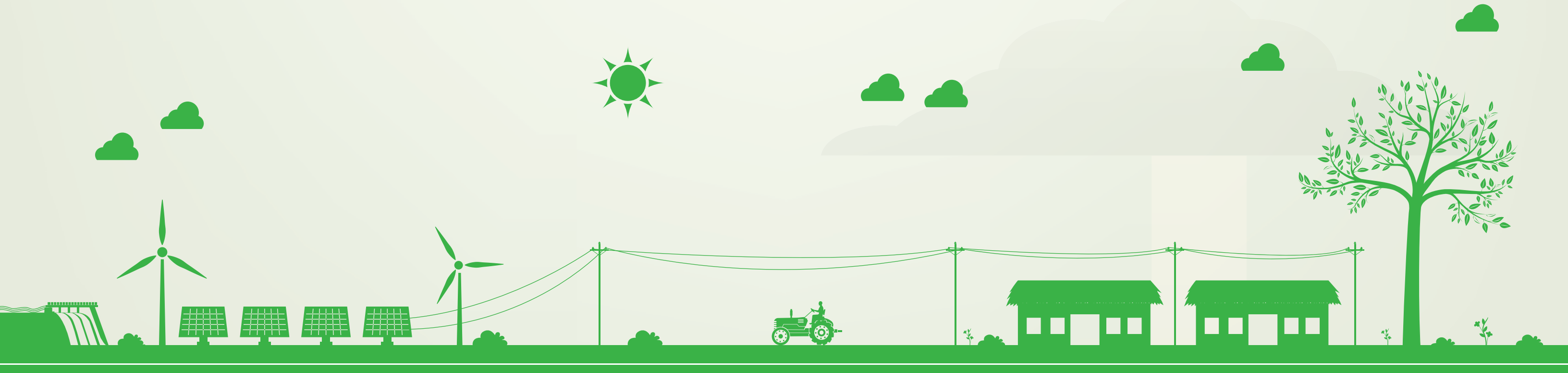
TRAINING MODULE:
ENABLING SERVICE ENTERPRISES WITH DRE FOR PRODUCTIVE USES

Module 2 – Technical



Supporting the Institutional Development of CLEAN

(Access to Energy in Rural Areas – IGEN – ACCESS)

Disclaimer

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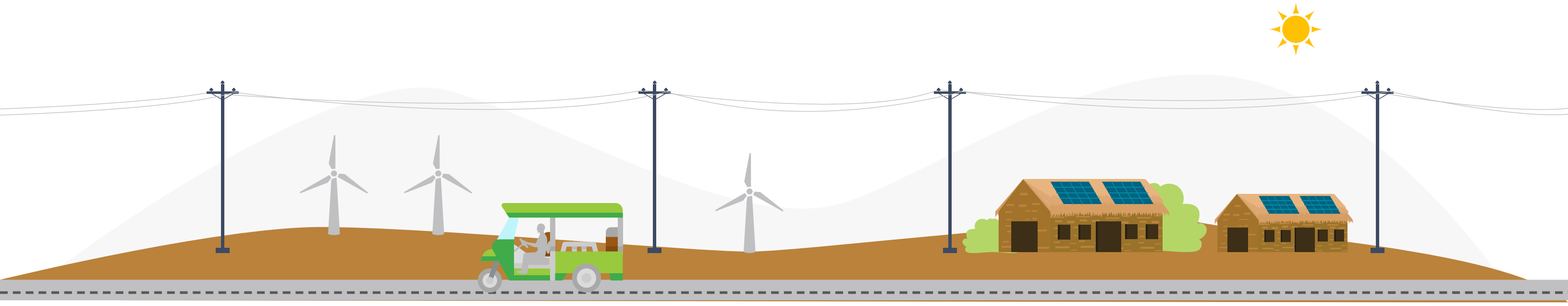
Contents



List of Abbreviations

AC	Alternating Current
CUF	Capacity Utilisation Factor
DC	Direct Current
DRE	Distributed Renewable Energy
EHV	Extra High Voltage
IPP	Independent Power Producer
IRR	Internal Rate of Return
kWhr	Kilo Watt Hour
LED	Light Emitting Diode
NGOs	Non-Government Organisations
NPV	Net Present Value
O&M	Operation & Maintenance
OPML	Oxford Policy Management
PSU	Power Supply Unit
RE	Renewable Energy
RO	Reverse Osmosis
SHGs	Self Help Groups

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ABOUT THE COURSE

1.1 | Setting the Context

1.1.1 What is a productive use?

A productive use can be defined as a routine economic activity undertaken in rural or urban areas to create and deliver a product or a service that has a commercial sale value to it. The goods or services are produced for the market, manufactured at a larger scale as compared to those meant for domestic consumption and sold for revenue generation and livelihood support.

There is a large variety of productive uses suitable for a rural setting, including supply of edible oil, woven fabric, tailored dress, bottled fruit pulp etc. Services include the provision of pumped water for irrigation, clean drinking water, grinding for flour and spices, carpentry, cold storage facility etc. Typically, mechanisation of these otherwise manual activities (powered sewing machines, weaving looms, motor driven grinders, hullers, oil expellers etc.) increases productivity, efficiency and output, boosting revenue earning capabilities of these rural enterprises.

1.1.1.1 Why engage in productive uses?

There are multiple drivers for engaging in productive uses. While the most obvious driver is for creating livelihood options in rural areas, engaging in productive uses also helps create electricity demand. Most of the productive uses require electricity supply to generate income, and these can be energised through Renewable Energy (RE) solutions, provided by the existing RE based mini-grid operators as well as by prospective mini-grid operators.

There can be an instance where an existing RE based mini-grid has a drop in demand serviced. Consequent to implementation of intensive electrification under government schemes such as *Saubhagya* or *Pradhan Mantri Sahaj Bijli Har Ghar Yojana Scheme*, domestic consumers may choose to move away from the mini-grid, as in most cases grid based electricity is cheaper. Introduction of RE based productive uses can be one of the effective ways to compensate for the loss of load and help these existing mini-grids to ensure commercial viability of the plant. Concomitantly, productive uses by rural enterprises also result in improved economic and social well-being of individuals and the community as a whole.

Apart from the impact on existing domestic consumers, there is a strong business case for the mini-grid operators, especially for those operating at low plant load factors, for promoting RE based productive uses. RE based rural enterprises can help such plants improve the load utilisation and also act as a driver for economic development. These rural enterprises can help create further demand in the area serviced by the mini-grid, developing a virtuous cycle of RE driven economic development.

[1] The grid supply may not be as reliable as that provided by the mini-grid; however, the decision to move to the grid is primarily driven by the favourable financials of the supply. Subsidies (direct and cross) provided for rural supply is one of the key contributing factors for cheap grid supply.

Similar cases have been seen on-ground, for instance, in case of mini-grids developed by Mlinda in remote areas of Jharkhand and West Bengal. The company has an objective of helping remote villages achieve an economic growth of 15% to 20% on a year-on-year basis by promoting RE based productive uses. It supports in developing sustainable business models for various RE based productive use based rural enterprises that can be serviced by the mini-grid. Mlinda has been identifying appropriate rural enterprises under its own initiatives or in collaboration with local rural entrepreneurs that ultimately help achieve better plant operating efficiency and financial viability. Mlinda has assisted entrepreneurs to set up oil expeller units, cold storage, grinding machines etc. that creates a win-win situation for the budding entrepreneurs and Mlinda itself as a mini-grid operator. This case illustrates the symbiotic relationship that can exist between the mini-grid operator and the rural enterprises that can be powered through mini-grid.

1.2 | Objective of the Training Manual

The objective of the training manual is to enable promotion of RE based productive uses in areas serviced by or expected to be serviced by mini-grids. The training manual captures all aspects of business planning and implementation that a mini-grid operator and/ or rural entrepreneur (referred collectively as ‘rural entrepreneur’ in the manual) need to be aware of while developing RE based productive use rural enterprise.

1.3 | Structure of the Training Manual

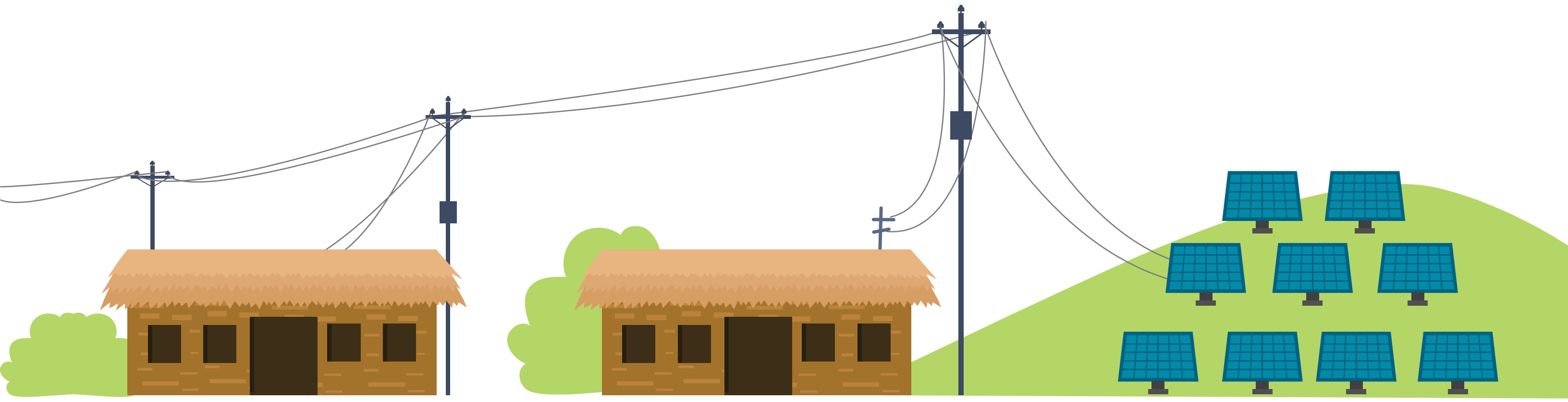
There are technical and non-technical aspects that the rural entrepreneur needs to be trained on for developing rural enterprises. These include technical aspects related to electricity and connectivity to the mini-grids and business related aspects such as developing a business plan and marketing plan, undertaking financial analysis and doing detailed market assessment etc. These are all diverse areas of work and require specialised skills to deliver on expected output. Given the diversity in the areas in which training is required, in order to improve delivery of the training and improve readability of the training manual, it has been structured in three separate modules.

1. **Module 1 – Market assessment and marketing:** The first module of the training manual focuses on the market related aspects of developing a rural enterprise and preparation of a business plan. This module discusses in detail the process of market assessment based on the which the most suitable rural enterprise can be selected/ prioritised. It also dwells into the basics of marketing and provides details for developing a marketing plan for the rural enterprise, along with developing market linkages and facilitating access to markets. Finally, the module provides the guidelines for writing a business plan for the rural enterprise.

2. **Module 2 - Technical:** The second module focuses on energy planning and technical aspects of integrating productive load into the mini-grid system. This covers areas such as productive load estimation, optimisation of load, load scheduling etc.

3. **Module 3 - Planning:** The third and final module focuses on planning aspects of developing the RE based rural enterprise. This module covers areas of financial planning. The financial aspects cover basics of finance, sources of funds and project planning. This module also touches up the various institutional structures that the rural enterprise can adopt for setting up the enterprise.

The current module focuses on Module 2. It focuses on the technical aspects of developing a RE mini-grid powered rural enterprise. The Module is most relevant for the mini-grid operator (existing and upcoming) and the technical experts of the rural enterprise. It touches upon the load estimation and integration of the rural enterprise with the existing load of the mini-grid and both of these can be optimised.



1.4 | Module Agenda

Following is the agenda covering the delivery of Module 2.

Training Day 2	
0930 to 1000 hours	**Setting the tone for the training programme** Interaction with Participants and debriefing on the proposed training programme
1000 to 1200 hours	**Session 5 (a): Module 2A: Technical Assessment: Energy Planning and Technical Aspects of DRE Powered Rural Enterprise** Coverage • Load profiling of the mini-grid and the identified productive load • Identify base load for the mini-grid with the revised load profile
1200 to 1215 hours	**Tea**
1215 to 1315 hours	**Session 5 (b): Module 2A: Technical Assessment: Energy Planning and Technical Aspects of DRE Powered Rural Enterprise** Coverage • Optimisation of load to be serviced by the mini-grid and the role of the productive use in optimisation • Introduction of the Optimisation Exercise
1315 to 1415 hours	**Lunch**
1415 to 1545 hours	**Session 5 (c): Module 2A: Technical Assessment: Energy Planning and Technical Aspects of DRE Powered Rural Enterprise** Coverage • Optimisation of load to be serviced by the mini-grid and the role of the productive use in optimisation • Completion of Optimisation Exercise and discussions
1545 to 1600 hours	**Tea**
1600 to 1715 hours	**Session 5 (d): Module 2A: Technical Assessment: Energy Planning and Technical Aspects of DRE Powered Rural Enterprise** Coverage • Technical Aspects of Mini-Grid implementation – DC Vs. AC mini-grids, DC appliance etc. • Live demos of DC equipment/ electric circuits[2]
1715 to 1730 hours	**Session 6: Summary of the Day and Quiz**

[2]Subject to availability of equipment on the site

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MODULE 2A

Energy Planning and Technical Aspects of Mini-Grid Implementation Module

2.1 | Course Overview

Course Title	Energy Planning and Technical Aspects of Mini-Grid Implementation Module
Objective	Detailed discussion on the technical aspects that need to be considered while developing Distributed Renewable Energy (DRE) based rural enterprise, where the electricity supply is provided by mini-grid operating in the same geography
Duration	5.75 hours (One day training programme)
Course Modules	• Load profiling of the mini-grid and the identified productive load • Optimisation of load to be serviced by the mini-grid and the role of the productive use in optimisation • Identify base load for the mini-grid with the revised load profile • Technical Aspects of Mini-Grid implementation - DC Vs. AC mini-grids, DC appliance etc.
Target Group	• Existing and possible mini-grid operators • Potential local entrepreneurs • Heads of Self Help Groups (SHGs), Non-Government Organisations (NGOs), local government units etc.
Minimum Entry Level	10th standard pass, ITI diploma/vocational training (desirable), with language skills to comprehend, read & write at basic levels
Employment Linkages	Mini-grid plants as operators, solar IPP plants as O&M service providers, RE productive use enterprises
Teaching/ Delivery Method	• In class lectures • Online documentaries covering interesting real applications • Small live demonstration of technical aspects of mini-grid functioning
Assessment Approach	• Interactive discussions on possible product or service enterprise options in respective areas
Facilities/ Tools Required	• Computer • Projector • Paper/pencils • Equipment for exposure discussions
Learning Outcomes: To make the mini-grid projects operate at full capacity to achieve full generation capacity of the plant.	

2.2 | Background

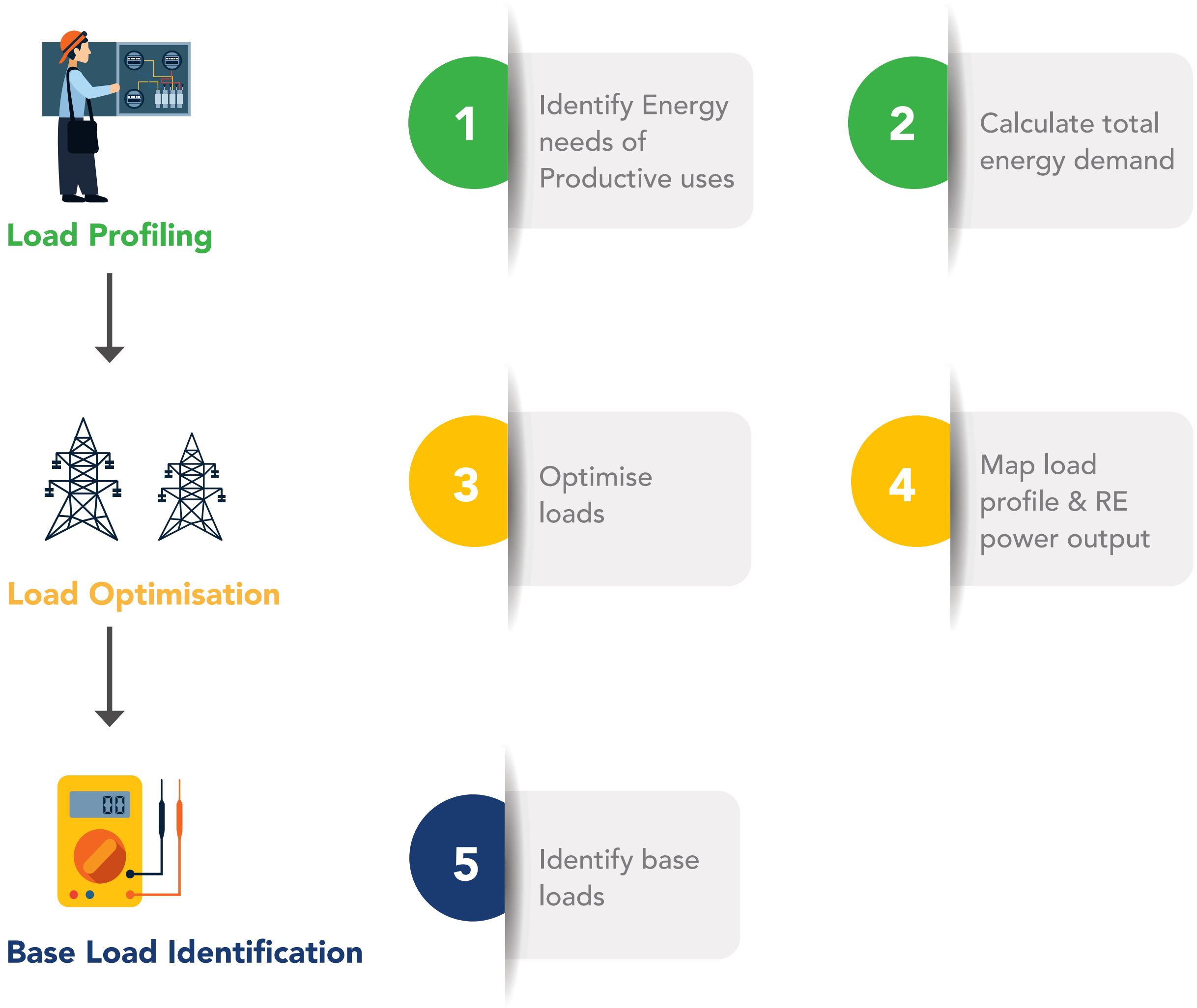
As mentioned in the previous section, this Module of the training manual focuses on technical aspects of including a rural enterprise in a mini-grid system. This module describes the step-by-step approach for energy planning for a DRE based rural enterprise. It is expected that the electricity supply for the rural enterprises will be provided by an existing mini-grid catering to the energy needs of households and commercial customers. Alternatively, there could be green field mini-grid projects planned and commissioned for meeting the power requirement of rural enterprises.

Understanding the technical aspects of integrating rural enterprises with mini-grids is the first step for developing DRE based productive, and this module dwells into in detail.

In order to serve existing household and commercial consumers and rural enterprises (such as oil expellers, cold storage, Reverse Osmosis (RO) water plant and rice mill etc.) energy planning is a key step. Energy planning involves three core steps: load profiling, load optimisation and base load identification.

Load profiling is the process of examining the variations in electric load over a defined period of time.[3] Load optimisation can be defined as the process of optimally scheduling different loads in order to maximise the demand serviced by the mini-grid. Base load identification is part of the load optimisation process, wherein base load can be defined as the minimum continuously available permanent load. The diagram below summarises the entire energy planning process.

Figure 1: Energy Planning process snapshot



Each of these processes is discussed in this module to help the mini-grid operator to integrate a rural enterprise into a mini-grid distribution system. The rural entrepreneur needs to understand this process as well because the electricity supply is one of the crucial inputs for operating the enterprise.

[3] Typically load profiling is done for a day, across seasons, weekdays and weekends spread over a year to capture the variation in load in a typical year.

2.3 | Load Profiling

2.3.1 | Step 1:

Identify energy needs of the probable productive uses

The aim of this step is to record the energy needs of various productive uses in standard units of energy (Kilo Watt Hour (kWh)) to arrive at the optimal generation for the mini-grid plant.

To capture this data a study is required to understand the energy needs of various productive uses within the defined geographic area that can be serviced by the mini-grid. The study includes the following steps:

- Estimate additional load on the system as rural enterprises are synchronised to the mini-grid
- Examine feasibility of scheduling the load from rural enterprises
- Estimate the additional infrastructure or equipment required to supply power to rural enterprises

It must be noted that the expected load from rural enterprises depends on the market demand for the outputs. Since RE generation is intermittent and there are seasonal variations in the supply, energy needs have to be captured across all the seasons, so that they can be suitably serviced.

2.3.2 | Step 2:

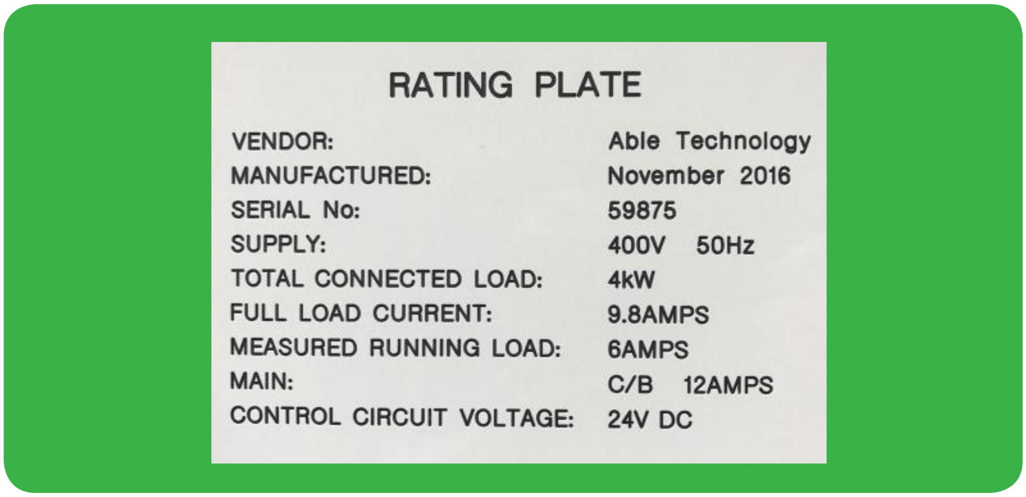
Calculate total energy demand of productive uses

The energy demand for each of the productive use can be calculated using the below formula:
Energy Demand (in kWhr)=(No.of equipments ×Wattage(in W)×Number of hours of usage in a day)÷1000

The Table below illustrates the above equation and subsequent aggregation of the load. For each of the productive use, the wattage of the machine and specific hours of usage in a day have been mapped. Based on this data, the daily demand for the respective productive use can be determined.

A mini-grid operator will need to map all the productive uses along with other consumers to examine the hourly demand it needs to service. Wattage of equipment can be explored from name plate (shown in figure below) on equipment or from manual provided with equipment.

Figure 2: Picture of a nameplate



Source: https://traffolytelabelcompany.co.uk/traffolyte-labels-2/

Example: Consider two oil expellers of 230 kW running for two hours a day. What is the energy demand?

Explanation:

Number of equipment = 2 | **Wattage = 230 kW** | **Number of hours in a day = 2**

Energy demand in kWhr = (No.of equipment ×Wattage(in W)×Number of hours of usage in a day)÷1000

= (2*230*2)/1000

= 0.920 kWhr

Table 1: Calculation of Energy Demand (Illustration)

					(F) Usage of Equipment – Time of day (Number of hours)																								
(A) Sl. No.	(B) Re-spondent	(C) Equip-ment	(D) Wattage (Watt)	(E) No. of Equip-ment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	(G) Total energy Demand (Energy consumption per day in kWh) G=(D*E*F) /1000
1	Kumar	Oil Ex-peller	230	2									Y						Y										0.92
2	Praveen	Grinder	300	3										Y	Y					Y									2.7
3	Ramesh	Oil Ex-peller	230	1												Y													0.23
4	Suresh	RO plant	320	2										Y							Y								1.28
5																													
6																													
7																													
8																													
9																													
Total			2230																										5.13

Exercise:

Consider the following productive demand addition:

Equipment	Number (A)	wattage (B)	Hours of use (C)	Total use (A*B*C)	In units (kWhr)
Oil Expeller	2	500	2	2000	2
Grinder	3	300	5	4500	4.5
RO plant	2	300	5	3000	3

Before the addition of productive demand, following is the generation-load scenario:

Hours (Time of day – 24 Hour Format) (A)	RE Power Output (B)	Existing Load (C)	Excess Generation(D)
0	0	0.5	-0.5
0100	0	0.5	-0.5
0200	0	0.5	-0.5
0300	0	0.5	-0.5
0400	0	0.5	-0.5
0500	0	0.5	-0.5
0600	3	0.5	2.5
0700	3	0.5	2.5
0800	3	1	2
0900	3	2	1
1000	4	2	2
1100	5	2	3
1200	5	2	3
1300	6	2	4
1400	6	2	4
1500	5	2	3
1600	4	2	2
1700	3	2	1
1800	1	2	-1
1900	0	3	-3
2000	0	3	-3
2100	0	4	-4
2200	0	1	-1
2300	0	0.5	-0.5
2400	0	0.5	-0.5

Comment on how you would prefer to add new load given that you have the flexibility to run these new productive load anytime of the day.

2.3.3 | Step 3:

Map load profile of existing consumers and productive uses load

The load profile of the productive uses obtained from the above study and the existing consumers for the three seasons needs to be mapped with the mini-grid generation. This is to ensure that the mini-grid can cater to the energy requirements of both the productive uses and the existing consumers through reliable supply over the entire year.

The figure below illustrates the mapping of the mini-grid supply and load profile to be serviced by the mini-grid for a typical summer day. A similar exercise will be required for all the days in a year to map the load against the DRE generation profile.

Figure 3: Illustration - Load profile of Productive uses and existing load mapped with RE Power output

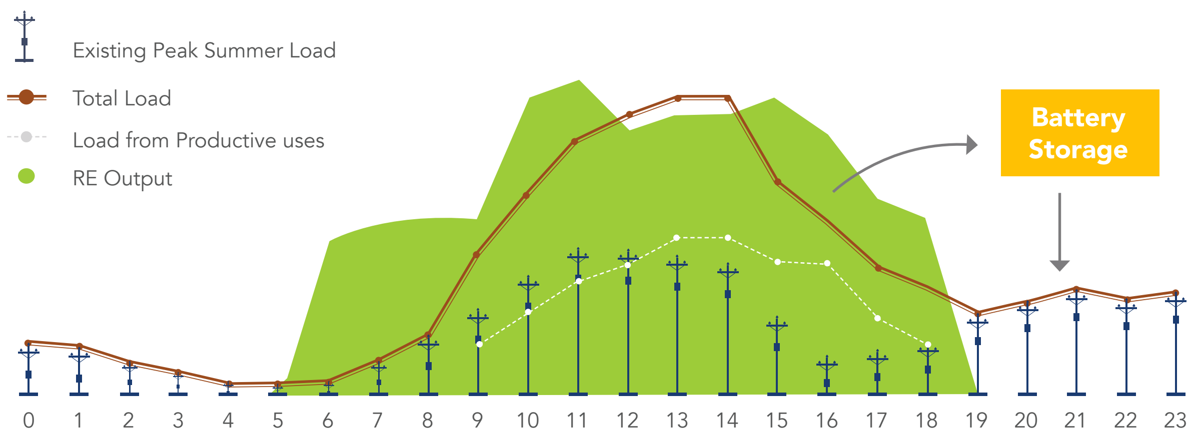


Table 2: Illustration Data values - Load profile and RE Power output in Kilo Watt (kW)

(A) Hours (Time of day – 24 Hour Format)	(B) RE Power Output	(C) Existing Load	(D) Load - Productive Uses	(E) Total Load (E = C+D)	(F) Excess Generation(F=B-E)
0000		20		20	-20
0100		18		18	-18
0200		12		12	-12
0300		8		8	-8
0400		3		3	-3
0500		4		4	-4
0600	59	5		5	54
0700	65	13		13	52
0800	67	23		23	44

0900	67	33	20	53	14
1000	111	45	30	75	36
1100	119	55	40	95	24
1200	99	55	50	105	-6
1300	106	53	60	113	-7
1400	106	50	60	110	-4
1500	112	30	50	80	32
1600	97	15	50	65	32
1700	74	17	30	47	27
1800	66	20	20	40	26
1900		30		30	-30
2000		35		35	-35
2100		40		40	-40
2200		35		35	-35
2300		39		39	-39
Total	**1148**	**658**	**410**	**1068**	
	CU Existing	**0.6**	**CU With Productive Use**	**0.9**	

In the above illustration, it is observed that the CU (capacity utilisation) improved from 0.6 to 0.9 after considering the load from productive uses. However, it is observed that the total load after considering the load from productive uses is greater than the mini-grid supply i.e., RE output between 1200 hours and 1400 hours.

CASE-I: CU existing = Existing load / Output = 658/1148 = 0.6

CASE –II: CU with productive use = Load/ output =1068/1148=0.9

Higher CU means better utilisation of solar power plant leading and higher efficiency of operation. Higher power sale will lead to improved profitability of the plant.

Daily generation from a solar power plant follows the movement of the sun. In the day, generation peaks in afternoon, giving maximum output and then reduces by the evening. However, load has to be catered in the evenings. In that case, extra generation during the day is used to charge the battery[4] to be utilised later in the evening and during low generation time periods. The mini-grid operator can overcome this limitation/situation by deliberately scheduling the load from productive uses in those hours where the load from the existing consumers is close to base load. This is elaborated in the next section on load optimisation.

[4]Concept of battery is discussed separately in the following section

2.4 | Optimisation of Loads

Most of the equipment for productive uses is run for just a few hours during the day. For the DRE mini-grid, these productive uses are additional loads that need to be serviced along with its existing loads such as household lighting or irrigation. Servicing of these additional loads should not impact the services provided to the existing consumers. Hence, it is assumed that productive uses will be energised by the mini-grids during the hours where it has surplus energy, after servicing the existing consumers.

In case of mini-grids with underutilised capacity, servicing additional productive loads can help improve the CUF[5] of the mini-grid and hence its financial viability.

2.4.1 | Step 3:

Optimisation of loads – Guidelines

Following are the guidelines that the mini-grid operator and the rural entrepreneur need to be aware of for optimisation of loads. These guidelines will also be helpful in determining the preferred productive use in cases where there are multiple uses that are being considered.

- Period of use and flexibility in timing: Productive uses have flexible loads in terms of timing i.e. they can operate anytime of the day or night. For instance, RO can filter the water any time of the day and similar is the case for an oil expeller. This gives the mini-grid operator flexibility in scheduling these productive loads, without compromising on the reliability of supply of the mini-grid to the existing consumers.

- No-load windows[6]: For servicing these additional loads, the mini-grid operator needs to identify supply windows where there is a surplus in the mini-grid. This implies identify windows of supply where existing demand is less than the supply or there is no demand. Such time periods are called no-load windows. Supply to productive loads during such time will ensure that the energy service to existing consumers is maintained.

- Connected load and Load Splitting: An important parameter for prioritising adoption of a productive use is the amount of connected load that the rural enterprise will require. The mini-grid needs to have the spare capacity in order to provide the connected load to the productive use. Also, in case of multiple rural entrepreneurs of the productive use, the simultaneous nature of demand also needs to be examined. This will help in understanding the flexibility that the mini-grid operator will have in scheduling the demand. For instance, in case of RO plants, the demand from the productive use is flexible, and if there are multiple plants, each plant could be scheduled to work at different hours to help the mini-grid operator manage its load better.

[5]The ratio of average power load of an electric power plant to its rated capacity

[6]No load windows are those timings of the day (or night) when there is no load or the total load is less than the maximum load at any other time of the day.

2.4.2 | Step 4:

Map load profile and DRE power output

Electricity demand and DRE generation both vary with season. In summers, maximum load comes from space condition and cooling equipment such as fans, coolers and refrigerators. In winters, the heating load is dominant. In small industries and commercial establishments as well demand fluctuates with season; for instance, cold storage will have high demand in summer and rice mills will have high demand just after harvesting season. On generation front, plant will generate higher electricity on non- cloudy days as compared to cloudy days. After quantifying the load and identifying the time slots in which the productive use can be scheduled, the total load profile of the productive uses and the existing consumers for the three seasons needs to be mapped with the mini-grid generation. This is to ensure that the mini-grid can cater to the energy requirements of the productive uses and the existing consumers through reliable supply over the entire year.

The figure below illustrates, mapping of the mini-grid supply and load profile to be serviced by the mini-grid for a typical summer day after deliberately scheduling the load from productive uses. The excess generation after meeting the load from the existing consumers and load from the productive uses is utilised to charge the battery.

In the illustration below, it can be observed that the load from productive uses is deliberately scheduled between 0700 hours and 0900 hours; 1500 hours to 1800 hours; where there is surplus generation after catering to the load from existing consumers and battery charging.

Figure 4: Illustration – After Load scheduling - Load profile of Productive uses and existing load mapped with RE Power output

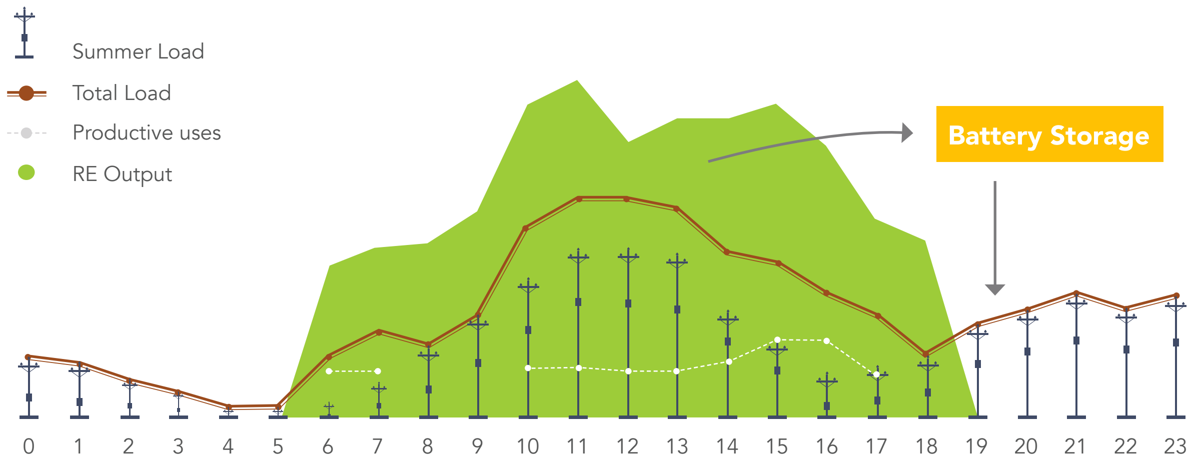


Table 3: Illustration Data values - Load profile and RE Power output in Kilo Watt (kW)

(A) Hours (Time of day – 24 Hour Format)	(B) RE Power Output	(C) Existing Load	(D) Load - Productive Uses	(E) Total Load (E = C+D)	(F) Excess Generation(F=B-E)
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0100		18		18	-18
0200		12		12	-12
0300		8		8	-8
0400		3		3	-3
0500		4		4	-4
0600	59	5		5	54
0700	65	13	30	43	22
0800	67	23	25	48	19
0900	67	33	25	58	12
1000	111	45	30	75	36
1100	119	55	40	95	24
1200	99	55	30	85	14
1300	106	53	30	83	23
1400	106	50	30	80	26
1500	112	30	60	90	22
1600	97	15	70	85	12

1700	74	17	40	57	17
1800	66	20		20	46
1900		30		30	0 -30
2000		35		35	-35
2100		40		40	-40
2200		35		35	-35
2300		39		39	-39
Total	1148	658	410	1068	
	Plant Load Factor Existing	0.6	Plant Load Factor With Productive Use	0.9	

Please note: Plant load factor = Cumulative Load/ Cumulative Generation

In case the total load of the productive uses and the existing consumers is greater than the capacity of the mini-grid plant, and the energy demand is large enough to achieve a good plant load factor, the commercial viability of additional capacity must be examined.

Apart from solar, mini-grids can also be powered by micro-hydro projects. An analysis of a database of more than 2100 mini-grids existing in India, reveals that more than 80% of these mini-grids are solar based.[7] The second preferred resource for powering mini-grids is micro hydro (11% of the mini-grids in India are micro hydro based). Details about micro-hydro technology are discussed in the Box below.

Box 1 | Details about micro-hydro based mini-grid

As compared to solar, small hydro is site specific, but there are locations, especially in mountainous areas, where small hydro can be a preferred choice for powering mini-grids. Within the small hydro projects, there is a classification of projects as defined by the Ministry of New and Renewable Energy, Government of India (table below) based on the installed capacity.

Table 4: Classification of Hydro Plants

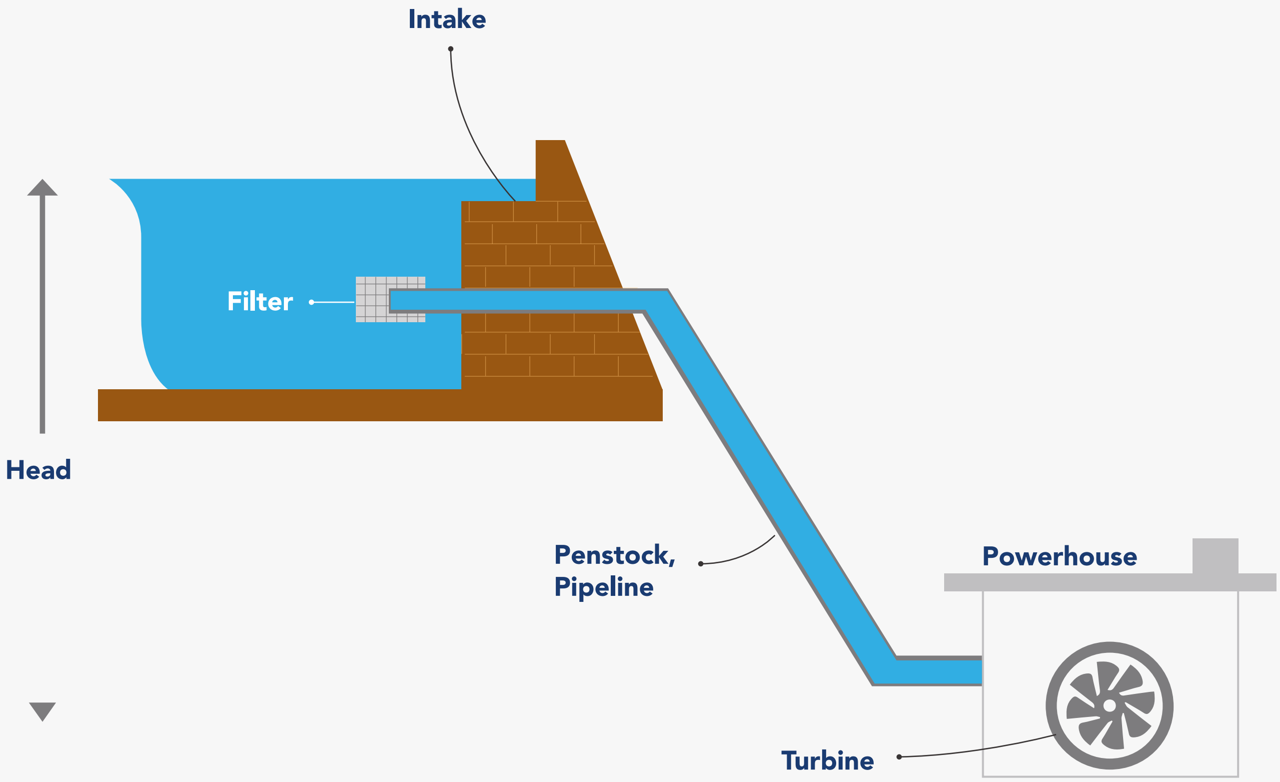
Large	All installations with an installed capacity of more than 25000 kW.
Small	All installations in the range between 2001 to 25000 kW.
Mini	Capacity between 101 to 2000 kW
Micro	Hydropower installations with a power output in between 1- 10 kW

[7]GIZ mini-grid database, February 2018

How is Hydro Electricity Generated?

Most hydroelectric power comes from the potential energy of dammed water driving a water turbine and generator. In this case, the energy extracted from the water depends on the volume and on the difference in height between the source and the water's outflow. This height difference is called the head. The amount of potential energy in water is proportional to the head. To obtain a very high head, water for a hydraulic turbine may be run through a large pipe called a penstock, see figure below.

Figure 5: Hydroelectric Power Generation Diagram.



Hydro System Components

1. **Water Diversion (Intake):** The intake is typically the highest point of a hydro system, where water is diverted from the stream into the pipeline that feeds the turbine. A water diversion system serves two purposes: provide a pool of water to create an air- free inlet to the pipeline, and remove dirt and debris

2. **Pipeline (Penstock):** The pipeline, or penstock, not only moves the water to the turbine, but is also the enclosure that creates head pressure as the vertical drop increases. The pipeline focuses all the water power at the bottom of the pipe, where the turbine is. In contrast, an open stream dissipates the energy as the water travels downhill. One or more bypass valves may be necessary. These should be installed at low points in the pipe to help get the flow going and to flush out air bubbles.

3. **Turbines:** Water turbines generate reliable power with simple designs. A runner or propeller is attached to a shaft that operates an alternator to generate power when water turns the runner. There are many types of turbines including two major styles: impulse turbines and reaction turbines. Each of these turbines is suitable for different types of water flows, as discussed below:

   a. Impulse Turbine: These turbines are most suited for high head[8] and low flow[9] locations. A narrow water jet impulse the blades of the turbine creating a momentum. A system using an impulse turbine drives the water into a pipeline. This pipeline leads the water to a nozzle, where the kinetic energy[10] of the water is used to push or impulse the blades coupled to an alternator.

   b. Reaction Turbine: Reaction turbines are most suited for low head and high flow sites. There are no nozzles in reaction turbine instead blades are projected radially, which forms the shape of nozzle.

   Efficiency of reaction turbine is higher than impulse turbine and has slower operating speed. However, reaction turbines require a greater flow to operate. Depending on the conditions at the site, the most suited turbine can be installed.

4. **Drive System:** The drive system couples the turbine to the generator. At one end, it allows the turbine to spin at the velocity that delivers the best efficiency. And at the other end, it drives the generator at the velocity that produces correct voltage and frequency.

5. **Generator:** Typically generators have two distinct designs: brush and brushless. Generators have brush to transfer current from moving parts to stationary parts. This causes high wear and tear resulting in frequent replacement. Alternative of brush is to use brushless permanent magnet. Its life span is higher, however, it is costly compared to brush configuration. In addition, brushless permanent magnet generators perform at higher efficiencies.

6. **Alternator Configuration:** Alternator can produce at different voltage level 12 V, 24 V, 48 V or 120V. Generation voltage is determined based upon the distance of load centre. If it is near to generation source voltage level is kept low and vice-versa.

[8] Vertical change in elevation between the head water (reservoir) level and tail water (downstream) level.
[9] Volume of water passing a point in a given amount of time
[10] Energy possessed because of motion.

Table 5: Servicing of load (existing and productive) by micro-hydro mini-grid

(A) Hours (Time of day – 24 Hour Format)	(B) RE Power Output	(C) Existing Load	(D) Load - Productive Uses	(E) Total Load (E = C+D)	(F) Excess Generation(F=B-E)
0000	50	20		20	30
0100	50	18		18	32
0200	45	12		12	33
0300	50	8		8	42
0400	45	3		3	42
0500	50	4		4	46
0600	50	5		5	45
0700	40	13		13	27
0800	45	23		23	22
0900	50	33	20	53	-3
1000	40	45	30	75	-35
1100	40	55	40	95	-55
1200	45	55	50	105	-60
1300	30	53	60	113	-83
1400	45	50	60	110	-65
1500	45	30	50	80	-35
1600	50	15	50	65	-15
1700	40	17	30	47	-7
1800	50	20	20	40	10
1900	50	30		30	20
2000	40	35		35	5
2100	50	40		40	10
2200	40	35		35	5
2300	30	39		39	-9

Two possible solutions for matching load.

1. **Without backup:** In this case loads need to be rescheduled to timings of over generation. From the above table we can deduce that excess generation is in time schedule of :

(A) Hours (Time of day – 24 Hour Format)	(B) RE Power Output	(C) Existing Load	(D) Load - Productive Uses	(E) Total Load (E = C+D)	(F) Excess Generation(F=B-E)
0000	50	20		20	30
0100	50	18		18	32
0200	45	12		12	33

0300	50	8		8	42
0400	45	3		3	42
0500	50	4		4	46
0600	50	5		5	45
0700	40	13		13	27
0800	45	23		23	22
1800	50	20	20	40	10
1900	50	30		30	20
2000	40	35		35	5
2100	50	40		40	10
2200	40	35		35	5

Loads which are not time dependent can be shifted to above mentioned excess generation times.

2. **With backup:** In this case, rescheduling or shedding of load is not required. A battery system is required to be placed so that during excess generation battery is charged and utilised when load is on the higher side.

From the above table, it is deduced that the system has generated 369 units extra which can be optimised, as about 367 units are required when load is on the higher side.

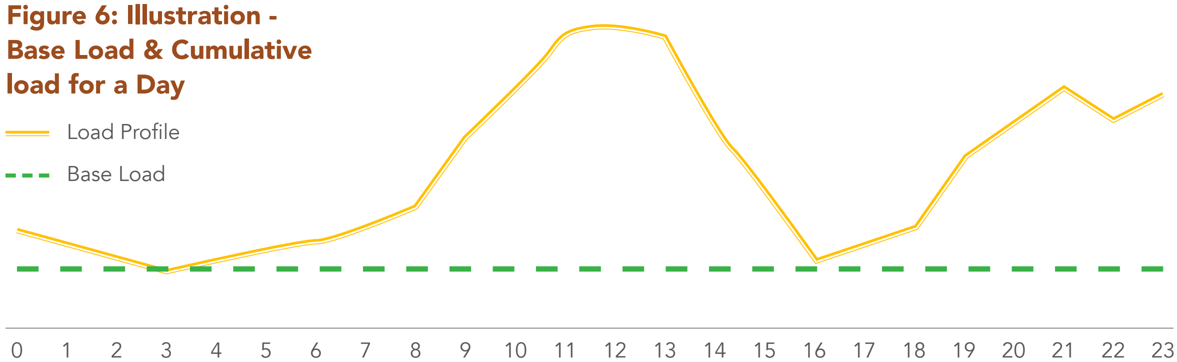
2.5 | Identifying Base Loads

2.5.1 | Step 5:

Identify base loads

This is the final step in the energy planning exercise. Once optimisation of loads is completed, the base load should be identified considering the criticality of the load i.e., non-negotiable nature of load. This quantum of load is always present in the system which is to be catered to. Base load has been presented in the figure below.

Figure 6: Illustration - Base Load & Cumulative load for a Day



The base load to be catered is one of the key parameters on which the mini-grid system can be designed. The system is designed in such a way that base load is catered to for 24 hours a day. As production from solar is for a limited period of time in a day, extra energy needs to be produced during day time and stored in batteries to be used in the night time. Accordingly, battery and solar plant need to be sized.

2.6 Technical Aspects of Mini- Grid Implementation

There are two types of electrical currents to use, transmit and store electrical energy. These are known as Alternating Current (AC) or Direct Current (DC).

Figure 7: Notation of AC and DC

2.6.1 Alternating and Direct Current

AC – Alternating Current: In AC systems, the electricity flows first in one direction and then the other, and this completes a cycle. This cycle is repeated about 50 or 60 times in one second; hence the system is called a 50 or 60 Hz AC system. In India, the grid utilities use 50 Hz AC system for transmission and distribution of electrical power.

DC- Direct Current: Contrary to AC systems, the power flows in one direction only. Normally DC cannot be used for stepping up or stepping down the voltage and therefore is not used by utilities (except DC power EHV transmission network by transmission utilities).

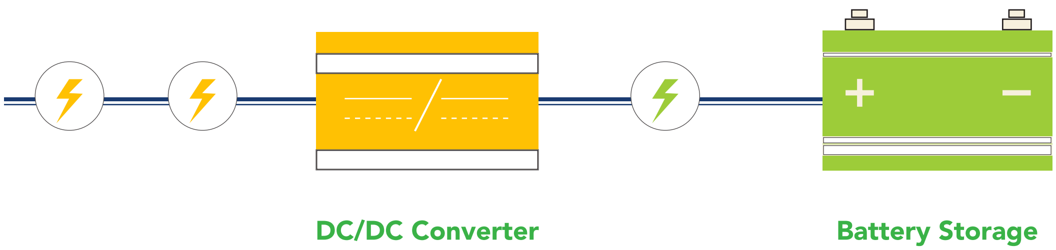
A solar based RE project generates DC electrical power, which can be used directly by DC compliant electrical equipment. For the storage of electrical power, batteries are used, which also store power in DC State. DC power can be converted into AC power with the help of an Inverter. This AC power is used by the end-user through commercially available equipment/ appliances. In case of a micro-hydro based mini-grid, the AC electrical power is generated and there is no requirement for an inverter for the DC-AC conversion.

2.6.2 AC and DC Systems

A solar power plant generates DC power, but as most of the consumer installations/ homes appliances in India (and in the majority of the world) run on AC, an inverter is required to convert DC solar power into appliance-friendly AC power. Solar inverters are normally included with every solar power generating system.

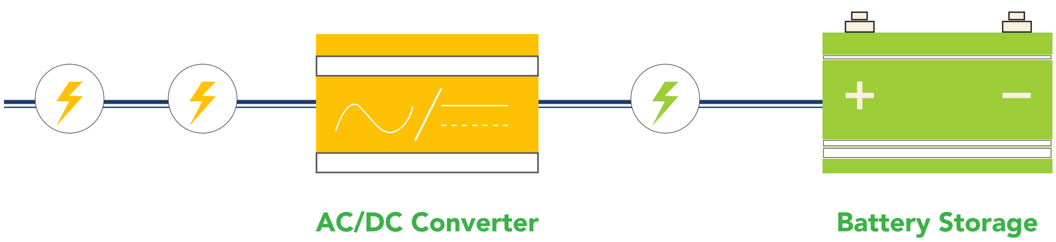
Similar to solar panels, batteries also operate on DC power. It stores and produces DC power and they use inverters to convert its stored DC power into AC power.

Figure 8: DC Battery System



An AC battery system has its own built-in inverter, allowing the battery to directly convert its stored DC power into AC power to electrify the AC devices and appliances.

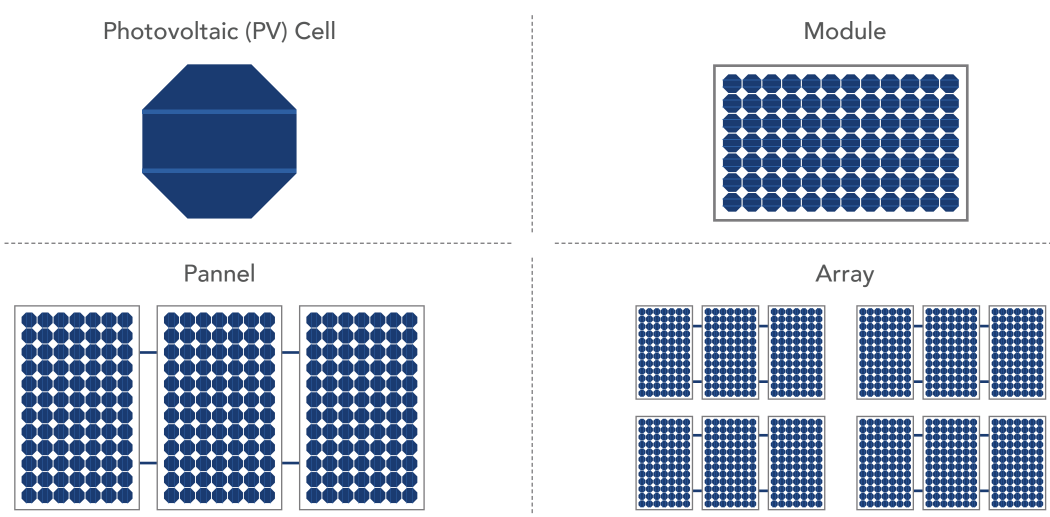
Figure 9: AC Battery System



2.6.3 Major Components in a Solar System

Photo Voltaic Array: A photo voltaic array is a complete power generating unit consisting of interconnected PV modules which function as a single unit. An array should be sized to allow full recharge of the batteries from maximum depth of discharge in an acceptable time frame as well as the capacity to provide an equalising charge. In a mini-grid without battery, the array should be planned taking into consideration the month in which solar radiation is the lowest.

Figure 10: Illustration - Photovoltaic Cell, Module, Panel and Array



Storage Batteries: Storage batteries use and store Direct Current (DC) and have a low voltage output that usually ranges 12V to 24V. In a solar based power system, the following types of batteries used - Lead acid, Lithium ion, Nickel Cadmium, and Nickel Iron. Lead acid batteries are the most commonly used and the batteries based on Lithium ion technology are fast evolving and widely adopted in the solar based power systems.

Figure 11: Illustration - Lead acid batteries

Batteries should be sized such that they meet both the power and energy requirements of the mini gird. For a mini-grid without a generator backup, minimum autonomy should be kept as 3 days for regular loads. For critical loads, autonomy should be more than 3 days based on weather conditions of the particular area. In a hybrid system with generator backup, an autonomy of 1-2 days may be considered.

Charge Controllers: Charge controllers are designed to protect the battery and ensure its longer life without impairing the system efficiency. Charge controllers prevent batteries from being overcharged (by limiting the charging voltage) and over-discharged (disconnect battery when it reaches a certain depth of discharge; prevent current flowing back into the solar panel during the night, called reverse current.

Figure 12: Illustration - Charge Controller

Source: http://powmr.com/pwm-solar-controllers/current/30amps/powmr-z20-20a-solar-charge-controller-clone/

Bidirectional inverters are used for conversion of both DC Voltage to AC Voltage and AC Voltage to DC Voltage. In the above figure, bidirectional inverter is used to convert AC voltage supply from grid to DC voltage supply required for DC loads and convert DC voltage supply from battery to AC voltage to feed into the grid.

Figure 13: Illustration- Bidirectional Inverter

Source: http://krannich.com.au/product/fronius-symo-large-10m/

Illustration of Sizing a Solar System

Consider the following generation and demand schedule.

Table 6: Generation and load profile for determining the system size and related equipment

(A) Hours (Time of day - 24 Hour Format)	(B) RE Power Output	(C) Existing Load	(D) Excess Generation
0000	0	0.5	-0.5
0100	0	0.5	-0.5
0200	0	0.5	-0.5
0300	0	0.5	-0.5
0400	0	0.5	-0.5
0500	0	0.5	-0.5
0600	0	0.5	-0.5
0700	0	0.5	-0.5
0800	0	1	-1
0900	0	2	-2
1000	4	2	2
1100	5	2	3
1200	5	2	3
1300	10	2	8
1400	9	2	7
1500	10	2	8
1600	5	2	3
1700	3	2	1
1800	0	2	-2
1900	0	3	-3
2000	0	3	-3
2100	0	4	-4
2200	0	1	-1
2300	0	0.5	-0.5
2400	0	0.5	-0.5

Given the above generation and load, the solar plan and the related equipment need to be sized. There are softwares such as PVSys that can be used to size the project. Illustrative calculations for the sizing are presented below:

Assumptions:

1. Size on a single panel: 250 Wp
2. 10 % extra panel considered for mitigating the effect of shading and maintenance
3. 20 % over loading considered on the inverter
4. Battery size of 100 Ah, 12 V

Estimations:

Total plant capacity = 10 kW
Modules required = Total capacity in watt / wattage of each panel
= (10*1000)/250
=40
10% extra modules considered i.e. 4 modules

Total modules at 6 kW plant = 40+4 = 44 ---------------- (A)
Inverter capacity required = 10kW
However, 20 % overloading can be done for Inverter (Assumption 3)

Thus, an 8.5 kW inverter with 20% overloading i.e. 10kW load can be served by the inverter.

From the chart, we can conclude that during day time extra production is of 35 kWh which is to be stored and utilised at night.

35 units = 35000 Whr

1 battery will serve load of = 12 V *100Ah = 1200 Whr

To serve 30000 Whr number of batteries required = 35000/1200 = 29

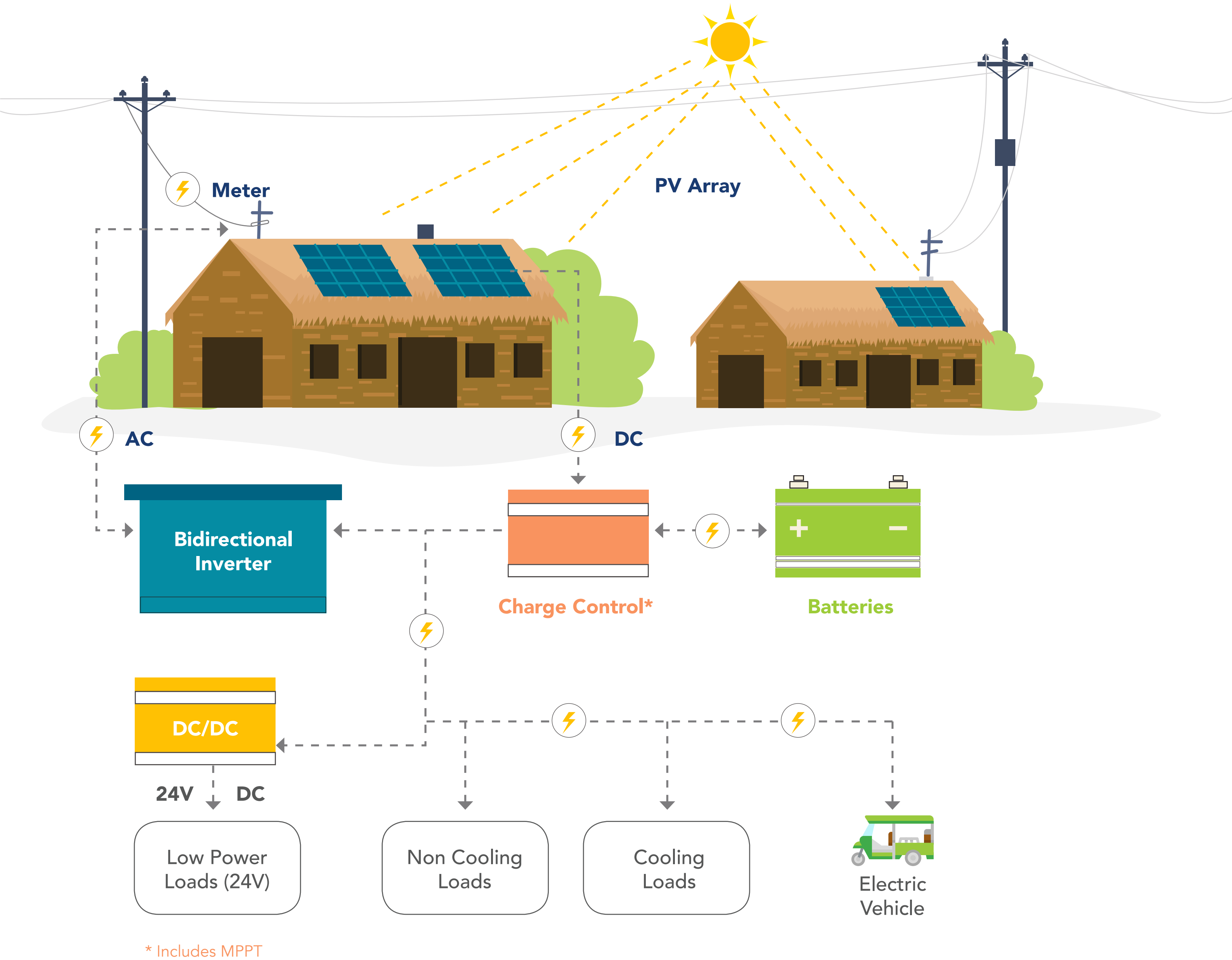
2.6.4 AC and DC Solar Systems

A solar power plant (including mini-grid) uses two types of battery for power storage, namely:

- **DC power generation, DC power storage and DC transmission and consumption**
  This is a complete DC system, where solar plant generates DC power, and the same is consumed by the consumer. Here no inverters are required, but there may be a requirement of DC voltage converters.

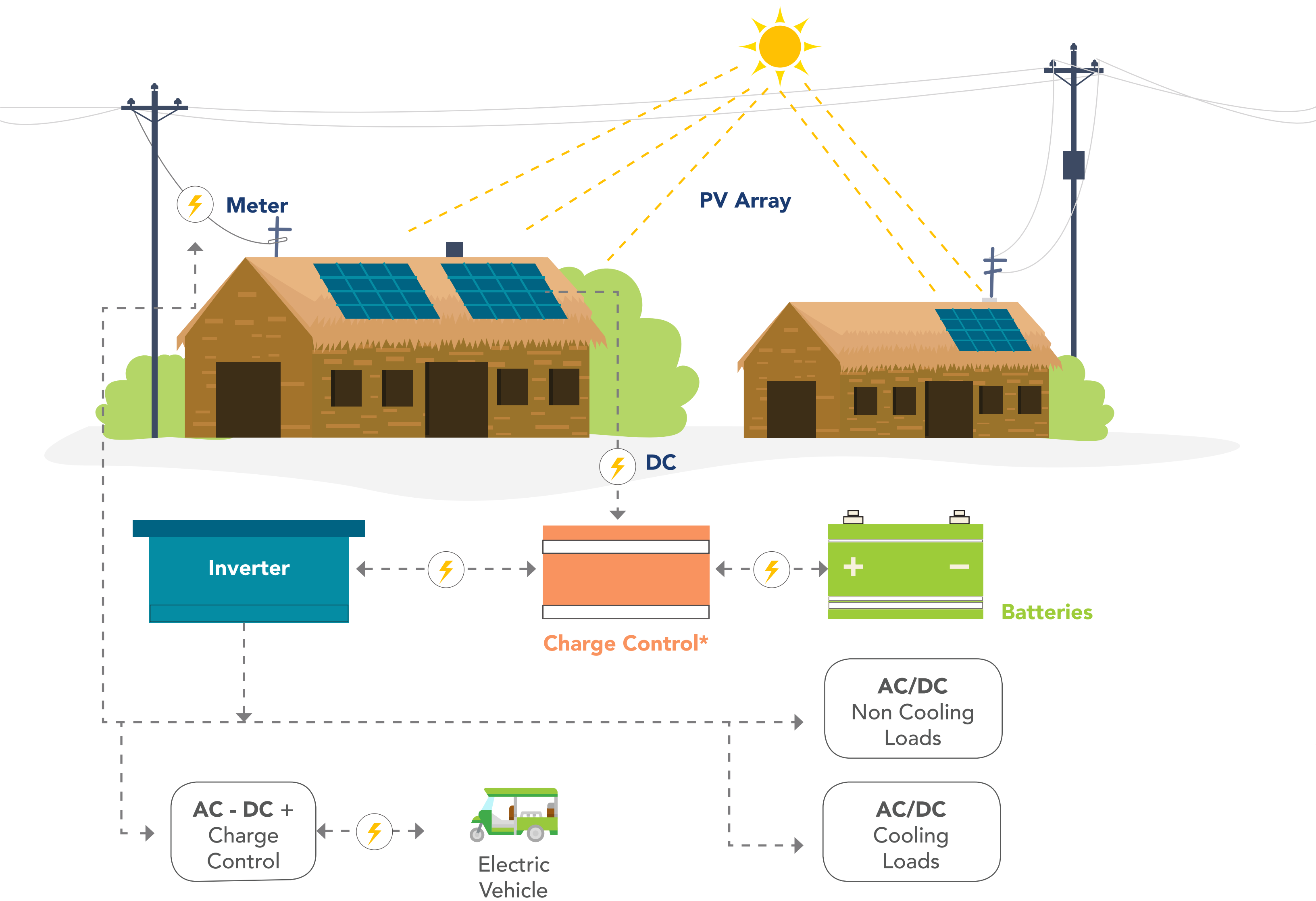
In an ecosystem, where DC power is stored in the battery system and where AC based grid supply also exists; bi-directional inverter is required for battery charging from the solar system during the day and from the grid in the night (See diagram below).

Figure 14: DC Power System with Storage



- **DC power generation, DC power storage and AC transmission and consumption**
In this case, although DC power is generated from solar, inverters are used to convert DC to AC at appropriate voltage level. The AC supply is used for the transmission of power and is also used by the end-user. Usage of DC power is limited for power storage in the battery system.

Figure 15: AC Power system with storage



* Includes MPPT

Inverter is used for conversion of DC voltage supply to AC voltage.

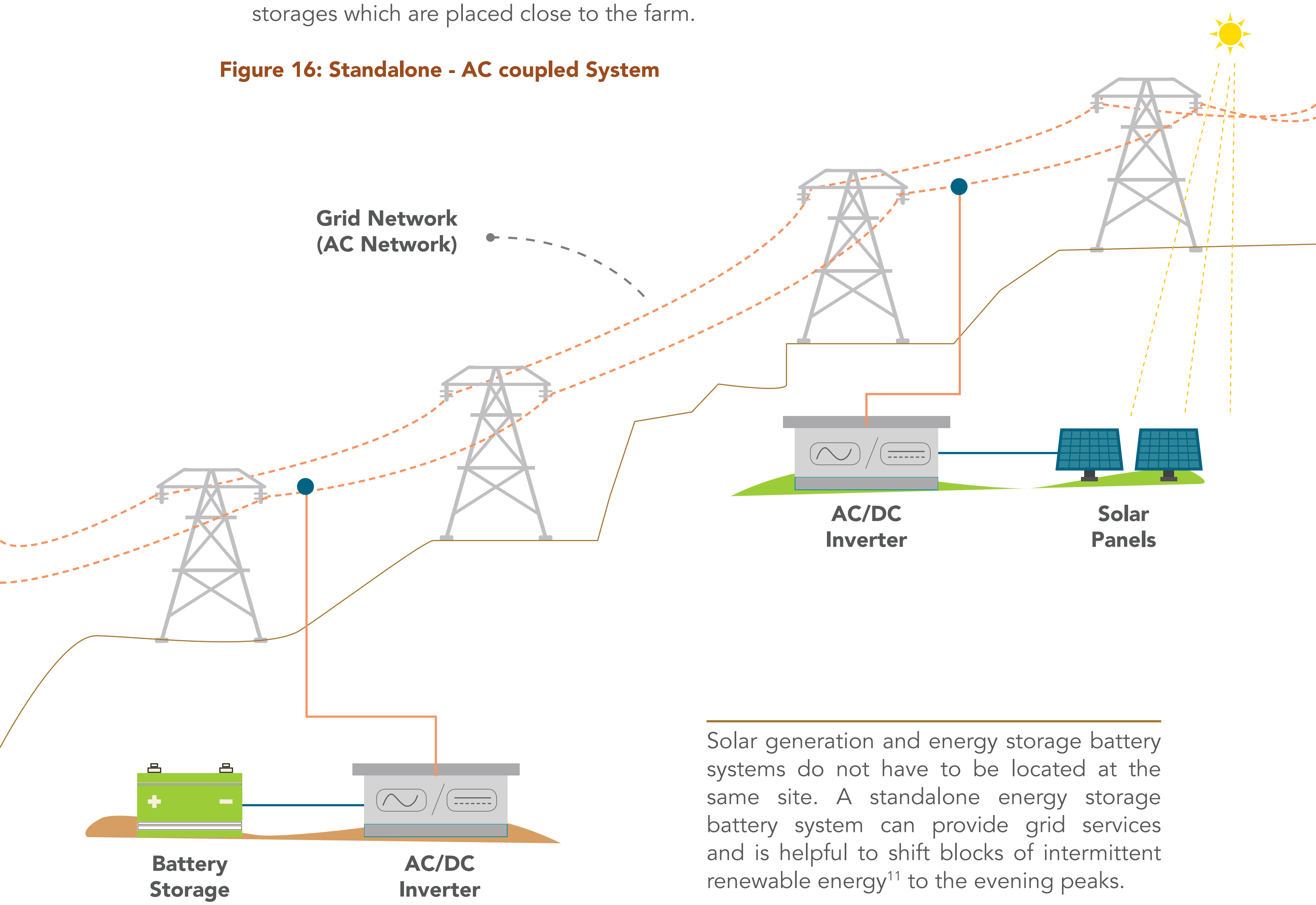
2.6.5 AC vs. DC coupling for solar generation systems and energy storage systems

When a battery storage system is used with solar generating system, there are two ways to couple these two systems — known as AC or DC coupling. There are three types of configurations possible for the coupling of solar generation and storage systems. These are discussed below.

- **Standalone - AC coupled**
  In this configuration, the energy storage battery system is located on a separate site independent of solar generation. This type of installation is often installed in a local load pocket to serve capacity constrained regions.

  This type of configuration where generation unit and energy storage unit are in different sites can be seen in EV charging stations where battery swapping is done and also in cold storages which are placed close to the farm.

Figure 16: Standalone - AC coupled System



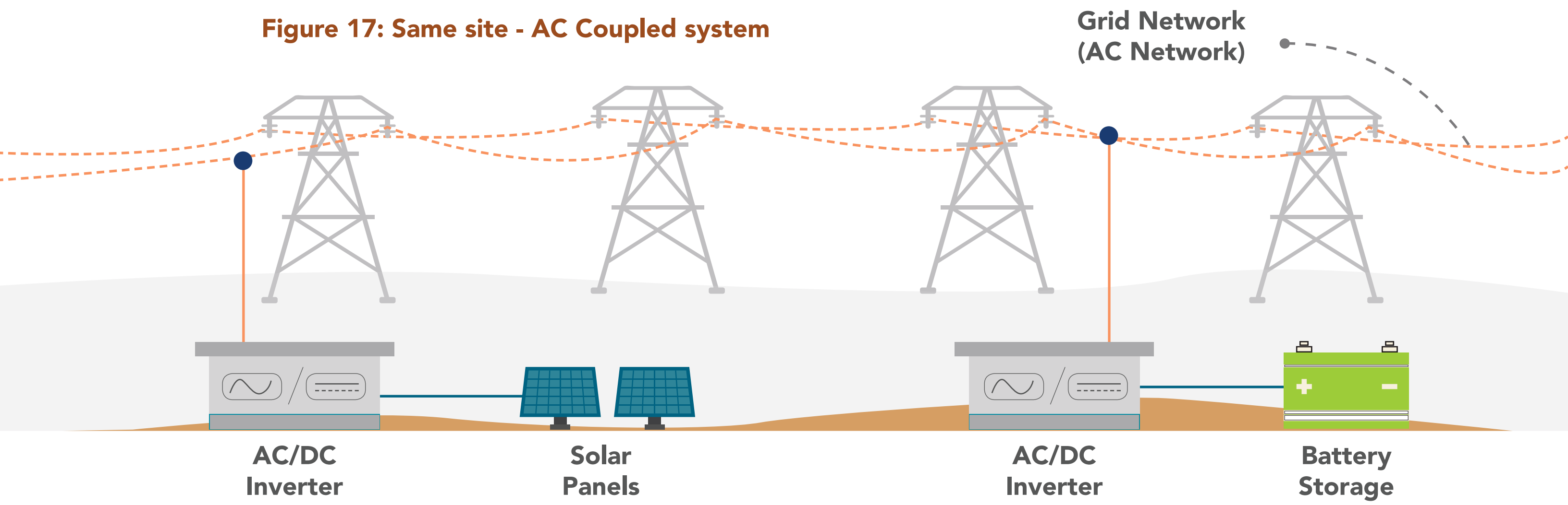
Solar generation and energy storage battery systems do not have to be located at the same site. A standalone energy storage battery system can provide grid services and is helpful to shift blocks of intermittent renewable energy[11] to the evening peaks.

[11]Intermittent energy source is any source of energy (usually renewable energy) that is not continuously available for conversion into electricity and is also outside direct control (unlike cola based generation) because the electricity generated cannot be stored. Intermittent energy sources may be predictable but cannot be dispatched to meet the demand of an electric power system.

- **Same site located - AC coupled**
  In the second configuration, solar generation and energy storage battery systems are located at the same site. These systems may be connected to the grid at a single point or at two different points. However, the solar and the storage systems are connected to separate inverters, and the energy storage is sited next to the solar generation. They can be dispatched together or independently.

  This type of configuration is seen in solar irrigation pumps. The latest innovation in solar pumps is that the entire setup including generation unit and battery storage unit is mounted on a three wheeler to make it mobile.

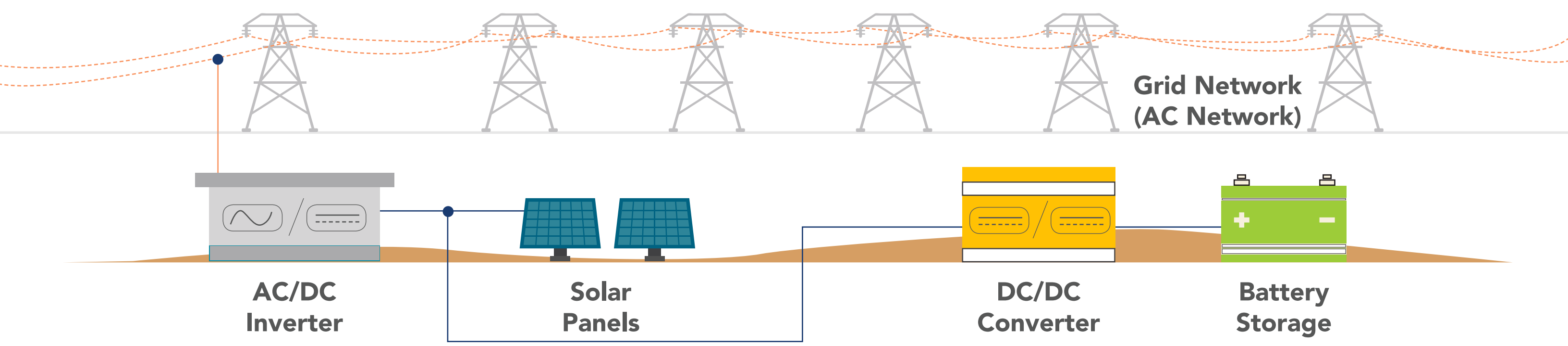
Figure 17: Same site - AC Coupled system



In this configuration, there are advantages of co-locating storage battery and solar panel systems – as it helps optimise various costs including the cost of land, labour, project management, interconnection and operations and maintenance etc. From a mini-grid perspective, such a design also gives flexibility to the generator for scheduling power from solar and battery separately, especially in case of a sudden surge in demand during the day.

- **Same site located - DC coupled**
  In this configuration, the solar generation and energy storage battery systems are located at the same site. The solar generation panel and energy storage battery systems are connected on the same DC bus and use the same inverter. They can be dispatched together as a single facility. Here DC to DC converter may or may not be used.

Figure 18: Same site located - DC Coupled



Co-located systems can either be AC coupled, where the solar PV panel arrays and storage battery systems are physically placed at the same location, but do not share the inverter (as shown in the figure for same site AC Coupled system), or it can be DC coupled, where solar PV panel arrays and storage battery systems are coupled on the DC side of a shared bi-directional inverter (as shown in the above figure). The cost savings from sharing the balance of plant costs may be substantial.

2.6.6 DC Usage Appliances

Below are some examples of household appliances that may be run by DC. Presently as the main source of electrical energy in a common household is a 230 V 1 phase or 400 V 3 phase AC supply, almost all the appliances mentioned below use an AC to DC power supply unit (PSU), which converts AC supply to suitable DC supply.

- Mobile / Cell phones
- Transistor Radios and Tape Recorders
- LCD / LED TVs (AC goes into the TV, which is converted to DC)
- Computers , Laptops, Printers and Scanners
- Rechargeable Torches & Flashlights
- LED Bulbs & Tube Lights
- Other electronic gadgets
- Hybrid and Electric Vehicles

It may also be noted that although the above mentioned appliances/ equipment need DC power, the level of voltage may differ. For example, a mobile phone usually needs a 5 Volt DC supply to charge its inbuilt battery and a desktop computer needs 5 Volts and 12 Volt supplies. Similarly LED bulbs may need 40 to more than 100 Volt DC for its operation. Mobile chargers may require 150 to 300-V AC supply to provide 5-V DC. Similarly, a laptop charger input may be 160 to 260-V AC and with output of 19 to 20 Volts DC to charge the laptop.

2.6.7 Pros and Cons of DC, AC, Mixed Loads of Productive Uses

Most of the power systems of modern day are based on AC. As transforming the voltage of the AC is easy and less expensive compared to DC, and other inherent advantages, power systems are based on AC. Following is the economic comparison of AC and DC distribution system in the same capacity and network topology[12]:

[12]Reference: Yuan, Xiaodong, et al. "Construction Costs and Transmission Efficiency Comparison of AC and DC Distribution System." Proceedings of the 2016 3rd International Conference on Materials Engineering, Manufacturing Technology and Control, 2016, doi:10.2991/icmemtc-16.2016.80.

- The construction costs of DC distribution system is higher because of expensive electronic devices
- The transmission loss rate of DC distribution system is significantly lower than the AC

This section elaborates the pros and cons of catering to the energy needs of productive uses based on DC load, AC load and mixed load considering the existing mini-grid is based on AC.

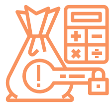
2.6.7.1 Productive uses - DC load

Pros	Cons
• **Utilisation of excess energy:** The excess energy generated can be utilised for productive uses, irrigation needs, when the load required and energy generation is simultaneous.	• **Cost intensive:** Catering to the DC load of productive uses is a costly affair that requires additional cost. This is done in two ways: o First, at the consumer end, by using AC-DC inverter or any other required electronic device to convert AC into DC. o Second, laying the distribution system from the generation terminal to the consumer end.
• **Low Capacity:** The DC loads are low when compared to AC loads for same output	• **Maintenance:** The DC motors requires maintenance due to the presence of multiple brush
• **Energy Efficient:** Compared to AC appliances, DC appliances are more energy efficient and used to serve off-grid market.	• **Expensive:** On the contrary, DC appliances are more expensive compared to AC counterparts.
• **Cooling Loads[13]:** Cooling loads have the temporal overlap with PV system output and offer the best potential for energy savings from direct-DC.	• **Conversion Losses:** Since the appliances are either DC compatible[14] or direct[15] DC, the incoming AC to be converted into DC, results in losses.

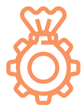
[13] Catalog of DC Appliances and Power Systems – Ernest Orlando Lawrence Berkeley National Laboratory
[14] DC Compatible – Technology that can be operated on DC, though DC is not required.
[15] Direct-DC – The direct use of DC power from DC generating power sources by appliances and equipment without converting to AC first

2.6.7.2 Productive uses based on AC load

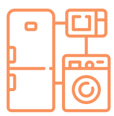
Pros



- **No cost implication:** They do not require any device as supply is AC, hence no cost implication.



- **Equipment cost:** The DC loads are low when compared to AC loads for same output

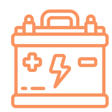


- Modern day appliances have built in rectifier/adapter that convert AC to run the DC Components present in the appliance.

Cons

- **High losses:** AC power transmission has high losses compared to DC power transmission

- **Hazardous:** Requirement of high voltage is hazardous and has an inherent risk of loss of life



- **Storage:** Alternating Current can't be stored whereas DC can be stored.

As most of the mini-grids that are currently operating in the country are on AC system, the preference for AC based system is well accepted. However, in case there are new mini-grids being planned, especially to service a smaller area, DC bases system may be considered. A detailed techno-commercial analysis will be required to make the technology choice. The mini-grid operator would be required to undertake this analysis.

The equipment choice of the rural enterprise will be determined by the grid it plans to integrate with. Given that DC appliances are more expensive, the choice of the grid will have a cost implication as well for the rural entrepreneur.

The mini-grid operator and the rural entrepreneur need to work closely in making the above choices.

The above discussion concludes the technical aspects that need to be considered while developing a rural enterprise with a RE based mini-grid system. Once the technical aspects are sorted, the business planning needs to be commenced, which is the focus on the next training module. This discussion is presented in detail in the Module 3 of the training manual, which focuses on financial planning of the rural enterprise.

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