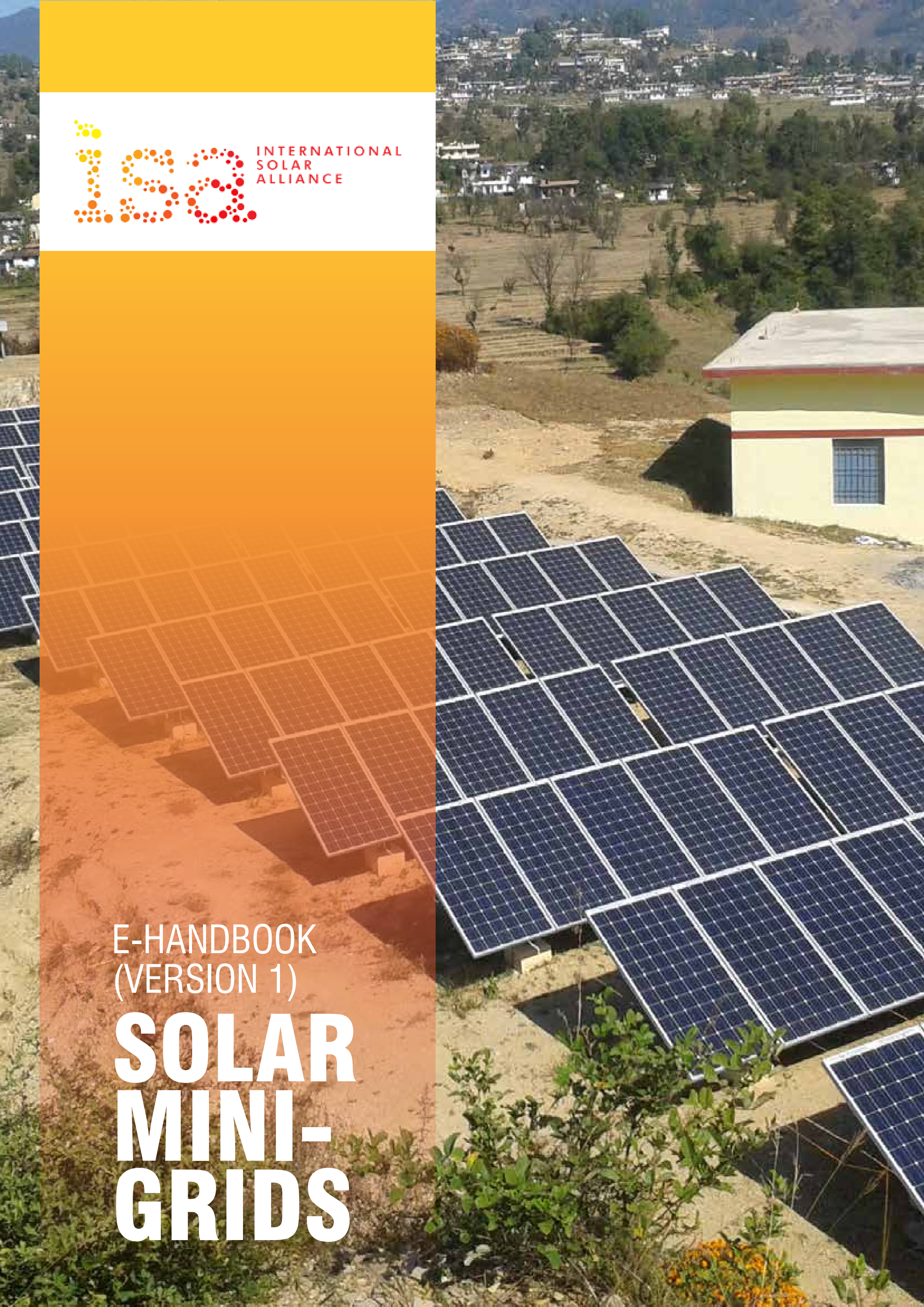


INTERNATIONAL SOLAR ALLIANCE

E-HANDBOOK (VERSION 1)

SOLAR MINI-GRIDS

KIND ATTENTION TO THE READERS

The purpose for publication of the E-Handbook for Solar Mini Grids is to support ISA member Countries to understand the basics of the Solar Mini Grid Projects. The details mentioned can help ISA member countries in creating awareness regarding the basic technical aspects of solar-mini grids. The feedback from the readers will help ISA Secretariat to update and customize the upcoming versions of this E-Handbook.

Disclaimer: The diagrams and photos in the E-Handbook are indicative and are not the only solutions. The drawings are not as per scale. The technical details are suggestive for optimization. The name of the organizations/departments/ institutions mentioned are as mentioned in the public domain.

CONTENTS

ABBREVIATIONS

AC	Alternating Current
AfDB	African Development Bank
ADB	Asian Development Bank
AMP	Africa Mini grids Programme
ARPU	Average Revenue Per User
ASER	Senegalese Rural Electrification Agency
BMZ	German Federal Ministry for Economic Cooperation and Development
BOAD	West African Development Bank
BS	British Standards
CFI	Climate Finance Innovators
DC	Direct Current
DFI	Development Finance Institutions
DG	Diesel Generator
DIN/VDE	German Institute for Standardization
ERA	Electricity Regulatory Authority (Uganda)
ESMAP	Energy Sector Management Assistance Programme
GCF	Green Climate Fund
GEF	Global Environment Facility
GMG	Green Mini Grids
HFO	Heavy Fuel Oil
IEC	International Electrotechnical Commission
IDA	International Development Association
IKI	International Climate Initiative
INR	Indian Rupee
IPP	Independent Power Producers
IS	Indian Standards
ISA	International Solar Alliance
ITT	Institute for Transformative Technologies

LDC	Least Developed Countries
MDP	Market Development Programme
NDC	Nationally Determined Contributions
NDP	Uganda's National Development Plan (NDP)
NEA	National Electrification Administration (Philippines)
NEP	Nigeria Electrification Project
NPC	National Power Corporation, Philippines
PLN	Perusahaan Listrik Nagara
PRES	Philippine Rural Electrification System
PV	Photovoltaic
RBF	Result Based Financing
RE	Renewable Energy
REA	Rural Electrification Agency (Uganda)
RERA	Renewable Energy for Rural Areas
RET	Renewable Energy Technologies
SEFA	Sustainable Energy Fund for Africa
SERT	Solar Energy for Rural Transformation
SHS	Solar Home Systems
SIDS	Small Island Developing States
SMG	Solar Mini Grid
SPUG	Small Power Utilities Group
TPRM	TP Renewable Microgrid
UEDCL	Uganda Electricity Distribution Company Limited
UiB	Utility-in-a-Box
UL	Underwriters Laboratories
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organisation
USD	United States Dollar
WBREDA	West Bengal Renewable Energy Development Agency

01

EXECUTIVE SUMMARY

Mini-Grids play a critical role in providing electricity to remote places, small islands, rural communities where electricity from conventional grid is either not existing or sparsely available and in helping to connect millions of people worldwide. Today the Mini-Grid market is dominated by hydro power and diesel resources. In island countries, the diesel run mini grids are popular owing to the ease of import and availability of the fuel. Such systems are often developed by local communities or entrepreneurs. In contrast, mini grids running on solar energy are often developed by private investors or international donors . Two challenges need to be overcome for solar mini grids to scale up. First, rural customers in need of reliable electricity access often have limited awareness and trust on renewable energy technologies. Second, Solar mini grids require substantial funding from investors and/or developers. Therefore, for successful mini grids, factors such as reliable operation, timely maintenance, sustainable performance, and positive return on investment becomes essential. Furthermore, participation of private sector players to invest in such technologies becomes critical in least developed countries for market development.

[1] https://www.seforall.org/system/files/2020-06/MGP-2020-SEforALL.pdf

Solar hybrid Mini-Grids that integrate PV and other distributed energy systems can complement and compete with main grid extensions in terms of the cost of electricity and the quality of supply. Grid extension has been the predominant approach to provide electricity access. However, the areas where the main grid can reach more economically than off-grid, alternatives are slowly being exhausted and the incremental costs of adding new rural customers via this route are becoming prohibitive. It is critical for governments and utilities to take a least-cost approach that takes advantage of the breadth of technology options, particularly given that many state-owned utilities are debt ridden and the need for electricity access is urgent.

ISA is cognizant of the fact that the role of solar Mini-Grid systems is paramount in accelerating solar deployment for creating a social impact, especially in off-grid areas with limited or no energy access and has therefore launched Scaling Solar Mini-Grids Programme. The objective of this programme is to address the challenges in integrating solar energy into limited or unconnected electricity grids and promote rapid deployment of Solar Mini-Grids at scale in ISA member countries.

In this regard, the E-handbook seeks to provide a comprehensive knowledge repository of solar Mini-Grid systems covering the general aspects of SMG including the advantages of SMG, current size of the SMG market, as well as key highlights to ensure the sustainable systems operation and maintenance. Further, succeeding versions of the E-handbook would be introduced based on the feedback and comments of relevant stakeholders.

02

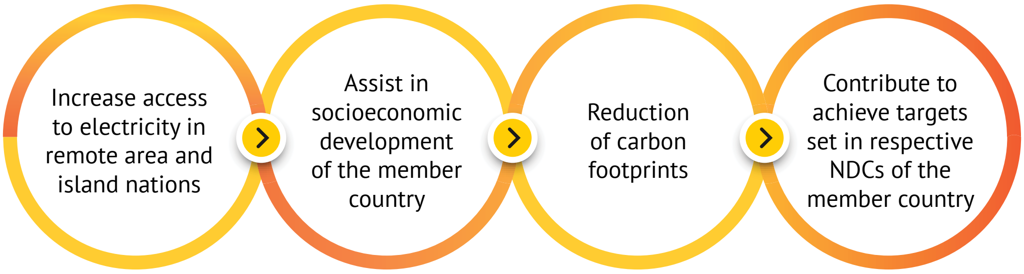
CONTEXT

Solar Mini-Grid have played a pivotal role in providing reliable energy to people living in remote, rural as well as off-grid areas. Affordability and environment friendliness of solar energy among all renewable energy alternatives makes it an option especially to those who are spending substantial funds for securing a reliable energy source; or are subjected to high-priced tariff from existing power systems. Around 90% people around the world has access to electricity, while remaining 10% of the total do not have access to electricity. According to United Nations Industrial Development Organization (UNIDO), around 180,000 Mini-Grids would need to be built to supply electricity to those lacking energy access. The World Bank estimates that 140,000 of these are needed in Africa.

Knowing the pain points related to electrification in energy deprived countries where millions of people do not have access to electricity, the role of solar powered energy systems seems paramount in addressing challenges related to energy access and energy security. ISA's third Programme, Scaling Solar Mini-Grids is an attempt to address the challenges in integrating solar energy into limited or unconnected electricity grids.

The Programme was launched with a special objective to cater to the energy needs of ISA member countries in identified areas with unreliable or no grid(s), and in Small Island Developing States (SIDS) and Least Developed Countries (LDC), having abundant potential to tap solar energy including replacing existing DG sets with solar systems.

The other objectives of promoting scale up of Solar PV Mini-Grids are:



The ISA Secretariat had organized its first field visit of Officials of Diplomatic Missions of ISA member Countries, based in India, on 26th December 2018, which was participated by 36 ISA Member countries. The delegation visited two Solar Mini-Grid plants The delegation also visited petrol pump, e-government kiosk, fully solar operated bank – running on solar Mini-Grid system.

ISA also had conducted a demand aggregation process for Solar Mini Grid for ISA Member Countries in which 12Countries participated. Demand Aggregation of more than 333 MWp of Solar Mini Grid was assessed in these twelve ISA Member Countries. The key objective of the demand aggregation exercise was to assess the potential Solar Mini Grids to enable the implementation of adoptable, viable and bankable solar Mini-Grid projects in the ISA member countries.

2.1 Definition of Solar Mini-Grid (SMG)

"A Mini-Grid is an aggregation of loads and one or more energy sources within a clearly defined boundary, operating as a single system providing electric power, either isolated and fully autonomous or connected to the main grid."

A modern Solar Mini-Grid includes Solar based Decentralized Distributed Generation, energy storage (if required), control systems and the dedicated Power Distribution Network System for distribution of the power from generation to consumers. Mini-Grid can be modular and scalable (Option of Capacity enhancement of generation & distribution) so that additional generation capacity may be added in future to meet the growing electrical loads due to various reasons, without compromising the stable operation of the existing Mini-Grid system.

This definition encompasses AC and DC based systems serving multiple customers through community-based power systems typically range up to MW size with dedicated distribution-level electrical interconnection. System voltage levels are less than or equal to the country's distribution voltage level.

03

CONFIGURATIONS OF SOLAR PV MINI-GRID

Solar PV Mini-Grid systems are custom designed for specific applications and need of the location/consumers. The following factors are generally considered while determining the system configuration for Solar Mini-Grid system.

- Target consumer and type of electrical appliances to be operated
- Load size and daily energy demand
- Time and duration of operation
- Correlation with electrical load on a daily, weekly and seasonal scale.
- Geographical spread of energy source and loads.
- Climatic conditions of locality.
- Soil conditions of locality
- Installed cost and maintenance costs
- User specific preferences
- Local regulations/ constraints/ benefits
- Solar PV based or hybrid generation

The system configuration should be chosen to satisfy the design criteria, to make it most cost-effective, efficient, reliable system operation and sustainable for long life. Economic evaluation of different options, if required, may be carried out based on life cycle costing.

3.1 Standalone or Off-Grid Solar Photovoltaic Mini-Grid System

Stand-alone or Off-grid Solar Photovoltaic Mini-Grid systems are the ones which are not connected to a central electricity distribution system and provide electricity to individual appliances, homes, or small productive uses such as a small business etc. (refer figure 1). They thus serve the needs of individual customers, while utilizing locally generated solar electricity. In general, Solar Mini-Grid systems can be designed for standalone AC operation. Depending on the capacity of the system and type of inverter, various types of AC appliances could be operated by this type of system.

Using a Standalone system is convenient as most of the electrical and electronic appliances available in the market run on AC. However, care must be taken, particularly in small system for overloading of the system and inverter, as the users may not be aware of limitation of the system and they may tend to think as conventional AC system and end up discharging the complete battery capacity/generation capacity using the loads continuously or damage the inverter connecting loads of larger capacity than the installed inverter capacity. The capacity of power generation through Solar PV Systems and the capacity of battery storage are designed based on the customized need of the consumers. However, with customized capacity of battery there could be limited hours of electricity supply and reliability of electricity supply could be at compromise, in case of excess need of power than generated.

For reference purpose, we can group Solar Mini-Grid system types into following categories:

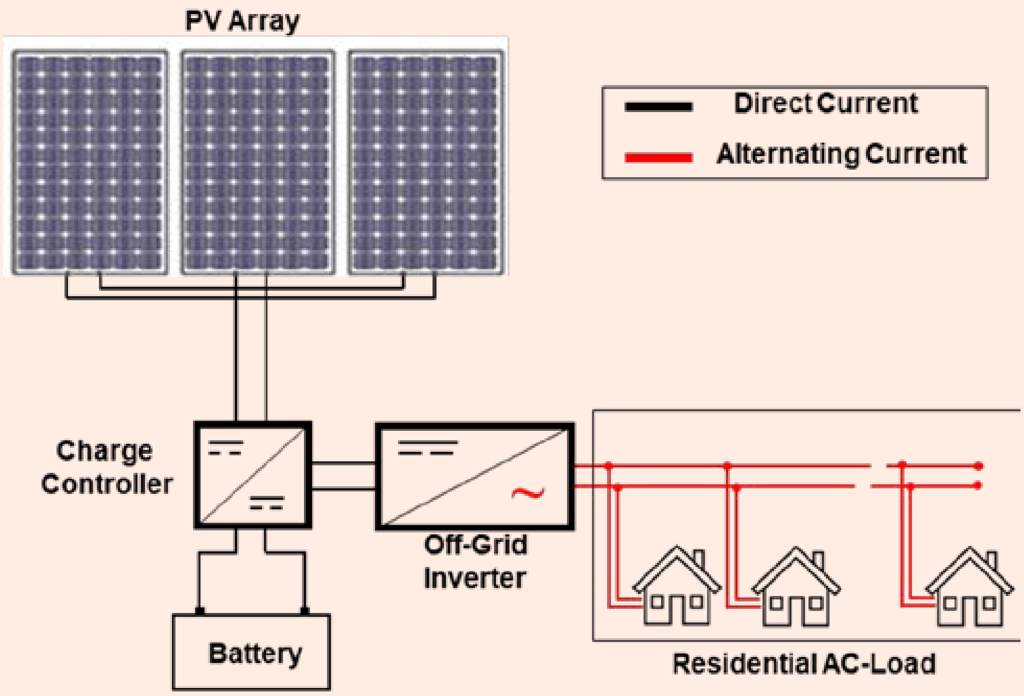


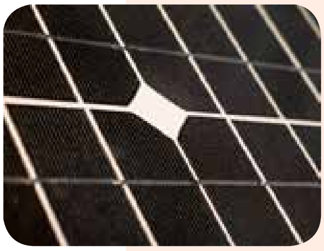
Figure 1: *Illustration of Standalone Mini-grid System*

3.1.1 Components of Standalone or Off-grid Solar Photovoltaic Mini-Grid System

The components of a Mini-Grid systems are as follows:

1. **Solar Photovoltaic (SPV) Modules**

   SPV modules are the devices that capture the Sun's energy and convert it into electricity, which is DC Power. There are a wide variety of modules available today which differ in the type of Semiconductor used, the manufacturing process, and the product quality. The vast majorities of commercially available PV modules are made from Semiconductor and differentiated into the three main varieties: mono-crystalline, polycrystalline and thin-film solar cells (refer figure 2). The different types of PV module vary significantly by cost, efficiency, capacity, and appearance. The choice is highly dependent on the application; however, the most important thing is to ensure that they are compliant to the relevant codes and standards, with respect to the need of the project.



Single/Mono crystalline

- Mono-crystalline have a black hue and are made from a single silicon crystal structure
- Mono-crystalline are space efficient
- Most expensive manufacturing processes.
- Monocrystalline solar cells are more efficient than their polycrystalline solar cell

Polycrystalline/Multi-crystalline

- Poly crystalline have a blue hue and are formed from many fragments of silicon that are melted together to form the wafer for the panels
- Less expensive then mono-crystalline
- Polycrystalline solar cells have lower efficiency ratings than monocrystalline solar cells.

Thin film

- Thin film PV panels are manufactured by depositing photovoltaic substances on a solid surface like glass
- A combination of substances is used to form a cell, e.g., Amorphous Si, Dyesensized solar cell, Copper indium gallium selenide (CIGS) solar cell, Cadminium telluride (CdTe), etc.
- Manufacturing cost is lower than other methods
- Least efficient in comparison to Mono and Poly crystalline cells

Solar PV module manufacturers use the standard test conditions (STC) output parameters for display on their nameplates. At STC, PV modules are exposed to artificial sunlight with an intensity of 1000 W/ m2 at 25°C and air mass 1.5 (AMl.5) to measure the output. The performance of a solar PV module in site conditions differs from those of the STC. Selection of array configuration is based on location specific irradiation, in a software-based simulation or based on the local available metrological data.

2. **Battery storage – type and classifications**

   SPV modules are the devices that capture the Sun's energy and convert it into electricity, which is DC Power. There are a wide variety of modules available today which differ in the type of Semiconductor used, the manufacturing process, and the product quality.

   The vast majorities of commercially available PV modules are made from Semiconductor and differentiated into the three main varieties: mono-crystalline, polycrystalline and thin-film solar cells (refer figure 2). The different types of PV module vary significantly by cost, efficiency, capacity, and appearance.

   The choice is highly dependent on the application; however, the most important thing is to ensure that they are compliant to the relevant codes and standards,
   with respect to the need of the project.

Some of the Secondary batteries that are commercially available and viable for use in photovoltaic system include.

- Flooded Lead Acid Batteries
- Valve Regulated Lead Acid (VRLA) Batteries
- Lithium Ion (Li-ion)

The different types of batteries commonly used in PV systems are described below:

a) **Flooded Lead-Acid Batteries**

   Tubular Positive Plates type flooded lead-acid batteries are the most common lead-acid batteries for PV application. They contain vents which allow the resulting hydrogen gas from electrolysis to escape. As a result, the electrolyte level will fall over a period, and must be monitored and topped up with water, preferably distilled water. The hydrogen gas produced is highly flammable. Care must be taken to ensure that there is adequate ventilation above and around flooded batteries.

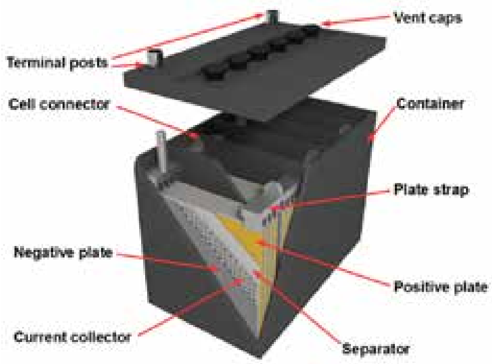


Figure 3: *Flooded Lead-Acid Batteries*
(Credit: https://doi.org/10.1007/s10008-018-04174-5)

b) Valve Regulated Lead-Acid (VRLA)

Valve regulated lead acid (VRLA) batteries are also known as captive electrolyte batteries and as the name implies, the electrolyte is immobilized in some manner and the battery is sealed under normal operating conditions. Under excessive overcharge, the normally sealed vents open under gas pressure through a pressure regulating mechanism.

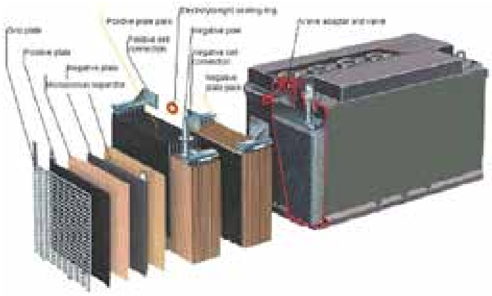


Figure 3: *Valve Regulated Lead-Acid Batteries*
(Credit: https://sites.google.com/site/acidsandbasesindepth

Electrolyte cannot be replenished in these battery designs; therefore, they are intolerant of excessive overcharge. VRLA batteries are available in two different technologies: Absorbed Glass Mat (AGM) and Gelled Electrolyte. These type of batteries does not need topping up and are compact due to which it requires less space than Flooded LA Battery Bank with same capacity.

c) Lithium-ion Batteries

Lithium-ion batteries have several advantages over other batteries, especially lead acid batteries. They are generally smaller and lighter for the same capacity, are faster at charging, and are less susceptible to degradation due to charging and discharging. However, lithium-ion batteries have a very high up-front cost, and they can be sensitive to extreme temperature and voltages. This type of batteries requires even less space than VRLA Battery Bank of same desired output.

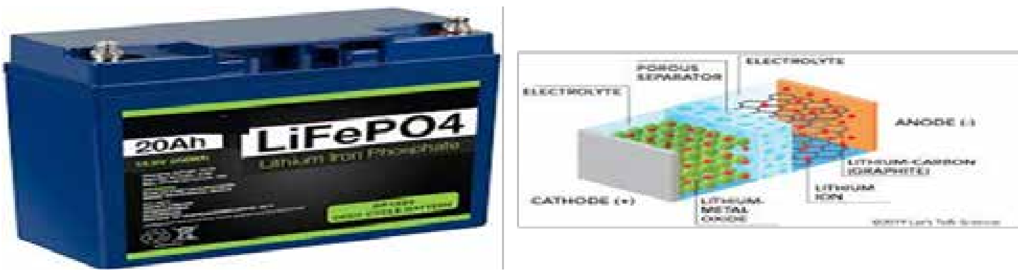


Figure 3: *Valve Regulated Lead-Acid Batteries*
(Credit: https://sites.google.com/site/acidsandbasesindepth

3. Charge Controller

The charge controllers are included in most PV systems for protect the batteries from overcharge and/or excessive discharge. The minimum function of the controller is to disconnect the array when battery is fully charged and keep the battery fully charged without damage.

Figure 6: *Charge Controller*
(https://www.powerstream.com/pv-control-extreme.htm)

4. Inverters & other Electronic Equipment

The photovoltaic array and battery produce DC current and voltage. The purpose of an inverter (refer figure 7) is to convert the DC electricity into a form suitable for AC electrical appliances and/or exportable to the AC grid. The typical low voltage (LV) supply into Mini-Grid will be either 230V AC single phase or 415V AC three phases.

Figure 6: *Solar Off-grid Inverter*
Image Source: 2-1.jpg (1513×1657) (didisolar.com)

The inverter in a stand-alone power system takes its power from the batteries to supply the AC circuit(s). The system controller (voltage regulator) itself can have an MPPT. The advantage of the MPPT controller is to optimize the battery charging. This function has no impact on whether the inverter itself will supply power to any AC circuits. Stand-alone inverters are typically voltage-specific, i.e., they are manufactured to operate from a specific nominal battery voltage e.g. 12V, 24V, 48V, 96V, 120V DC or above, as per their power handling capacities. The inverter will convert the solar DC power to an AC sine wave that matches the AC supply in voltage and frequency to which it is connected.

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5. **Balance of Systems Equipment**

   In addition to the PV modules, battery, inverter and charge controller there are other components required in a solar PV Mini-Grid system; these components are referred to as Balance of Systems (BoS) equipment .

BoS equipment includes:

a) **Solar Array Mounting Structure:** The equipment used to safely secure the PV modules to the mounting surface or ground. These Structures are normally customized/designed with respect to the need of the location capacity of Solar PV Systems and place of installation. It can be on ground or rooftop.

Image: Courtesy CREDA

b) **Cabling:** Both DC and AC cabling is required to connect components. The selection of size and type of cables will be based on the technical design of the Solar PV System.

c) Array Junction Box (String Combiners): This may or may not be required depending on the type of inverters e.g. Central / String Inverters. Whereas, PV strings can be directly connected to string inverters, for Central Inverters the strings have to be combined in the combiner boxes.

Image Source: *nordic-one-page-flyer-7-500x500.jpg (500×500) (imimg.com)*

d) Protection and Disconnect Switches: These components ensure the isolation and safety of the system.

Image Source: *https://th.bing.com/th/id/OIP.Q6f2NcH2OtXizZ8eZPUJtAHaHa?pid=ImgDet&rs=1*

e) Earthing:

Earthing system is a protection system for Solar Mini-Grid, through which all the electrical installations are connected to the earth to protect living beings from getting electric shocks.

Image Source: *industrial-earth-pit-500x500.jpg (500×500) (imimg.com), earth-pit-chamber-500x500.jpg (500×281) (imimg.com)*

f) Lightning Protection: May be installed depending on the requirement to protect the system from lighting strikes as per international / local standards.

Image Source: *lightning-arrestor-150930.jpg (210×210) (exportersindia.com)*

g) Metering: Measures the quantity of electricity generated by solar or quantity of electricity consumed by a customer.

Image Source: *secure-3-phase-net-bidirectional-meters-for-solar-application-500x500.png (500×429) (imimg.com)*

h) System Monitoring: Shows the system owner exactly how much electricity their system is producing and can be helpful in detecting a problem within the system.

Image Source: *secure-3-phase-net-bidirectional-meters-for-solar-application-500x500.png (500×429) (imimg.com)*

i) **Control Panels:** These Control Panels can be as following
   - AC Distribution Board
   - DC Distribution Board
   - Battery Protection Panel
   - Any other Panel for precise monitoring and O&M activities

j) **Signage:** PV systems installed requires various signs to ensure safety.

3.2 SPV Hybrid Mini-Grid System

SPV Hybrid Mini-Grid systems are the ones that use a combination of source like solar-DG set or any other RE / fuel-based generators to enhance the reliability along with power availability during any season or weather condition during the year, even in non-sunny hours. The figure 9 illustrates a Solar PV-Diesel Generator (DG) based Hybrid Mini-Grid System. In many SIDS and LDC countries electrification are majorly done through DG set, hence Solar Hybrid Mini-Grid systems are most appropriate for such locations which operates on DG-sets.

AC power output generated from Solar PV System or from DG Set can be directly connected to AC loads. A transfer switch is needed to prevent generator power from feeding backwards in the inverter. An automatic transfer switch can be electronically operated or a manual change over switch can be installed. The generator can also be used to recharge the batteries.

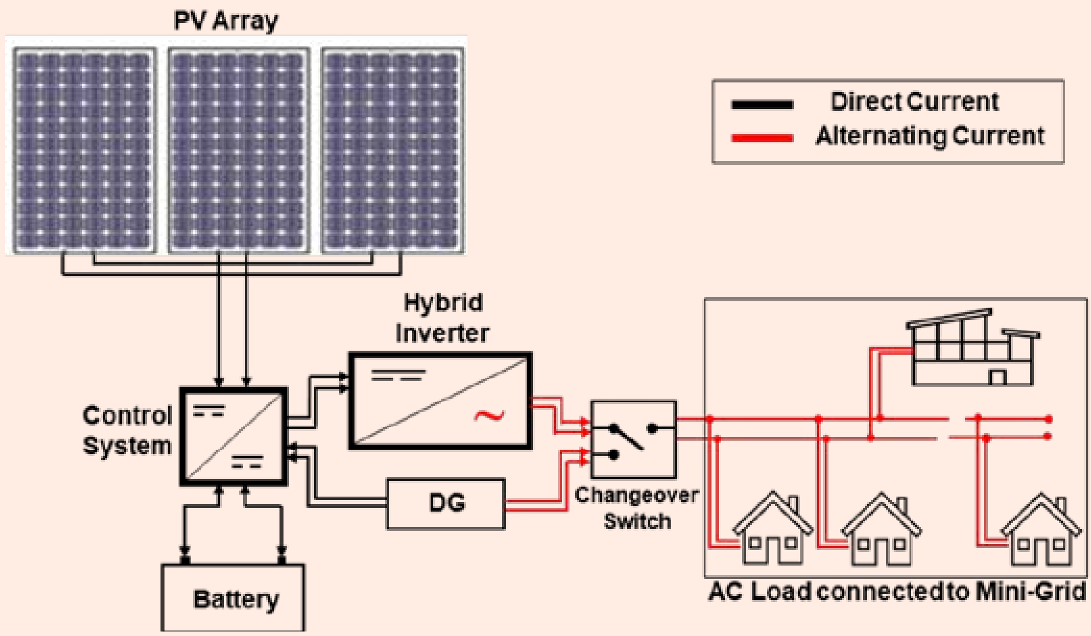

Figure 9: *Illustration of Hybrid Mini-Grid system*

3.2.1 Components of Solar Hybrid Mini-Grid System

The components in Solar Hybrid Mini-Grid System are as follows (for brief explanation, refer to section # 3.1.1.1 to 3.1.1.5).

1. Solar Photovoltaic (SPV) Modules
2. Battery storage
3. MPPT Charge controller
4. Changeover switch
5. Solar Hybrid Inverters & other Electronic Equipment

Image Source: *On-Grid-Solar-Inverter-100-250KW-500x500.jpg (500×500) (akkumega.hu)*

Solar Hybrid Inverter control the flow of energy intelligently, during the day, the PV plant generates electricity which can be provided to the loads, fed into the grid and/or charge the battery in order of priority. The electricity stored in batteries can be supplied when the loads require it during the night/non-sunny hours, when electricity from other sources are not available. Additionally, the power/conventional grid can also charge the storage devices via built in Power Conditioning Units. These types of Hybrid Inverters can also be synchronized/retrofitted with electricity generated through DG Set in such a manner that there is saving of diesel.

6. Balance of Systems Equipment

3.3 Grid Tied Solar Mini-Grid System

In general, Solar Mini-Grid is standalone and installed in such areas where there is no grid or access to energy. Solar Mini Grids can also be installed in the locations where Grid is available but not adequate or availability is uncertain. A solar Mini-Grid system can be connected to the main grid through different methods. However, such integration must be as per requirement of international standards / local grid code. Connecting Mini-Grid system to the main grid may provide multiple benefits as below:

- Solar Mini-Grids are typically designed with extra capacity to take care of energy demand during the months when solar radiation is low. If Mini-Grid system is connected to the main grid, surplus power can be injected into the grid, which will increase capacity utilization factor of the plant.
- The consumers connected to Mini-Grid system will have more flexibility in use of electrical appliances when Mini-Grid is connected to the main grid.
- Due to availability of grid, battery capacity may be reduced or even removed if grid is reliable.

Such type of technical provision can also be done, as and when the main grid is extended to the areas where Standalone Solar Mini-Grids are installed. If the main grid is extended to such locations Mini-Grid systems may become obsolete or have less importance due to its limited power generation capacity in comparison to the main grid. The best way to avoid such situation is to make the Mini-Grid systems compatible to interface the main grid (refer figure 10)

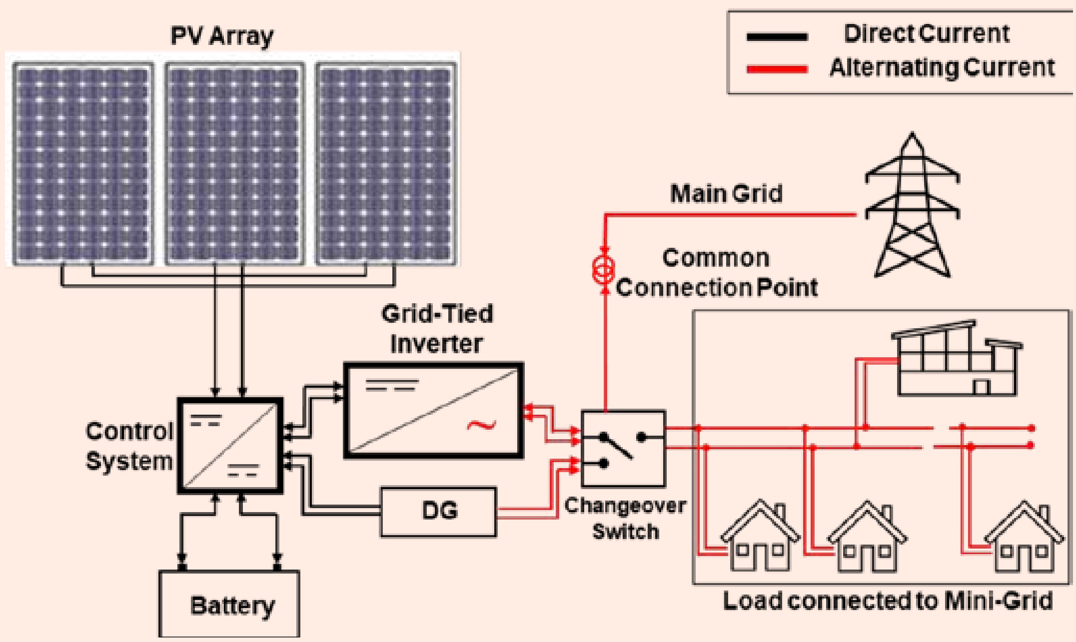

Figure 10: *Illustration of Grid tied Solar Mini-grid System*

3.3.1 Components of Grid Tied Solar Mini-grid System

The components in grid tied Solar Mini-Grid System are as follows (for brief explanation, refer to section # 3.1.1.1).

1. Solar Photovoltaic (SPV) Modules
2. Battery storage, wherever required.
3. Grid-Tied Inverters & other Electronic Equipment
4. MPPTs
5. Change over switch, (If required)
6. Balance of Systems Equipment

Image Source: *2000W Single Phase Grid Tie Solar Inverter|inverter.com*

However, there are some important changes in terms of connections and equipment such as inverters due to connection with distribution power system. Such installations also need to comply the safety measures, Regulations and Grid Protocols of respective Country.

3. Inverters & other Electronic Equipment

In a grid-connected PV system, the PV array is directly connected to the grid-connected inverter. The grid-connected inverter is the device which converts the DC power generated from solar system to the AC power and supply to main grid system. The PV array is configured so that it operates within specific range of DC voltages to suit the grid-connected inverter's specifications. The inverter will convert the solar DC power to an AC sine wave that matches the AC supply.

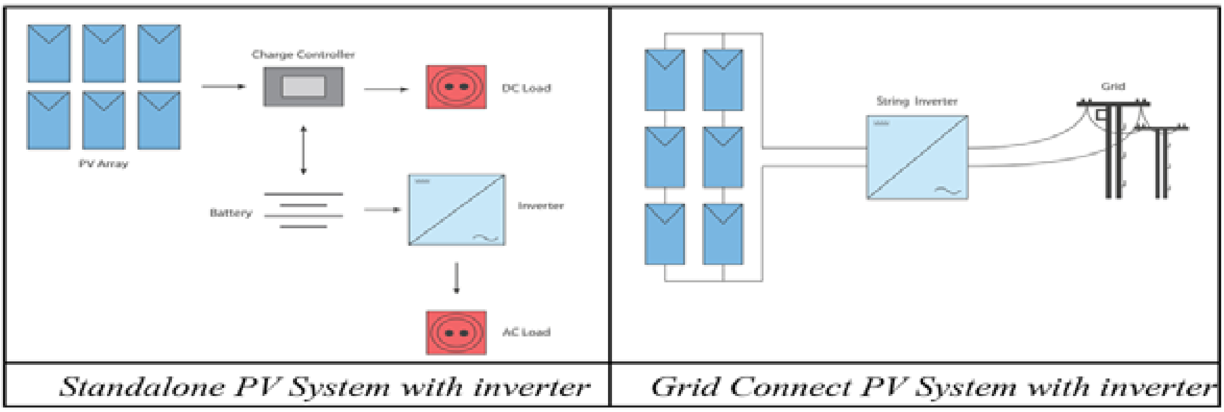

Figure 11: *Standalone PV System Inverter vs Grid Connected PV System Inverter*
Image Courtesy: *MNRE*

The key role of the grid-connected inverters is to synchronize the phase, voltage, and frequency of the AC inverter output with that of the grid. Solar grid-tie inverters are designed to instantly disconnect from the grid if the utility grid goes down to ensures that in the event of a blackout, the grid tie inverter will shut down to prevent the energy it produces from harming any line workers who are sent to fix the power grid. This feature is known as islanding property of the inverter which a mandatory safety norm which are compiled by every grid connected inverter manufacturers.

04

TARGET BENEFICIARIES OF SMG

Population residing in remote communities or islands with considerable energy requirements; and who receive sporadic power supply from existing Mini-Grid running on biomass, hydropower, diesel generators; also including the areas where grid electricity has not reached owing to geographical islands. In the countries where Mini-Grids operate on the Diesel Generator Sets, installation of SMGs may reduce the consumption of diesel in phased manner.

4.1 Advantages of SMG

There are multi-dimensional advantages of SMG. It not only contributes to social development of people but also help in better and economically managing power systems. However, advantages can be listed under following headers:

a) Reduction in usage of polluting fuels such as kerosene/diesel and biomass

Energy being the fundamental commodity to humans, those living in the rural areas mostly rely on local resources to fulfill their basic requirements. Using non-environment friendly energy sources are known to create a negative impact on nature. Fossil fuels and biomass are among the heavily exploited resources of energy among humans. Biomass is abundant in most of the rural areas and is heavily utilized by the locals to meet their energy requirements. Burning of biomass not only creates pollution for the environment but also affects human health leading to respiratory problems.

b) Boosts overall system flexibility.

Installing PV modules in Mini-Grid generally improves their economics as compared to just using diesel. Adding day-time demand can cut the overall cost of electricity as it correlates with the generation profiles of PV systems powered by the sun. This boosts the utilization rate of the Mini-Grid, leading to a lower cost of electricity and higher average revenue per user (ARPU).

c) Increases productivity and employment opportunities

Solar PV Mini-Grid will provide energy needs during the day as well as meet lighting requirements to carry out chores during the night hours. This leads to increased productivity among rural people. With increase in productivity with reliable power, local businesses can remain open for longer hours creating more opportunities for economic growth. Employment opportunities can be created for local population by providing them training in operations, maintenance of Solar PV Mini-Grid systems. By carrying out training and capacity building, a skill development center can be established in the region to encourage others to become solar entrepreneurs in their areas.

d) Reduces burden of grid balancing on utilities

Mini-Grid under smart technology arrangement or what is known as smart grids, can address the issue related to grid integration of various small renewable energy assets. They can help reduce the burden on utilities in managing injecting power from intermittent renewable energy into the grid, since much of the necessary balancing can instead be done locally, within the Mini-Grid itself. When there is a market for demand response or ancillary grid services, the smart feature of Mini-Grid control system can also determine when it is profitable for the Mini-Grid to participate.

e) Improves quality of life

Inadequate lighting makes it hard for people to carry out chores effectively. Furthermore, it also brings difficulty for school going children to study in dim-lit conditions and makes medical aid also inaccessible and more challenging at night. Better living conditions is aided from the reliable access to electricity. Furthermore, it can be used to save lives by assisting health workers in effectively manage and effectively address critical life-threatening medical conditions in a well-lit facility.

Switching to solar energy technologies such as a Solar PV Mini-Grid can eradicate problems associated with using pollution causing energy substitutes bringing a much cleaner and environment friendly alternative in rural and/or off-grid areas.

f) Increases resilience in terms of energy supply

Rural population that relies mostly on fuelwood and other biomass to meet their energy requirements and are known to spend substantial amount of time in collecting natural resources. In communities where labor allocation is unequal, women are the ones responsible for collection. This practice exploits time and efforts of not only women but young girls who are given this responsibility at a young age, severely affecting their education. While kerosene lamps have been the most popular energy source since many centuries, it comes at a cost to the environment as well as poor population. A reliable power source such as a Solar PV Mini-Grid displaces expenditure on kerosene lamps and candles, besides reducing indoor air pollution over and above fire and burn risk.

g) Fulfillment of commitments laid down though the country's NDCs

In addition to many benefits of using Solar PV Mini-Grid, owing to the non-polluting, environment friendly technology features which contributes to the NDC efforts of the country in reducing national emissions and adapt to the impacts of climate change is also achieved to some extent.

h) Operation and Maintenance can be managed by local Manpower:

For optimum sustainability of SMG, planned Operation & Maintenance (O&M) activities plays an important role. Through capacity building and appropriate technical support to the local manpower the O&M task can be well managed by local manpower with sufficient spares and toolkits in place.

05

CURRENT MARKET SIZE OF MINI-GRID

As of March 2020, around 5,544 Mini-Grids are operational in Sub-Saharan Africa, Asia, and small island nations with some in Latin America[2]. Out of the total operational Mini-Grids, around 3,500 (63%) were solar or solar hybrid systems, 1,164 (21%) were hydroelectric powered Mini-Grids, and around 610 (11%) Mini-Grids are powered by diesel/heavy fuel oil. It is further estimated that around 111 million households located in Sub-Saharan Africa, Asia and island nations can be served by Mini-Grids by the end of 2030.

[2] https://www.seforall.org/system/files/2020-06/MGP-2020-SEforALL.pdf

The levelized cost of electricity for isolated solar hybrid Mini-Grid for productive use customers plus households is estimated to range between USD 0.49 – 0.68 per kWh. However, this may vary in several regions due to varying prices for diesel, equipment, installation, and financing.

Solar hybrid Mini-Grid are known to be the fastest growing segment of the global Mini-Grid market. With the falling prices of Solar PV modules and batteries, developers are making use of battery energy storage with the solar PV Mini-Grid that are being installed today.

While 90% of the total population has access to electricity, it is a worldwide target to achieve universal electricity access by 2030. However, it is estimated that approximately 238 million households will need to gain electricity access in Sub-Saharan Africa, Asia, and island nations by 2030 to achieve universal electricity access. Mini-Grids can serve an estimated 111 million households, which is 50% of the estimated total. It is therefore a normal assumption that this will require huge capital investment. While most Mini-Grid developers have relied on public funding such as grants from governments, development finance institutions (DFIs), donor agencies and foundations. To date, most committed financing has come from grants and developers' balance sheets, with limited debt financing. Result Based Financing (RBF) has increased significantly and is favored by developers as well as private investors, because it improves returns, reduces risks of early-stage debt or equity finance, and potentially unlocks private capital (e.g., working capital needed to pre-finance connections and project equity needed for pre-development costs), provided the investors are confident of the developer's ability to deliver electricity connections.

06

OPERATIONS & MAINTENANCE

ISA always recommend the use of best components, systems in the design and installation of SMG which are locally / internationally available in the market. The association with the best workmanship will always result in the minimum maintenance requirement and long-lasting service from the installation. Still regular operation and maintenance activities for desired output from SMG is very much necessary and mandatory.

Operations and Maintenance (O&M) is very important for the sustainability of the project and ideally should be planned well in advance of the start of operations, rather should be part and parcel of the SMG project form designing level For O&M of Solar Mini-Grids, capacity building of relevant stakeholders should be the first step towards ensuring sustainability and economic viability throughout the life of the project. The relevant stakeholders may include, consumers/end Users, technicians, supervisors, policy makers etc. There are various approaches to implement a successful O&M schedule:

a) Trained local manpower
b) Outsourcing to third party service provider
c) The developer or system integrator, the one responsible for installation and commissioning of the system
d) A separate government entity

However, trained local manpower could be the most economically attractive option. It would not only hone the skills of local population but would also generate employment. The O&M schedule of following components of Solar Mini-Grid must be periodically maintained and monitored.


Image Courtesy: *CREDA*

Table 1: Operation and Maintenance Schedule of Major Components

	Inspection	Action Required	Inspection Frequency
A	**Solar Modules**		
1	Dust Deposition	Cleaning of modules	Weekly
2	Module Junction Box malfunction, visual inspection	Replace the module in case of failure	Monthly
3	Module Cable connectors	Replace cable/connectors	Monthly
B	**Solar Module Mounting Structure**		
1	Inspection of mounting structure and hardware	Check Fastners- take remedial measures in case of any issues	Quarterly
		Check Lugs of earthing conductors for corrosion	
C	**Junction Boxes**		Monthly
D	**Solar Inverter/Charge Controller/Power Conditioning Unit**	Schedule Maintenance as indicated by inverter supplier	Quarterly
1	Loose cable termination	Tighten the connection	Quarterly
2	Air Filters	Cleaning	Weekly
3	Performance Monitoring		Daily
4	Report preparation		Monthly
E	**Battery / Battery Charger**		
1	Schedule Maintenance	As indicated by OEM	Monthly
2	Battery maintenance	Tightness, Battery topping up with distilled water (in case of flooded lead acid battery)	Quarterly
		Terminal Cleaning & Applying Gel	
	Note: The battery should never be allowed to remain in deep discharged condition for more than 2 to 3 days, necessary steps may be taken to provide external boost charge if need arises.		
F	**Cables (AC & DC)**	Visual inspection	Bi-Weekly
G	**Earthing**		Half Yearly
H	**Lightning Arrestors**		Half Yearly
I	**Power Distribution Network**	Schedule Maintenance	Half Yearly
J	**Control Room (Wherever Required)**	Schedule Maintenance	Quarterly
K	**All other equipment's**		Monthly

Note: The above-mentioned O&M schedule is indicative and may vary as per site conditions and adapted technology.

The basic suggestive equipments / tools required to perform O&M effectively are mentioned below:

- Multimeter or Clamp Meter
- A set of screw drivers including testers
- Safety equipment such as Insulated gloves, rescue rods, earthing and short circuit kits, warning signs and tapes, insulated ladders etc.
- Spanners as per requirement
- Compass

Spare Parts Management is also an inherent and substantial part of O&M aimed at ensuring that spare parts are available in a timely manner for Corrective Maintenance to minimize the downtime of a Solar PV Mini-Grid System. the spare parts should be owned by the asset Owner while normally maintenance, storage and replenishment should be the responsibility of the O&M Contractor. it is considered a best practice not to include the cost of replenishment of spare parts in the O&M fixed fee. The list of spare parts that are considered essential are below:

- SPV modules (if viable)
- Spare inverter/Charge controller/Power conditioning unit or spare PCB's
- MC4 Connectors
- MCBs as per requirement
- Junction Boxes (if viable/required)
- Glass fuses/Diodes/SPD's for required capacity wherever necessary
- Distill water, Gel or Grease, Hydrometer, Cell tester, Hand gloves, Rubber Boots etc. in case of flooded lead acid batteries

In case of power distribution system of SMG is also to be maintained then following additional spares are suggested

- Cables of required size and capacity
- Luminaries of required size and capacity
- Spares to maintain overhead/Under Ground cable network

However, domestic connection even when it is a part of the project, O&M responsibility should be under the scope of beneficiary.

Disclaimer: The description and explanation about the distribution network will be explained in the version 2 of the E-handbook

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