriculture, or some other forms of physical labour [2], the need for respite is a pressing one. These residents feel that they themselves are being robbed by the utility companies due to high tariffs and inconsistent power [2]. As far as they are concerned, their action is not "theft", but a retrieval of what they are owed [2].

This is where solar energy comes into the picture. India has untapped solar potential due to its favourable location in the solar belt (40◦S to 40◦N) [3]. The National Institute of Solar Energy has assessed India's solar potential to be about 748 GW, based on the assumption that 3% of the waste land area is covered by Solar (photovoltaic) PV modules [4]. However, as of end-2019, only 28.2 gigawatts (GW), or 7.6% of India's total power production, came from solar. The "Jawaharlal Nehru National Solar Mission" (JNNSM), launched in January 2010, is aiming to fill this gap in the country's solar scenario by establishing 100 GW of grid-connected solar installations by 2022 [5]. Given that India has a total installed power generation capacity of 371 GW [6], the success of the JNNSM could really transform the power generation landscape in India.

In addition to the national scheme, state governments in India have also been promoting solar generation [3]. There is already a precedent for solar solutions in rural settings, in the form of solar water heaters. They are a perfect example of a popular stand-alone solar-based product, showing the potential for the use of solar energy in a rural setting. In fact, the Haryana government offers subsidies for installing them [7]. Therefore, solar installations have the capacity to reduce the need for electricity theft by providing backup.

Advances in solar technology over the last decades have been accompanied by a decline in costs. A 2002 study [9] comparing off-grid PV systems and diesel generators in India showed that PV systems were the lowest-cost option up to 15 kWh/day. In fact, further improvements in technology have reduced the cost of solar panels over the past decade from around 9$/W in 2002 to $0.068/W in 2019 [10]. Thus, that advantage over traditional diesel backup systems would be even greater in 2020.

This research study sought to build upon the existing endeavour to harness the potential of the solar energy for the rural sector in India by introducing a stand-alone PV solar installation as a power backup in rural households in Haryana and assessing its viability. Within the context of this study, a Solar Installation may be defined as a system consisting of photovoltaic panels, batteries, and an inverter, while “stand-alone” equates with “not contributing to the National or State power grid” [3][8]. (To learn more about the technical aspects of the solar installation, please see Appendix A.)

More than just a theoretical exercise, the research paper would involve designing a standalone PV system that is customised to the electricity consumption of the needs of the targeted population and evaluate its effectiveness in alleviating the episodes of power shortages experienced. My inspiration to utilise whatever little resources I could harness as a high schooler for the pursuit of this research study was sparked by an interaction with a household-helper, who was complaining about the power cuts in her village: “Often during the summers, there are power cuts at night. In the heat, it can be very difficult to get sleep. It becomes very tiring to work the next day.” Knowing that she faces very high physical demands, cooking and cleaning in multiple households every day, I was acutely sensitive to the fact that a good night’s sleep was vital to her well-being. It was hard to imagine how anyone could get sufficient rest in a poorly-ventilated home, with no electricity to run even a fan, in 40-degree heat.

Our short discussion above made me realise my unique position, as a high school student with the time and passion for solar energy, to be able to do something to improve the lives of the people who do so much for me. It was an opportunity to put my belief in the power of applying technology to improve the lives of others to the test. This was the impetus for me to create “Surya”, a customised standalone PV solar unit for the household of my driver in the Chakkarpur village of Haryana.

II. Description of the Research Study

A. Research Aim & Research Approach

The research aim of this study was to develop “Surya” — a customised DIY standalone photovoltaic (PV) system — and evaluate it as a feasible solution for supplementing the power supply in villages in Haryana. A mixed method approach was used for this research study. Under the quantitative approach, the number of hours of power outage before and after the installation of Surya was compared.

The hypothesis tested is as follows:

- **Null hypothesis**: There is no difference between the mean number of hours of power outage with and without the installation of Surya.
- **Alternative hypothesis**: There is a difference between the number of hours of power outage per day with and without the installation of Surya.

Additionally, the financial viability of the system was qualitatively analysed in the conclusion.

B. Research Design

In order to achieve this objective, the research study involved three steps:

1. The target sample for these questions were citizens who live in semi-rural areas, with limited disposable income, specifically residents of the Chakkarpur and neighbouring villages in Haryana. They were surveyed regarding their electricity consumption needs based on the types of appliances commonly used and the current level of provision of power to the villages. Due to the ongoing COVID-19 pandemic that made on-site data collection unsafe and the lack of access of targeted residents to the Internet, data were collected through phone interviews.

   Potential respondents were verbally asked a set of questions with specific intent. For a start, they were asked about their monthly power bill to understand the full extent of their power consumption and the appliances they use most often (see Appendix B). Specifically, respondents were asked whether they used a fridge, how many lights and fans they had, and their perceived power cut frequency and time period on a weekly basis. These responses were used to generate a baseline for the power requirements the system would have to fulfil. If backup was only required during the day, the PV system could forgo the battery. Additionally, it asked respondents their perception of power-cut frequency, which encompassed its daily and seasonal variations. Seasonal variations in insolation mean that the wattage of PV panel required for the same amount of power in the winter would be far greater than in the summer. The survey also collected information about the respondents' location of residence and roofing material. These questions were designed to assess the physical viability of installing PV panels at their homes.

   In addition to these quantitative questions, the survey also included qualitative questions, whereby respondents were asked to comment on their electricity situation and how their lives would be improved with a steady electricity supply. Their answers gave insights into their lifestyles and any other possible issues they face with their electricity situation.

   Ultimately, these questions would provide the necessary information for the remaining steps of the research design: a) the power specifications that a product would be required to fulfil; and b) a rough estimate of the price point at which a product could be marketed.

2. Designing Surya involved researching the required technical specifications of the solar installation based on the data gathered from the residents in order to put together a customised system. This process involved balancing the product’s capabilities with its cost, as the market for this product is a price-sensitive segment.

3. Finally, Surya’s effectiveness in reducing power cut frequency was tested by calculating average power cut period per day before and after its installation of the product. Its economic feasibility for the targeted population was also considered.

C. Data Analysis

The evaluation of the project that involved the practical design of an effective and affordable standalone PV encompassed two primary components:

a. **Comparison of the average daily hours of power cut before and after the installation of Surya**: Descriptive statistics will be used to present the change in the mean rating of the daily hours of power cut with and without Surya. A 2-sample t-test was run to determine the statistical significance.

b. **Assessment of the financial viability of the product**: This was done in the form of recommendations offered in the paper’s conclusion, as suggestions of how to implement the system should it be successful.

Along with the analysis of the qualitative input of the respondents, these composite findings would enable me to produce a viable product that can serve low- to moderate-income households and solve a major social problem.

III. RESULTS

A. Calculation of the Surya’s Specifications Based on Survey Results

Based on the results of the survey, the respondents experienced an average of 3-4 hours of daily power cuts during the summer months. These power cuts occurred mainly during the summers, both day and night. Based on the survey, the most popular appliances used by respondents in the summer were lights, fans, and a cooler (see Table I).

TABLE I

QUANTITY OF APPLIANCES USED AND ENERGY REQUIREMENTS

	Units reqd.	Energy (Watts)	Total Energy (Watts)
Lights	2	18	36
Fan	1	60	60
Cooler	1	200	200
Socket	1	10	10
Home requirement			306
Factor of safety			30
Total energy requirement			336

To give the system a buffer for days with exceptionally poor power, the system was designed to handle a maximum of 5 hours of power cuts in a day. Table II presents the calculation performed to determine the battery requirement for the system. The battery chosen was a C10, instead of a C20, as it supplied a higher current over its maximum 10-hour time period. As the system was designed to run a home over a 4-hour period, this was the most suitable battery choice

TABLE II.

BATTERY REQUIREMENT FOR 5 HOURS OF BACKUP

P	Energy required per hour during grid-cut	336	Watts
Q	Duration	5	Hours
R	Energy storage required (PxQ)	1680	Wh
	Battery storage requirement @ 12 V (R/12)	140	Ah
	Commercial lead-acid battery available	150	Ah

TABLE III

SYSTEM SPECIFICATIONS

P	Revised power requirements	1.68kWh
Q	Average hours of peak sunlight	4h
R	Total PV wattage reqd. (P/Q)	420W
S	Commercial PV module available	165W
	No. of PV modules reqd. (R/S)	2.54
	Rounded up	3

Given the limited availability of parts due to the lockdowns caused by COVID-19, the most suitable PV modules selected were three 165W panels (see Table III). Speaking to a member of the product development team of Luminous India, the panel manufacturers, revealed that the conversion of DC to AC in an inverter is the least efficient part of this system. Therefore, it was important to select an inverter with a large amount of buffer so that it can handle the entire load without constantly running at its maximum supported current. Thus, an 1100VA (volt-amps) solar inverter was selected, which had an integrated charge controller, to allow for easy grid bypass. The charge controller is responsible for directing the flow of current from the panels either to the home or to the battery, based on the situation.

TABLE IV
REVISED SYSTEM SPECIFICATIONS

Item	Quantity	Power Rating	Model
Solar Panel	3	165W	12V Luminous
Solar Inverter	1	1100VA	NXG - 1100
Lead-Acid Battery	1	150Ah	Solar TT C-10

The three PV panels were connected in parallel to keep the nominal voltage at 12V in order to increase the wattage to the inverter. Based on the directions of Luminous India, the panels were mounted south-facing at a 30-degree angle, as Haryana is located in the northern hemisphere, and the 30-degree angle maximises the amount of light it receives through the day.

B. Installation of Surya

After speaking to the respondents of the survey, my house-helper's home appeared to be the ideal testing location, due to its close proximity and his willingness to test the system. The panels (see Fig. 1) were mounted on the rooftop, clear of any obstructions, at a 30° angle facing South, in accordance with the directions from Luminous. The panels were temporarily installed using resources such as bamboo and bricks during the testing period. Once it was ensured that the system was functioning as intended, the system was installed in a more permanent way.

Fig. 1. Rooftop panel mounting

The inverter was installed according to its installation guide and functioned as expected (see Figure 2). Specifically, the inverter was connected after the mains box. On the back of the inverter, the battery switch was put into “tall-tubular” mode, as the battery in the system was a “tall-tubular battery.” The “i-Charge” mode was disabled to save power. As shown by the indicator lights, the inverter was connected to the mains and the battery, and was receiving energy from the panels. This indicated that it was installed in the proper manner. The inverter was configured such that the home first utilised the available solar power and supplemented it with power from the grid. Therefore, the system would reduce the home’s monthly power reading and reduce the electricity bill as well.

Fig. 2. Installed inverter

The battery was a 150Ah, tall tubular “deep-discharge” battery (see Fig. 3). This ensures that it supplies a steady potential difference independent of how much it is charged. This is important in the case of a home power backup, as the battery is expected to function as intended even when close to being completely discharged.

Fig. 3. The solar battery

The effectiveness of Surya is evidenced by the absence of mean hours of power cuts with the installation of the system within a two-week period (*M* = 0 hours, *SD* = 0 hours), as compared to the pre-installation mean power cut hours prior to the installation (*M* = 2.36 hours, *SD* = 3.01 hours) (see Table V). The user experienced zero hours of power cuts. The solar inverter made a distinct beeping noise when grid power became unavailable. As such, the users were accurately able to keep track of when the system was running solely on Surya and when it was using a combination of the system and grid power. This data was used to conduct a two-sample t-test comparing the number of hours of power cut with and without the system over the same time period. As both sets of data were gathered over the same period of time, the research study eliminates the issues caused by the erratic and unpredictable nature of power-cut frequency.

TABLE V

DESCRIPTIVE STATISTICS

Without the system		With the system	
Mean	2.357142857	Mean	0
Standard Error	0.804227449	Standard Error	0
Median	1.75	Median	0
Mode	0.5	Mode	0
Standard Deviation	3.009143575	Standard Deviation	0
Sample Variance	9.054945055	Sample Variance	0
Kurtosis	9.205625992	Kurtosis	#DIV/0!
Skewness	2.812725754	Skewness	#DIV/0!
Range	12	Range	0
Minimum	0	Minimum	0
Maximum	12	Maximum	0
Sum	33	Sum	0
Count	14	Count	14

As shown in Table VI, the result shows statistical significance: $t(26) = 2.93$ (higher than the critical value of 2.06), $p<.01$ (two-tailed). The average number of hours of power cut experienced was lower than what we designed the system for. Further testing may show that these values could be closer. However, if the average remains the way it is, then the cost of the system can be reduced for this installation because the system will have to handle a smaller load. This could have been caused by a discrepancy between the reported power-cut amounts and the actual values.

TABLE VI

TWO-SAMPLE T-TEST : COMPARISON OF POWER CUTS WITH AND WITHOUT SURYA

t-Test: Two-Sample Assuming Equal Variances		
	Power cuts without the system (hours)	Power cuts with the system (hours)
Mean	2.357142857	0
Variance	9.054945055	0
Observations	14	14
Pooled Variance	4.527472527	
Hypothesized Mean Difference	0	
df	26	
t Stat	2.930940569	
P(T<=t) one-tail	0.003477551	
t Critical one-tail	1.70561792	
P(T<=t) two-tail	0.006955102	
t Critical two-tail	2.055529439	

The last day of testing illustrated the practical effectiveness of Surya. Torrential rains had caused damage to the power lines in the region; as such, there was no grid power supplied for a 12-hour period through the night. Although Surya was not built to handle such a long backup period, the users managed to experience no perceptible power-related issues, and were able to rest comfortably by disconnecting their cooler and reducing their usage of a few select appliances through the night.

This overwhelmingly showed the effectiveness of the system in mitigating issues caused by erratic power. My driver was personally very satisfied with the system’s performance, and reported that his neighbours and visitors were extremely intrigued by it, and inquired about how they could install it in their own homes.

IV. COSTS

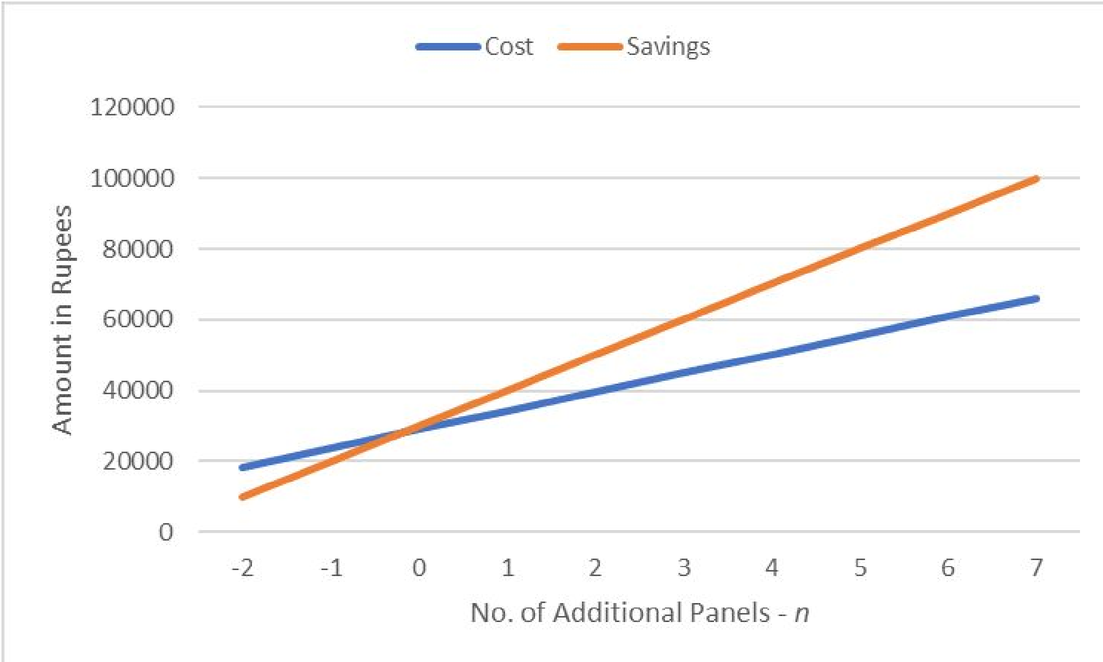
Accounting for all parts and labour, the system cost ₹35,000, roughly equivalent to $500 at the time of writing. Of course, it is important to point out that the pricing for the prototype in this paper is not a fair reflection of the cost of a larger-scale rollout of a system like Surya. As with many mass-produced items, solar energy greatly benefits from economies of scale, both in terms of manufacturing and total system costs [10]. In rural settings, this can be achieved by building systems that support groups of houses rather than individual homes. As shown in Table III, the system requires just 2.5 panels, meaning half of the third panel installed was redundant. With greater availability of parts, panels with lower/higher wattage could be chosen to reduce the discrepancy between the requirements and the system output.

As per the data collected, there was a large fluctuation in the number of hours of power cut per day, from 0 to 4. However, the system was designed to provide four hours of backup every day. Thus, on a day with no power cuts, the excess power generated is actually used to reduce the power consumed from the grid. This would lower the electricity bill considerably, and these savings are a direct consequence of installing this system. Therefore, to calculate the actual cost of the system, we should subtract the electricity bill savings from the total cost of parts.

The household reported an approximate savings of ₹500 per month. Over a 5-year period (the period before any component would require maintenance or replacement), the savings amount to ₹30,000. However, according to the data collected post installation, the daily number of hours of power cuts was below the expected 4 hours, and much below the system's buffered capacity. Therefore, the system could be better optimised to the given situation, by reducing its capacity from 4 hours to 2. Even with an extra 1 hour of buffer capacity, it allows us to reduce the battery capacity from 150Ah to 100Ah. This gives us a cost reduction of approximately ₹7000, bringing our total to ₹29,000.

Another thing to consider is that the time period required to recoup the up-front cost actually reduces as system capacity is increased. The equation between cost and savings is given as

$$
\begin{aligned}
cost &= 5300n + 29000 \\
savings &= 500 * 12 * 5 * \frac{(n+3)}{3} \\
&= 10000n + 30000
\end{aligned}
$$



Where *n* is the number of additional panels installed in the designed system. The two lines meet when *n* is equal to -0.213, showing that savings and costs over a 5-year period are equal when the number of panels is 2.78, and the break-even period is 4.83 years. But the slope of the *savings* equation is greater than that of the *costs.* As we add more panels, the savings increase beyond the costs, till the point where the household's sole electricity source is solar energy. If, in the same system, we added 3 additional panels, costs would increase to ₹44,900. However, the break-even point would be 3.74 years, after which the electricity would be essentially free. This would be an especially viable strategy in households with higher disposable incomes.

Costs could also be brought down by scaling the system to support multiple households [10]. In 2010, residential installations in India above from 2-5kW had a maximum cost of $3500/kW, while installations above 10kW had a maximum cost of $3000/kW. Applying this to Surya, combining approximately 10 homes would give a price reduction of 14.3%, bringing down its per-home cost to about ₹25,000. The new equations for cost would be

$$cost = 5300n + 25000$$

Savings and costs equalise in 5 years with just 2 panels. With 3 panels, the break-even period is 4.16 years, and with 3 additional panels, this can be brought down to just 2.1 years.

Finally, large savings can be made if these households choose to use DC appliances instead of standard AC ones, as it removes the need for inverters. This will require forethought, and it would be recommended that the Indian government advise this demographic to buy DC appliances for their homes. This would further reduce the up-front cost to ₹20,000. This would allow the standard break-even period to reach 3.33 years, and just 1.66 years with 3 additional panels.

V. CONCLUSION

In conclusion, by conducting surveys of the target audience to determine their requirements, designing a standalone power-backup system using solar technology, and conducting a two-factor t-test to determine its statistical significance, Surya proved it has the technical capability to eliminate the issues caused by erratic power supply in rural settings. The family whose home the system was installed in was very pleased with its capabilities, and the system even caught the attention of some of the neighbours. Thus, we can reject the null hypothesis, and accept the alternate hypothesis. The technology itself is more than capable, but the true test for this system will be in its delivery at an achievable price-point.

While Surya's costs can be reduced, the current up-front costs are too high for financially-sensitive customers to afford. Decreasing panel, battery, and inverter costs will increase the ease of adoption in the coming years. Currently, the largest component of the up-front cost in the system is the battery. The lead-acid batteries used today also only have a warranty period of about five years. The only real alternative today are Lithium-ion batteries that generally have a 10-year warranty period; however, this would pose an even higher up-front cost. Nonetheless, with the electric vehicle revolution around the corner [11], one should expect home-scale Li-ion batteries to become widely available. Speaking to professionals in the field, there is a feeling that EV batteries, once unfit for vehicular use when their capacity falls to 80%, can still be used to provide home-scale backup [12].

Battery technology remains a crucial area of renewables-focused research. A possible implementation of this system is as a testing bed for new battery and panel technology. EV or renewable companies could use this project as a platform to test battery variants, new battery technologies, or panel types. In doing so, they could pick up some of the financial burden, as it provides them with valuable research specific to the Indian market. This tie-in would provide great value to both parties involved- the consumer as well as the companies.

While the project was successful in its result, an unexpected barrier that was encountered during the early course of the project was people's insecurities and hesitation about revealing their power situations. This may be partially attributed to the fact that most respondents do not directly pay their bill to utility companies, but instead pay a landlord a fixed monthly fee. This barrier was further exacerbated by the inability to conduct face-to-face interviews. Thankfully, there were respondents who were open and willing to test out the product, and for the purposes of this study, just one installation needed to be completed. For further studies of this kind, more time should be spent developing relationships with the people involved, as it would hopefully overcome these divides by highlighting the benefits of research studies for people in disadvantaged circumstances. As evidenced by the interest shown by my driver's neighbours, once people understand how Surya functions as well as its capabilities, they would appreciate the change it would bring about in their lives.

VI. ACKNOWLEDGMENTS

I would like to thank Mr. Naveen Goudar and Mrs. Kah Ying for offering their guidance and expertise through the research. Their valuable insights were crucial to the success of the project.

APPENDIX A
DESCRIPTION OF A STANDALONE PV SYSTEM

As shown in Fig. 5, the photovoltaic (PV) module generates a DC current when exposed to sunlight. The charge controller decides whether this current is used to: a) charge the battery, or b) bypass the battery to go straight into the inverter. During the day, if the battery is not fully charged, all the current produced from the panels is used in charging the battery. If the battery is already charged, then the current produced by the panels may be used to reduce the total grid-power consumption of the household. If a power cut occurs during the day, a combination of the current produced by the panels and the charge stored in the battery will be used to power the home's appliances. At night, the panels do not produce any power; so the battery alone delivers the power backup. In the system built for this paper, a "solar inverter" was used instead, which combines the charge controller and inverter into a single device for ease of use.

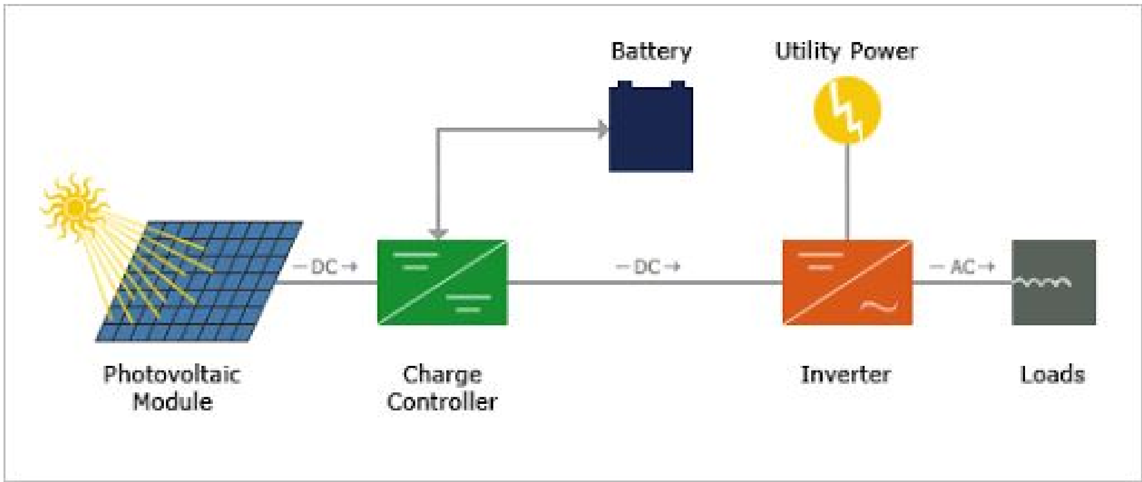


Fig. 5. Basic diagram of a stand-alone PV system

APPENDIX B

SAMPLE QUESTIONNAIRE

1. What is your location of residence? - To determine the viability of a PV installation at their residence.
2. What is your monthly power bill? - To get an estimate of how much power they consume, and how much backup they might require.
3. What appliance do you most commonly use at home, and in which season they use them: To determine the most important appliances for the respondents. Examples of appliances include the following:
    a. Fans
    b. Lights
    c. Water pumps
    d. Kitchen mixers
    e. Refrigerators
    f. Geysers
    g. Air coolers
    h. Electric mosquito repellents
    i. Hand-held torches
4. What is your roofing material? - To assess the viability of the physical installation of a PV system at their residence.
5. What is the perceived frequency of power cuts at your residence in summers? - To provide a baseline reading pre-intervention.
6. Out of 24 hours, approximately how many hours a day is there a power cut at your residence? - To provide a baseline reading pre-intervention.
7. Day and night variations in power cut frequency: To determine the system's requirements.
8. Seasonal variations in power cut frequency: To determine the system's requirements.[1]
9. Their satisfaction with the power they receive, and any improvements they would see with more stable power.

APPENDIX C

DATA COLLECTED FROM THE INSTALLATION

No. of hours of power cuts		
Day	Without the system	With the system
1	2	0
2	0.5	0
3	0	0
4	3.5	0
5	2.5	0
6	1	0
7	0	0
8	3	0
9	0.5	0
10	2.5	0
11	1.5	0
12	3	0
13	1	0
14	12	0

REFERENCES

[1] M. Ram, “Failed Aspirations - An Inside View of the RGGVY,” Greenpeace, Sep. 2011. Accessed on: Jul. 2, 2020. [Online]. Available: doi: 10.13140/RG.2.2.11757.18402

[2] S. Saini, “Scenario of distribution losses — A case study from Haryana”, *International Journal of Research in Economics and Social Sciences*, vol. 8, no. 1, pp. 163-175, Jan. 2018. Accessed on: Jul. 2, 2020. [Online]. Available: http://euroasiapub.org/wp-content/uploads/2018/02/15ESSJan-18-5992-1.pdf

[3] Department of Renewable Energy, Govt. of Haryana, *Guidelines for Installation of the Grid Connected Rooftop Solar Power Plant in the State*, Department of Renewable Energy, Govt. of Haryana, Jun., 2018. Accessed on: Jul. 10, 2020. [Online]. Available: http://www.dnreapplyonline.gov.in/displaydata/default/submenuofsubmenudata?pageid=1&parentid=4&subpageid=1

[4] Ministry of New and Renewable Energy, *Solar Energy: Overview*, Ministry of New and Renewable Energy, Government of India, Mar. 31, 2019. Accessed on: Jul. 10, 2020. [Online]. Available: https://mnre.gov.in/solar/current-status/

[5] NTPC Vidut Vyapar Nigam Limited, *Jawaharlal Nehru National Solar Mission*, NTPC Vidut Vyapar Nigam Limited, 2018. Accessed on: Jul. 10, 2020. [Online]. Available: http://nvvn.co.in/Introduction.php

[6] Ministry of Power, *Power Sector at a Glance: All India*, Ministry of Power, Government of India, Aug. 13, 2020. Accessed on: Jul. 10, 2020. [Online]. Available: https://powermin.nic.in/en/content/power-sector-glance-all-india

[7] Ministry of New and Renewable Energy, *Approximate Cost and Subsidy*, Ministry of New and Renewable Energy, 2020. Accessed on: Jul. 12, 2020. [Online]. Available: http://www.dnreapplyonline.gov.in/displaydata/default/submenuofsubmenudata?pageid=50&parentid=8&subpageid=18

[8] M. V. Ramana, *Rural Energy Alternatives in India*, Woodrow Wilson School of Public and International Affairs, Feb. 2014. Accessed on: Jul. 15, 2020. [Online]. Available: https://spia.princeton.edu/sites/default/files/content/591f%20Rural%20Energy%20Alternatives%20in%20India.pdf

[9] M. Kolhe, S. Kolhe, and J. C. Joshi, “Economic viability of stand-alone solar photovoltaic system in comparison with diesel-powered system for India,” *Energy Economics*, vol. 24, no. 2, pp. 155–165, Mar. 2002. Accessed on Jul. 15, 2020. [Online]. Available: doi: 10.1016/S0140-9883(01)00095-0

[10] IRENA (2020), Renewable Power Generation Costs in 2019, International Renewable Energy Agency, Abu Dhabi. Accessed on: Jul. 17, 2020. [Online]. Available: https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019

[11] A. Khurana, V.V. R. Kumar, M. Sidhpuria, “A Study on the Adoption of Electric Vehicles in India: The Mediating Role of Attitude,” *Vision: The Journal of Business Perspective,* vol. 24, no. 1, pp. 23-24, Mar 2020. Accessed on: Jul. 25, 2020. [Online]. Available: doi: 10.1177%2F0972262919875548

[12] S. Enckhardt, *A second life for disused modules and EV batteries,* PV Magazine, Mar. 2020. Accessed on: Jul. 28, 2020. [Online]. Available: https://www.pv-magazine.com/2020/03/19/a-second-life-for-disused-modules-and-ev-batteries/