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Solar Panels - Design, Implementation and Impacts on Rural Learning Centers

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Abstract

Sustainability is a growing field in the world currently and is a promising solution to protect the future of our earth. The falling costs of renewable energy make it pave the way forward for decarbonisation and economic and social benefits.

I am currently in my last year of high school at Dubai College and am aspiring to pursue Engineering in University, with a keen interest in Solar Energy. This paper presents my learnings from my three-week internship at The SELCO Foundation, India through an exploration of solar energy, and will look at solar panels specifically, their components, the different types of systems, and how energy is generated. The primary purpose of this paper is to study the impacts of solar energy in a broader context by exploring the process of its implementation into an area and consequential impacts it had, through a case study. This particular case study deals with 'The Smart Anganwadi Program' implemented by a company called The SELCO Foundation (who provide need-based solar solutions to rural areas). It will begin by going through the basics of a solar system and its components, how the components are sized and furthermore, the calculations required to create a solar system for a specific area. It will then focus on the case study and the program implementations of solar panels in specific learning centers in India, and further will include an analysis of the solar solutions provided and suggest possible future improvisations.

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Introduction

This project will look at the design, implementation and impacts of solar panels in rural learning centers called Anganwadis, evaluate and further conclude whether the implementation of solar technology can benefit these centers. Anganwadis are rural child care and learning centers that are easily affordable and accessible and are found all throughout India, especially in rural locations. These centers provide many services including food and nutrition and pre-school education. Anganwadi workers supervise the children and parents here, and their jobs include having to conduct weekly surveys of all families as checkups, organize pre-school activities for the children, educate parents about child growth and development, identify disabilities in children, and so on. There will also be one Anganwadi leader who will take surveys to see who the program is benefiting and if any improvements can be made to the existing Anganwadis.

Each Anganwadi contains different facilities, designed according to the specific location and the requirements of the people in that area as well. The SELCO Foundation specifically targets rural areas in which either there is a lack of access to the grid electricity, or the people living in the area cannot afford it. The main issue with these areas is based around the fact that the government is not willing to loan money to fund for electricity or technology because there is a stigma around the idea that “the poor don’t repay” as mentioned by one of the town-folk in one of SELCO’s project videos. In some of these rural areas, The SELCO Foundation has implemented solar systems, digital education programs charged by solar, integrated energy centers and more.

The particular project I was studying was called the 'Smart Anganwadi Pilot Program’ which provides sustainable energy access through the introduction of solar powered fans, lights and educational tablets. The reason behind the implementation of this program is that the government-run Anganwadis are facing a massive drop in enrollment due to a lack of suitable facilities, technology and educational materials. The benefits of the program are suggested to address all these issues by providing a more enriching educational program and better technology (like the tablets), and thus a better quality of education. The program also gives an incentive for people to send their children to school, hence increasing enrollment and increasing the retention rate. It is also an ideal way of spreading awareness of solar technology, which encourages the children and parents to make a sustainable change for their future.

I. Methodology

To understand the impact that Solar Technology has, it is first essential to understand the technology itself and look at how a solar system is designed for a specific area or load. I will start by looking at the panel principles, and then move on to looking at its components, how the components are sized and lastly perform calculations of my own for a Model Anganwadi Classroom and Play-school. Using this knowledge, I will analyze the existing systems implemented in the Anganwadis and suggest ways to improve on what has been implemented. All dated collected here has been secondary data apart from the excel sheet of calculations done by me.

Solar Panel Principles

A solar panel is comprised of many smaller units called photovoltaic (PV) cells. Photovoltaic cells are devices that allow for the direct conversion of light into electricity. Each cell is composed of two layers of semi-conducting material - usually silicon (making up roughly 90% of solar modules today). A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. The N-type layer has a negative charge because phosphorus adds extra electrons, creating a negative charge, while the P-type layer has a positive charge due to the addition of boron, which has fewer electrons. Due to the potential difference, an electrical field is created near the top surface of the cell where these two materials are in contact (this is called the P-N junction).

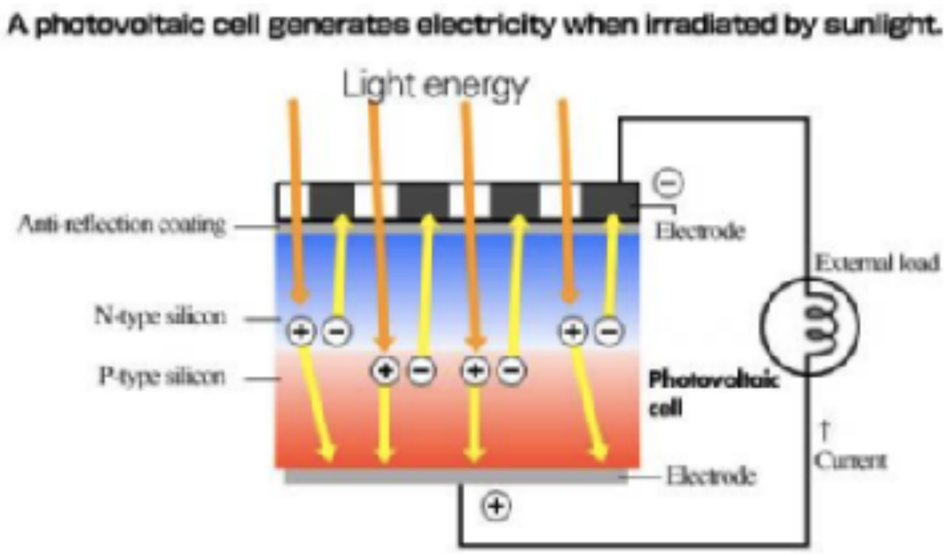

Figure 1: Basic Solar Cell Structure

When photons of light (light energy) hit the panel, they knock electrons free from atoms, and the electric field between the layers pushes the electrons along, causing a flow of current, producing electricity. The current generated here usually travels to charge a battery, which is then used to power appliances and load.

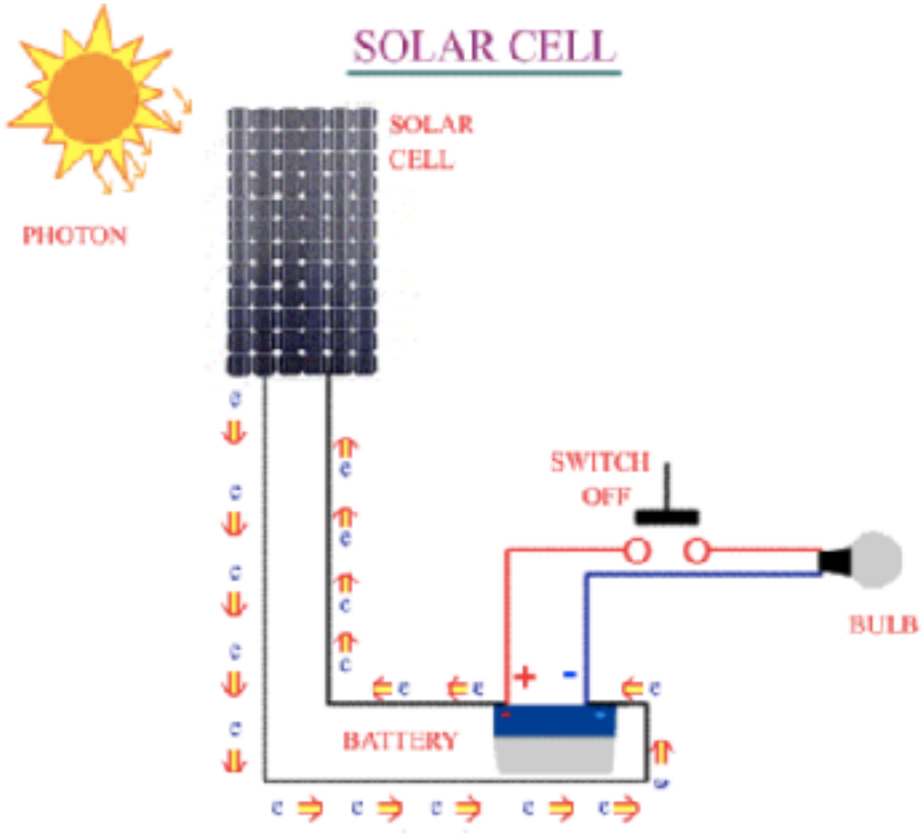

Figure 1: A typical solar cell circuit

Types of Systems and their components

There are two main types of systems: an AC (alternating current) system and a DC (direct current) system. Direct current electricity is the electricity produced by the solar panels and what is stored in the battery. However, alternating current electricity is the electricity used in the grid and in most households. Both systems have many of the same components, including:

1. Solar Panels - as discussed, used to convert light into the electricity used
2. Charge Controllers - This regulates the power flow from solar panels to batteries, and from the batteries to the load. When excess electricity is being generated, it stores it in

the battery, and controls how much is given out at night from the battery (when no electricity is being created from the solar panels. It also prevents overcharging and helps optimize the charging process.

3. <u>Battery</u> - This acts as a store of energy. When energy is converted from light to electrical, not all is used, some is stored to be used at night in the battery.

The only difference between the two systems is that the AC system also includes an inverter that converts DC current into AC current for the grid, or for households as most home appliances require AC instead of DC. DC systems also sometimes have a DC-DC converter, which either steps up a lower system voltage to a higher load voltage or steps down a voltage from high to low.

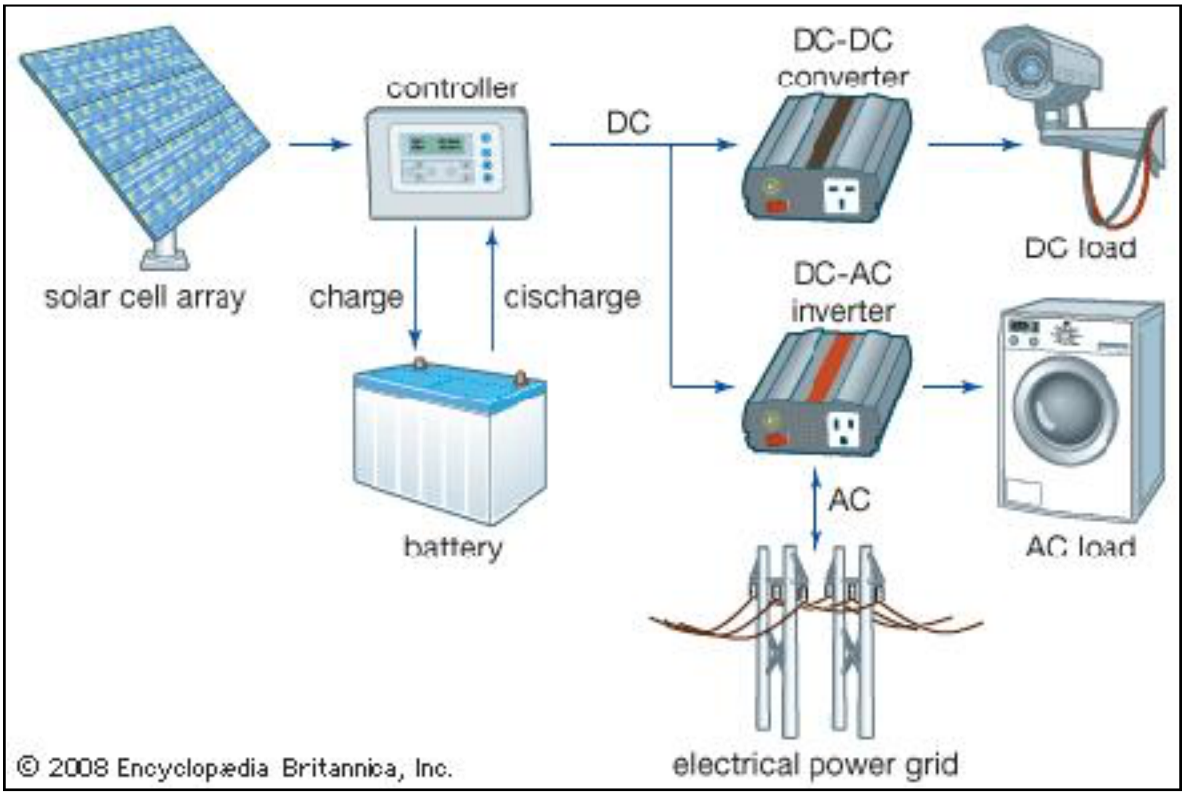

Figure 3: Typical solar power system diagram

The I-V Curve

Before going on to do the calculations, it is important to look at the I-V curve to understand what is meant by most terms given on a PV module specifications sheet. A typical sheet looks like the one presented in Figure 4, and provides information to be used when creating the solar system model.

Electrical Data at 1000 W/m², 25 °C and AM 1.5 (STC in Accordance with EN 60904-3)		
rated power at STC [1]	125 Wp	150 Wp
module efficiency at STC [2]	13.3%	11.3 %
open-circuit voltage V_{oc}	43.20 V	43.42 V
short-circuit current I_{sc}	3.73 A	4.48 A
rated voltage V_{mpp}	35.64 V	35.82 V
rated current I_{mpp}	3.55 A	4.26 A

[1] The measurement tolerance of the rated power is ± 3%.
[2] At low irradiance (200 W/m², 25°C and AM 1.5) the module yields at least 97% of the STC efficiency.

Electrical Data at 800 W/m², NOCT, 1m/s Wind Speed and AM 1.5		
rated power P_{max}	101.3 W	121.5 W
open-circuit voltage V_{oc}	42.79 V	43.01 V
short-circuit current I_{sc}	3.00 A	3.60 A
rated voltage V_{mpp}	35.77 V	35.95 V
rated current I_{mpp}	2.86 A	3.44 A

Figure 4: PV Module specification sheet for 125Wp and 150Wp panels

When looking at the specifications sheet, you will realize that the PV modules are rated with two different voltage values:

1. Open Circuit Voltage (Voc) - occurs when there isn't any load connected to the modules and current isn't flowing. This can be seen from the graph in Figure 5, as at this point of Voc, the current is zero. Therefore, at this point, no power is being generated
2. Max power voltage (Vmp) - is the amount of voltage produced by module that corresponds to the max amount of power for that module. As you can see from the graph in Figure 5, the Vmp is at the point where the power is at the maximum, at the turning point of the P-V curve.

Pv modules are also rated with two different current values:

1. Short circuit current (Isc) - occurs in a scenario where positive and negative terminals from PV module are in direct contact. This value is rarely taken into account.

2. Max power current value (Imp) - is the amount of current produced by module that corresponds to max amount of power for that module. On the graph, this is directly under the turning point of the P-V curve, right on the I-V curve.

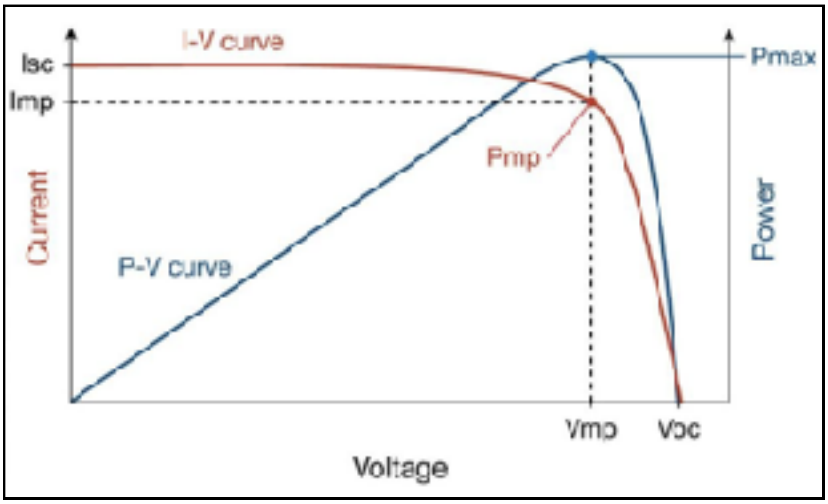

Figure 5: The I-V curve

The product of the maximum power voltage and maximum power current (Vmp × Imp) results in the maximum power value in watts. This is the point on the graph where the point is labelled Pmp. Differentiating between the different currents, voltages and values are important when performing calculations; the Voc and Isc shouldn’t be taken into consideration for designing a working system as these suggest values for when the system isn’t working normally.

Design - Component Sizing

All formulas used in the component sizing were given to me by SELCO as these are what they use for their designing.

Before sizing any component, the total load, for which you’re creating the system, must be determined in watt-hours (Wh). In order to do this you must:

1. Record each different type of appliance part of the load the solar system is being designed for, and its given wattage.
2. Record the amount of each appliance.
3. Record the amount of hours the appliance will run for.

4. Multiply the given wattage of each appliance by the amount of each appliance and the amount of hours each appliance will run for to get the load of each appliance (in watts-hours / Wh)
5. Add the loads of each appliance together to get the total load of the system in watt-hours.

1. <u>Panel Sizing</u>

Panel sizing involves determining the panel wattage required for a particular load, as well as determining how many panels are required to be put in series and in parallel. The steps to calculate panel sizing are as follows:

1. Calculating the maximum daily load:

The total load in watt-hours has already been calculated above, which is then divided by

Maximum Daily Load = (Total load in watt-hours/(load efficiency x system voltage) **Ah**

the product of the load efficiency and system voltage to give a reading with the units Ampere-hours.

Load efficiency in this case means how efficiently the load will use up the electricity provided to it, and the system voltage is the actual measurable voltage present in the circuit (this, in normal systems, is usually either 12V or 24V).

2. Calculating the total current required:

Sunshine hours represents the amount of hours during which direct solar intensity exceeds

Total Current Required = (Maximum daily load/(sunshine hours x charging efficiency x dust factor)) **A**

a threshold value of 120 W/m². This is measured and calculated for each region on earth, so the value for the region you're in is easily accessible online. Charging efficiency is is the ratio of the energy you can take out of a battery divided by the energy you put in. This value is usually less than 1 as some energy is lost to the surroundings as heat energy. The lithium batteries we are dealing with usually having a charging efficiency of 0.8, which is the value used here. Dust factor is the amount of dust taken into consideration that lands on the panels, this isn't always accurate so it isn't always 100%, its usually 95% (we take the value 0.95 for the equation).

3. **Calculating the total panel wattage required:**

Total Panel Wattage Required = (Total current required x system voltage x (real panel voltage / input panel voltage)) **Wp**

The system voltage taken in this case is ideally 12V (24V is not as common). Real panel voltage is given to you with the panels, as a rating of a certain amount of volts. The input voltage is usually taken as the same as the system voltage, so in most cases 12V.

4. **Number of modules in series required:**

Series module = System Voltage / Input panel voltage

5. **Number of modules in parallel required:**

Parallel module = Panel Wattage required / (series modules x panel wattage)

2. Battery Sizing

1. **Calculating the battery capacity required:**

Battery capacity required = (Days of autonomy x maximum daily load) / (depth of discharge x discharging efficiency)

The days of autonomy is the length of time which a battery bank can support a specific load without overcharging. For DC systems, it is 3 days, and for AC systems, it is 2 days. The depth of discharge is expressed in % is the safe level (specified by the manufacturer) to which battery could be discharged beyond which the battery might be damaged permanently, the maximum value taken here is 80% (0.8). The discharging efficiency is the discharging ampere hours divided by the charging ampere hours, which is usually a value of 0.85.

2. Number of batteries in series required:

Series batteries = System Voltage / Input voltage

3. Number of batteries in parallel required:

Parallel batteries = Battery capacity required / Solar battery Ah

The different capacity solar batteries can be found online, and when choosing one, you will be looking at the one that is nearest to the battery capacity required that you have calculated.

3. Charge regulator Sizing

1. Rated current for panel used with allowance:

Rated current for panel (with allowance) = (Rated current x 1.25) **A**

The panel watt-peak used has been calculated in the panel design and using this value you can find specifications for that panel of that size, which will have the rated current value given. There is a 25% tolerance given, from SELCO, which why the current is multiplied by 1.25.

2. Current from charge controller to load:

Current from charge controller to load (with allowance) = ((Total wattage / system voltage) x 1.25)**A**

Total wattage is the sum of the wattages of all the types of appliances part of the load. This is then divided by the system voltage and multiplied by 1.25 to allow 25% tolerance.

3. Charge regulator required:

Both values from step 1 and 2 are taken into consideration, and the greater one of the two is always looked at. The charge regulator has to be of a value equal to, or greater than, that value.

4. Inverter Sizing (only for AC system)

1. Finding the power factor for each appliance in the system

Most electronic devices have a power factor of 0.9, while others have a power factor of 0.8, but these can also be determined by looking at the specifications of the appliance you have.

2. Finding the Volt-amperes (VA) of each appliance

Volt-ampere of an appliance = Wattage of appliance / power factor of appliance

3. Finding the resultant VA

Resultant VA = sum of VA's of all appliances

Once you get the resultant VA, you find the related inverter size with a VA equal to, or greater than, the resultant VA you have calculated.

Model Anganwadi Calculations

After doing some research, I gathered information on what a Model Anganwadi Classroom would contain, and what a model Anganwadi play-school would include. Along with this information, I devised photovoltaic systems, using the formulas above, for both areas.

1. DC System - Model Anganwadi Classroom
   - Load details:
     - 10W LED tube light X 1 for 4 hours
     - 14 W Wall mounted fan X 1 for 4 hours
     - 10 W Tablet X 2 for 3 hours
     - 41 W 32" LED TV X 1 for 1 hour

2. AC System - Model Anganwadi Playschool
   - Load details:
     - 10 W LED tube light X 2 for 3 hour
     - 75 W Ceiling fan X 1 for 4 hours
     - 41 W 32" LED TV X 1 for 2 hour
     - 5 W Mobile Charger x 2 for 3 hours

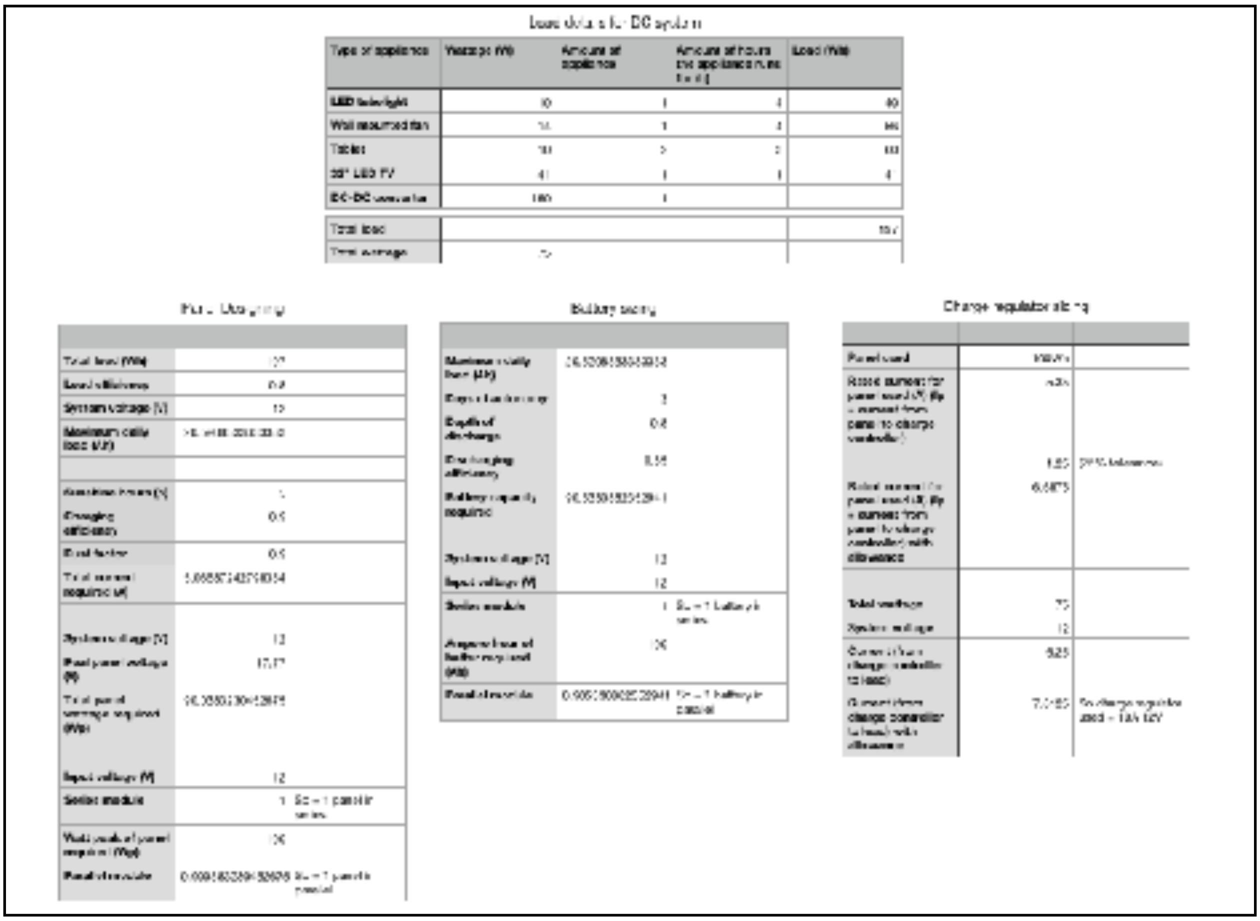

Figure 6: DC system Classroom - 100Wp panel with a 100Ah battery and a charge regulator of 10A 12V required

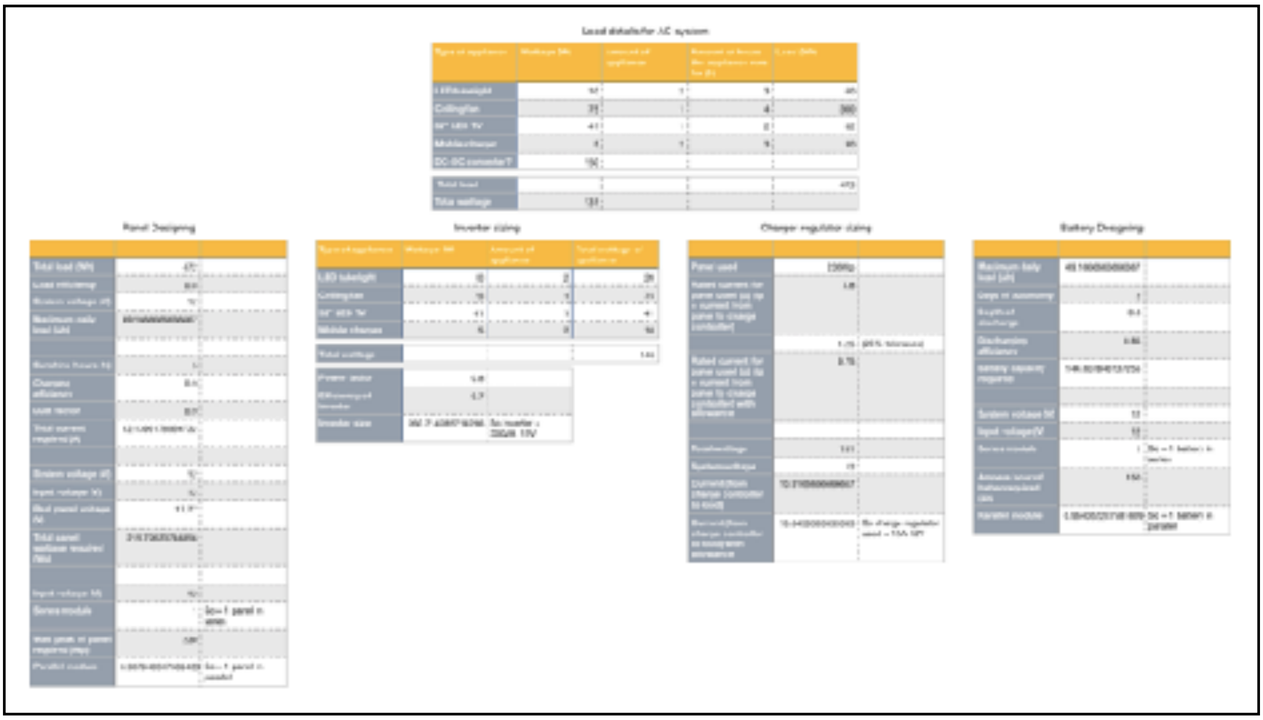

Figure 7: AC system Play-school - 230 Wp panel with a 150Ah battery, a charge regulator of 15A 12V and an inverter of 300VA 12V

II. Case Study

The Smart Anganwadi project has already begun its implementation in several areas throughout India, but the chosen case study looks into the implementation and impacts of the system in Mangalore and Puttur in Karnataka.

Before its implementation, it was essential to understand why the people were sending their children to the Anganwadis, to correctly understand their needs and thus build a system around it. Therefore, I carried out a survey for the families living around the Anganwadi center asking them their reason for sending their children in. From my research, there were 4 main reasons:

1. The families could not afford midday meals, and the Anganwadis provided these.
2. The families could not afford clean water, which the Anganwadi provided, although it was in short supply.
3. The parents could not afford to give the children a quality education, and the Anganwadi provided the children with the same.
4. The parents wanted the children to get familiarized with digital technology which only the Anganwadi had access to, thus paving their way to jobs in the future.

- To summarize, a model Anganwadi should facilitate a **learning**, **nurturing** and **stimulating** environment for children.

Next, I conducted research as to why Solar was being implemented, or what were the benefits to it being implemented. For this research, I had to consult not only the people, but also the Anganawadi leaders, as well as SELCO workers, and found the main reasons behind the need for implementation were:

1. Some Anganwadis are in rural areas and don't have access to the grid electricity but still need it.
    - Power cuts can also be a problem
2. Although having access to the grid, some families couldn't afford it.
    - Initially, the cost of the panels may be a lot more than paying for grid electricity, so thus It seems like a more expensive option. However, in the long run, it is

the cheaper option as it is only the initial cost of implementation that is high, after that there aren't many expenses for it.

3. Spreading awareness - thinking sustainably since a young age, more likely to continue doing so as they grow up

Implementation

To tend to the requirements of the people around the Anganwadis and in the rural areas, each of the learning centers a system has been implemented with the likes of a light, a ceiling fan, and two tablets. Using the formulas above, the final system design for the Anganwadis would be:

Option 1 : DC System for 2 Tabs (including TAB cost)

Sl.No.	Products	Capacity	Qty
1	Solar Module	18 Wp, 12 V	1
2	Solar Battery	20 Ah, 12 V	1
3	MMS	18 Wp, 1M	1
4	CR	10 A, 12 V	1
	DC-DC Converter - EMSYS	12 V - 5 Vdc	1
	Iball Slide 3G Q27 16GB WI-FI+4G Blue		2
5	Cables red+black	2.5 sq.mm.	30
6	Consumables		1

Figure 8: System design for Anganwadis with a light, ceiling fan and two tablets

The Iball Slide 3G Q27 mentioned in Figure 8 under the products represents the name of the tablet being brought for the Anganwadis. As shown in figure 8, 2 of each tablet were bought for an individual Anganwadi.

Feedback from the Implementation

The feedback from the implementation has been highly positive. This includes:

- The new ‘Tab for Anganwadi’ programme has given a vast opportunity to develop our toddlers’ minds for optimal utilization of technology to develop favorable balance in behavior, motor and cognitive skills.
- The Tab is a great way to teach and learn, which was a common opinion among teachers and parents.
- The teachers believe it is the favorite of the toddlers as they give more attention towards graphical and sounds produced in different apps
- Use of the Tab has made it easy to control the kids, behavior and bring in more discipline.
- The retention rate has increased as more parents want to send their children to the Anganwadi centers for the tab learning

However, there was some criticism received, such as:

- Lots of teaching relies heavily on the tabs but not all the children can view the tab at the same time.
- Children were getting bored of repeatedly going on the same apps, there wasn’t enough choice for apps
- The tablets are easily dropped and can be damaged
- The people are happy with the fan but they feel the air quality still isn’t good
- There isn’t enough water, more water is required for the increasing amount of children

Suggestions for Improvements

Overall the feedback was highly positive in terms of the system implemented, but there were some minor issues, which have been stated below as criticisms. In order to improve the Anganwadi, the criticisms must be addressed and solutions must be thought of to tackle them. Doing some research, I was able to come up with a few solutions of my own that I believed could further improve the situation at the rural learning centers.

Light

Instead of putting in a light in the room, you could allow ample natural light into the room with a skylight.

- If being incorporated, it should be placed in the center to ensure every corner is lit
- The skylight could be made out of polycarbonate, a transparent material that is a cheaper substitute for glass (polycarbonate also allows light rays to diffuse, so will spread the light around the room more) (***costing $500/light).***

Taking out the light would be beneficial as the Anganwadis are only run during the daytime, so there will be ample daylight coming into the room if the skylight is implemented. It would also cut down on the costs of paying for the system with one less appliance, and the money could instead be used for investing in more educational apps to be used on the tablet.

Natural Ventilation

To make the air less polluted and cleaner for the students to ensure a safe learning environment, an air purifying paint could be used - such as Nippon odorless aircare (***costing $6.98/ litre***) - which absorbs all impurities in the air to convert it into fresher air for the students.

<u>Interactive environment</u>

A major problem was the fact that children weren't getting enough time on the tablet as not all of them could view the tablet at the same time because the screen was too small. To combat this problem, my personal suggestion was installing a projector (powered by solar, ***costing $1044/unit***), which could connect tabs or laptops and show what the teachers want to teach. This would have a much bigger screen, so more children could view it. The benefits of having a projector over a TV would be that it would be less expensive and take up less energy. However, it depends on the amount of light in the location. If there was too much, a TV might be more suitable.

Another issue was that the teachers at the Anganwadis were relying too heavily on the tab to teach the children, and this isn't ideal because too much time on the tablet might bore the children, or strain their eyes. My opinion to approach this problem would be to paint the walls with chalkboard paint, and use chalk to write on them to teach the children. This would increase interaction between students and teachers, and allow for greater collaboration in the class to solve problems as everyone could view the boards and work together on them. The other walls could then be filled with children projects, pictures of alphabets, numbers, animals etc. as visual cues to help children learn faster.

<u>Water</u>

Water is a basic need for all the children as well as the teachers at the Anganwadis, and there should be plentiful supply to account for all of them. For water supply, I suggested using a solar powered water pump, which would collect dirty water, kill out any bacteria from it using a UV filter, and then transfer this clean water to the Anganwadis for the children and teachers to use - ***costing $1170/unit***.

III. Conclusions

Working at SELCO foundation provided me with an in-depth knowledge of the understanding of solar panels, how they work, how to design a system and even allowed me to study the impacts of their implementation on an area, thus enhancing my knowledge.

In my opinion, solar is hugely impacting the world, especially in rural areas where the Anganwadis are situated, allowing the underprivileged access to electricity ; thus improving their socio-economic conditions. The 'Smart Anganwadi' project seems to be imparting great positive and beneficial effects on the quality of the life of the children and the families of the villages, furthermore creating a safe, educational environment all based around clean energy. The implementation of digital technology and the awareness of solar technology given by the programme to the children is vital as both digital technology and sustainability are valuable for the future generations and for the Earth.

Inspired by the project, I will be striving to spread awareness about the initiatives The SELCO foundation undertook and create awareness about the impacts that solar energy has on the communities around us, thus inspiring people to undertake initiatives to implement solar around them and ensure a more sustainable environment.

I was gratified to embark on this journey with The Selco Foundation to not only learn the technical aspects of solar panels and their implementation, but the social, economical and environmental benefits they imparted.

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