ANNEX V: SOLAR SOLUTIONS TECHNICAL SPECIFICATIONS AND MARKET PRICES

1 SOLAR BASED SOLUTIONS

1.1 GENERAL CONSIDERATIONS

There are several different PV based solutions to be taken into account in the rural electrification options, with different levels of service, from solar shops to mini-grids and off-grid alternatives. Different solutions require different components, and as such a brief description of the main elements is made below:

- PV modules – Photovoltaic panels are the primary component of PV based systems, as they are responsible for the generation of electricity from solar radiation;
- Inverter – Converts the DC generated by the PV modules to AC that can be fed to the mini-grid or used by an off-grid network. In systems with storage, an inverter with grid-management capabilities may be valuable;
- Battery System – Needed for systems where energy storage is required. The use of a storage system allows energy to be used even if the PV modules are not generating enough, as long as the batteries are charged;
- Charge Controllers – Required for systems with batteries, as charge controllers limit the rate at which electric current is added to or drawn from the battery system, preventing overcharging;
- Diesel Genset – Consists of a diesel-fueled engine and a generator, having the advantage of providing constant and predictable power, since it does not depend on meteorological conditions. A system with both PV and diesel generation is denominated a hybrid system;
- Other components – Apart from the main components listed above, core elements such as the mounting system, grid lines and transformers are usually required.

1.2 PV BASED ALTERNATIVES FOR RURAL ELECTRIFICATION

Three distinct PV based alternatives were considered. Two alternatives take into account distinct approaches of hybrid PV/Diesel systems with different PV penetration ratios, depending on the storage system, if it exists. Note that the main objective of implementing solar power into an existing diesel mini-grid is to achieve diesel fuel savings, thus reducing on-going operational costs, diesel fuel price exposure and fuel supply vulnerabilities. The third alternative consists on a 100% PV solution, considering individual home systems. It is also important to mention that depending on whether there is storage or not, a battery inverter and charge controllers may be needed, instead of a PV inverter.

Hybrid PV/Diesel (no batteries)

This alternative includes a solution based on a 100% diesel system along with a solar system without batteries, as illustrated in **Figure 1.1**. In this approach, solar penetration could reach up to 20% of the diesel genset nominal power.

This scenario would translate in a robust design proven in harsh environments, high tolerance for wide voltage and frequency ranges as well as integrated management functions for weak grids. This represents a low investment solution, since no batteries are required. However, fuel savings are reduced, translating into higher operation costs.

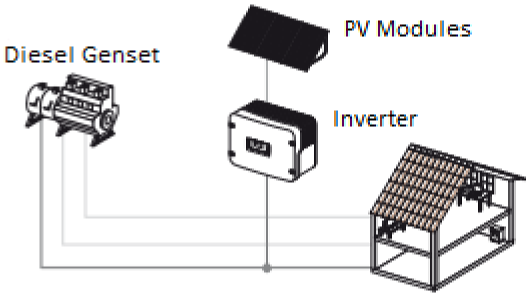

Figure 1.1 - Hybrid system without storage.

Figure 1.1 illustrates a simplified scheme for hybrid power generation without storage. Power from the diesel genset is directly connected to the consumer, but the PV modules need an inverter. The above scheme is merely indicative and should only be seen as an example.

Hybrid PV/Diesel (with batteries)

This system takes the previous system one step further, with the addition of batteries. With the inclusion of a battery bank, it is possible to store energy produced by the PV modules, allowing its use when the PV modules are not producing. As previously stated, systems with batteries need charge controllers and a battery inverter, as depicted in **Figure 1.2**. An intelligent management through the battery inverter ensures that the amount of solar energy fed into the system matches exactly the demand at that time. PV penetration depends essentially on the size of the battery bank, and could ascend up to 100% to reach economic optimum, including support for diesel off-mode. The advantages of this hybrid solution are that there is a reduction in the greenhouse gas emissions, in the diesel fuel consumption and in generation costs. On the other hand, diesel generators run at a lower efficiency rate and to enable high resource penetration, additional technology would be needed, mainly batteries.

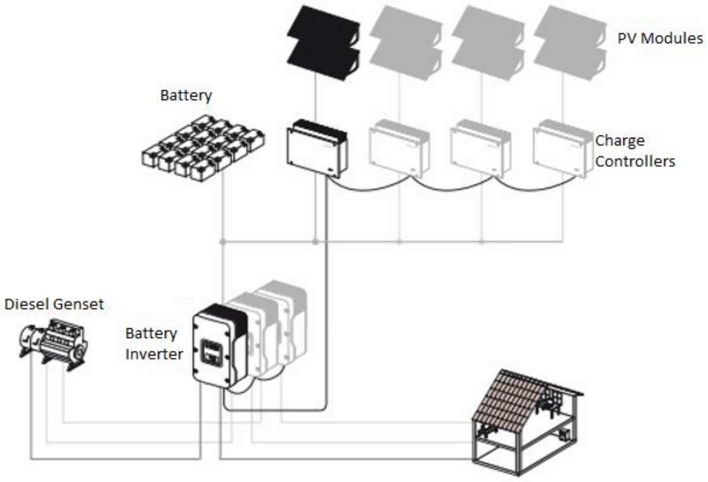

Figure 1.2 - Hybrid system with storage.

The scheme in **Figure 1.2** differs from the previous one, as the battery inverter manages the power generation by controlling how much power the diesel genset should generate, according to the PV production and battery state-of-charge. Additionally, the battery bank and the charge controllers are also illustrated in the scheme.

Like in the previous alternative, the above scheme should be interpreted as an example.

100% PV Standalone (Solar Home Systems - SHS)

This alternative consists in individual 100% solar powered systems with battery storage, also needing a battery inverter and charge controllers, as depicted in **Figure 1.3**. Since there is no diesel genset, operation costs are significantly reduced, although the initial investment cost is higher.

The scheme for Solar Home Systems is similar to the hybrid scheme with storage, only differing in the fact that SHS do not use a diesel genset.

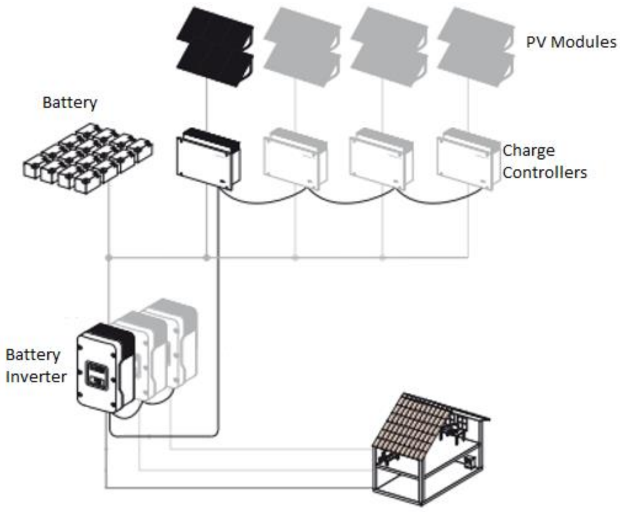

Figure 1.3 - Solar Home System.

1.3 SOLAR/DIESEL TRANSITIONAL GRIDS

Solar/Diesel hybrid systems are a very interesting solution to anticipate electrification in more remote settlements, where the national grid may take several years to come.

In the present work, a simple solution to enable grid anticipation was considered in a way that the implemented equipment of the mini-grid can continue in operation when the system is integrated in the national grid, thus optimizing the initial investment. The Solar/Diesel Transitional grids consist on several distributed LV mini-grids connected to different hybrid solar/diesel systems which would provide in the short-term, a first stage of electrification in an off-grid location. These hybrid systems are to be scattered within the community, as if they were MV/LV transformation stations, forming several small clusters of isolated micro-grids. To avoid high PV and storage capacities, which would translate in high CAPEX costs, lower household service levels could be provided. As a hypothesis, a 12 hours supply service and 1 Amp per client limitation were considered.

The hybrid systems may have a wide range of design solutions, depending on several aspects, as PV radiation or consumption profiles. In order to ensure service continuity, thermal generation should always be designed for 100% peak load (**Hybrid PV/Diesel (with batteries)** alternative).

To maximize its efficiency of operation, diesel generators would operate only in peak hours (~4 hours/day), and the remaining hours would be supplied by the renewable source. As discussed above, PV penetration depends on the combination of PV installed power and storage capacity, and several near-optimum solutions are possible.

In the long-term, when grid coverage is available, the hybrid systems would be replaced by transformation stations that would be connected to the existing LV grid and PV systems, which would remain in operation. For national network integration, the transformation stations would be connected with the required medium voltage distribution lines.

Transitional Solar/Diesel Grids can be an interesting alternative to electrify remote communities until national grid access is available. This solution is a renewable energy based alternative with the objective to substitute diesel fuel consumption, thus reducing operational costs and contributing for the reduction in greenhouse gas emissions. In addition, due to the small storage needs, investment costs are also reduced. Continuity in service is guaranteed by diesel backup and storage capacity. One of the main aspects of this solution is the optimization of the initial investments, since both the PV system and the low voltage grid can continue to be used, when the system is connected to the national grid.

2 TECHNICAL SPECIFICATIONS

Based on a market analysis and on the Consultant's experience, **Table 2.1**, **Table 2.2** and **Table 2.3** with the technical specifications are presented. The information provided is merely indicative, and although the values and comments are the most generally encountered, they are not intended to be restrictive.

Table 2.1 - Solar modules technical specifications.

Solar Module characteristics	
Typical operation mode	Depending on solar radiation
Net efficiency	12 – 16 %
Availability	99% based of solar radiation
Status of development	Mature technology
State of the art	Proven and globally available
Expected lifespan	20 - 25 years
Degradation rate	0 · 8%/year and a median value of 0 · 5%/year

Table 2.2 – Inverter technical specifications.

Inverter characteristics	
Max PV power (per unit)	0 – 1250 kW (typically)
Input voltage range (DC)	200 – 1100 V
Output voltage range (AC)	180 – 460 V
Nominal output frequency	50/60 Hz
Maximum efficiency	94 – 97 %
Status of development	Mature technology
State of the art	Proven and globally available
Expected lifespan	8 – 10 years
Degradation rate	Negligible

Table 2.3 - Batteries technical specifications.

Battery characteristics	
Nominal capacity (per unit)	200 – 5000 Ah
Voltage range (DC)	2 – 48 V
Efficiency	85 – 95 %
Status of development	Mature technology
State of the art	Proven and globally available
Expected lifespan	4 – 8 years
Degradation rate	Dependent on Depth of Discharge (DOD)

3 MARKET PRICES

3.1 SOLAR SYSTEM

To estimate the cost per kW of the system, several components were analyzed. **Table 3.1** provides the base cost solutions found, estimated through market analysis and assessed using the Consultant's experience in the area. Although this approximation is considered to be fairly reasonable for small-scale generation, it is important to state that these costs are merely indicative, and variations will most likely exist when estimating the costs for a specific mini-grid or off-grid system. Note that the table provides only the base cost, which does not include either the diesel generation or the batteries cost.

Table 3.1 - System costs estimation.

Component	Cost [USD/kWp]	Relative Cost Comparison	
Solar Module	605	100%	100%
Inverter	448	74%	141%
Structure	91	15%	
Installation	60	10%	
DC Cabling	60	10%	
Grid Connection	73	12%	
Infrastructure	48	8%	
Other BOS components	73	12%	

Table 3.1 allows estimating the overall system costs by calculating the cost ratio between the solar module and the rest of the system. The value obtained was approximately 141%, meaning that the overall system base cost may be estimated with the equation below:

$$Base\ Cost\ (\text{USD}) = (1 + 1{,}41) * Solar\ module\ cost = 2{,}41 * Solar\ module\ cost \qquad (3.1)$$

Considering again 605 USD/kWp as the cost of the solar modules, the equation for the base cost as a function of the installed solar capacity becomes:

$$Base\ Cost\ (\text{USD}) = 2.41 * 605 * Solar\ Capacity = 1458 * Solar\ Capacity\ (\text{kW}) \qquad (3.2)$$

Apart from the base cost, other components for the types of systems defined previously include a diesel genset, for hybrid systems, and batteries, for systems with storage. These costs are estimated separately.

3.2 STORAGE SYSTEM AND DIESEL GENSET

For systems with storage, batteries are needed. Deep-cycle, lead-acid batteries have been employed in renewable energy and reliably used in off-grid applications for decades all over the world. They provide a robust solution, with a long-lasting design and high operational safety, not requiring much maintenance.

With an analysis similar to the one performed for the solar system costs, the storage system cost has been estimated to be approximately 230 USD/kWh. The size of the battery bank determines the storage capacity, and therefore the investment cost needed.

For hybrid systems, a diesel genset is required. From the Consultant’s analysis, a CAPEX of approximately 250 USD/kW was calculated, considering various gensets specifications. It is relevant to state that diesel generation implies considerable OPEX, estimated to be 10% of CAPEX. Both the CAPEX and OPEX vary with the size and model of the chosen genset. Nonetheless, the values here provided are considered to be a fairly good approximation for preliminary studies.