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SOLAR PV POWER GENERATION: KEY INSIGHTS AND IMPERATIVES

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ABSTRACT: *This paper gives an insight into a key arm of Renewable Energy (RE) - **Solar PV (Photo-Voltaic)**. It presents key definitions, processes and technologies behind the Solar PV power generation process. The literature is clarified in such a way as to ensure a primary understanding of the concept and its processes for anyone willing to key into Solar PV as a clean alternative to electricity power generation. With further deepening of knowledge around this area, acceptability and patronage of Solar PV can be enhanced especially within the country Nigeria, leading to a spiral effect with beneficial implications for competitive/cheaper energy prices, reduced air pollution, improved urban-rural energy accessibility, and reduced global warming and climate change environmental effects. This paper posits that the acquisition of basic knowledge and understanding of the concept is critical, and would influence buy-in and patronage. Ultimately, the prospect of a paradigm shift away from fossil power generation to renewable sources is enhanced.*

KEYWORDS: Solar PV, Renewable Energy, Solar Inverter, Solar Battery, Grid, Solar Systems.

INTRODUCTION

The Solar Photovoltaic (PV) System represents the most visible, competitive and popular Renewable Energy (RE) in Africa. It enjoys relative affinity with the general population especially when compared with other RE sources like Wind, Biomass, Geo-thermal and Wave. Accordingly, it is imperative, that knowledge around this field is stimulated to drive and deepen understanding and awareness. Solar PV consists several components including solar panels, inverter, photovoltaic mounting systems and other critical accessories that make up the system. Solar PV is distinct from Solar Thermal and Concentrated Power Systems. Solar PV is designed to supply domestically usable power made possible by the use of photovoltaic.

Photovoltaic (PV) as a process was first discovered in 1839 by Alexander Edmond Becquerel, while experimenting with a solid electrode in an electrolyte solution. Silver Chloride, while connected to platinum electrodes, was placed in an acidic solution and illuminated. Becquerel discovered that a voltage was developed when light struck the electrode. The Photovoltaic effect at the time, was called the Becquerel Effect, **[29].**

The first solar module was built in 1883 by American inventor Charles Edgar Fritts, who constructed solar modules by coating a copper plate with Selenium topped with a thin semitransparent layer of gold leaf. The module, produced a current which he described as, 'continuous, constant and of considerable force'. The current he discovered was not only responsive

to sunlight, but also to daylight and candle light. German scientist, Werner von Siemen, after examining Fritts' Solar Panel, presented it before the Royal Academy of Prussia and in doing so, he declared that the Fritts' panel marked the first direct conversion of sunlight energy into electrical energy, in what was also regarded as the first solar photovoltaic process, **[32]**. Selenium (Se), is a chemical element, a non metal commercially produced as a bye product of refined metal sulfide ores. It is a semi conductor used in photo cells. It occurs as a major part or constituent of the Copper Indium Gallium Selenide cell (CIGS), which is a thin-film solar cell used to convert sunlight into electric power.

Solar PV systems have developed into mature technology competent for mainstream electricity generation. The cost of photovoltaics has also declined owing to advances in technology and increase in scale of manufacturing and sophistication levels. The Global PV market is fast growing with forty times the installed capacity it was ten years ago. Solar PV is currently responsible for contributing at least 1% to electricity generation worldwide. The International Energy Agency (IEA) envisages that solar power will be the world's largest source of electricity by 2050.

Problem Statement

Research reveals a low level of citizen awareness, basic understanding, and knowledge of Solar PV in Nigeria as an alternative source of sustainable energy. This constitutes a barrier preventing the buy-in or adoption of Solar PV by prospective energy end users country wide. A sample survey of Respondents across the six geo-political zones of the Federal Republic of Nigeria in 2018, [15], indicated 53% had little to no awareness and understanding of Solar PV/Renewable Energy with specific regard to what it is, how it works and its source. Another 17% were not sure if they had any understanding at all (itself an indication of a seeming lack of complete awareness). Only 19% of Respondents acknowledged an average to high understanding and awareness of Solar PV - what it is and how it works. Accordingly, this paper addresses Solar PV (its process and how it functions to generate electricity), in such a way as to stimulate primary knowledge and understanding which is key to influencing citizen sensitization, information and buy-in.

The Solar Photo Voltaic (PV) Process

Solar Photovoltaic (PV) comprises a process in which electric current/voltage is generated when silicon crystals embedded in the Solar Panel are exposed to sunlight. Crystalline and Amorphous Silicon are modified silicon crystals, and they are the embedded materials responsible for light conversion to electricity, [6]. The Solar Photovoltaic Cell (Solar Cell) converts sunlight (photons) into electrons as Direct Current (DC). Photo means light, while voltaic means electricity; light-electricity is its literal meaning. The PV power system at the first instance, generates DC, which is not constant and fluctuates with sunlight intensity or lack of. Hence, for safe domestic use, DC is converted to Alternating Current (AC). Inverters are instrumental to DC to AC conversion at the required voltage and frequency. This is important because this is central to making it compliant for use in appliances, electronics and other gadgets requiring electricity to function or operate at safe output, [13]. Also, considering the fact that sunlight irradiance is not constant through the day but limited to most parts of day time, solar energy saving devices like batteries are required to save up or conserve the solar energy captured by the solar panels during the day, hence ensuring a consistent and efficient electricity supply through night time.

A **Solar Panel** consist of Photovoltaic Cells which are made from Silicon. Silicon is responsible for the transformation of incoming sunlight into electricity. Solar PV cells comprise positive and negative Silicon films which are placed mostly under thin glass. When sunlight falls on the glass and onto the PV cells, the sunlight photons knock the electrons off the Silicon. The free electrons are attracted to one side of the Silicon cell which creates an electric voltage that is then channeled. Electricity produced at this stage is Direct Current (DC), and for domestic use purposes, the DC is converted to Alternating Current (120 Volts AC) by the Solar Inverter, [29].

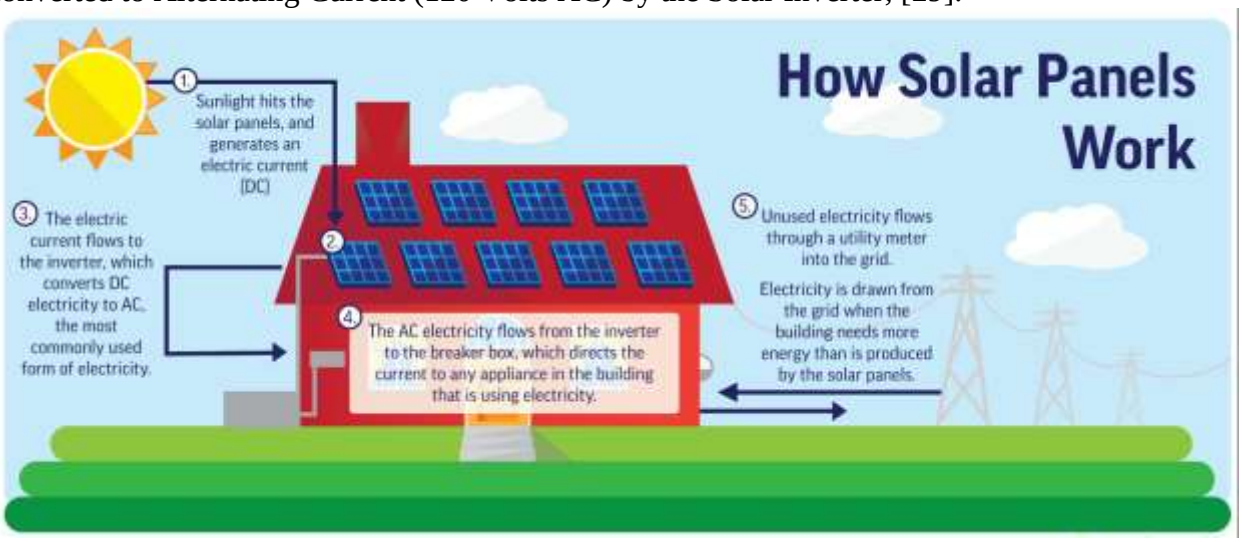

Figure 1: **Illustration** - How Solar Panels Work, **[25]**

A **Solar PV Inverter** is a major component of the Photovoltaic System. It is an electrical device that combines mechanical and electronic circuitry in changing or converting DC (fed in from the solar panels), to AC, [1]. The inverter is the heart of every PV set up, it controls and monitors the system ensuring it is operating at the right temperature and radiation dependent power. It is important that the inverter is at a good conversion efficiency meaning the proportion of energy 'fed' in as DC is outputted as AC at a minimum of or above 95%. The inverter optimizes power irrespective of the solar radiation intensity (or not) on the day, and does so by identifying and continually monitoring the optimal operating point on the power characteristic curve so as to bring out maximum power from the Solar PV modules, [19]. The optimal operating point is called the Maximum Power Point (MPP). The inverter monitors and secures the Solar PV system ensuring the yield is observed and any problems detected, it also monitors the grid that the PV system is connected to, and works to disconnect the PV system from the grid in the event of a safety problem or the need to support the grid. The inverter has an in-built device to cut or interrupt current from the Solar PV modules which are always live as long as the sun is shining and cannot be switched off, hence the inverter moderates and limits what would have been an unrestricted flow of Direct Current (DC). Selecting a suitable inverter is essential especially when it comes to efficiency, performance and technology. An undersized inverter is bound to have a negative effect on the Solar PV system yield as it will not have the required capacity to process a large amount of module power transmitted during high solar radiation periods. To prevent damage, the permissible inverter input voltage must not be exceeded by the maximum Direct Current voltage, [22]. The inverter is

used in both grid and off grid solar power set ups. Solar Inverters are of three major types, namely, The Grid Tie, Stand Alone and Battery Backup Inverters.

(i) **The Grid Tie Inverter (GTI)** is an electronic device which converts DC to AC and is capable of operating in parallel with the utility grid. The DC voltage converted by the inverter can be fed by storage batteries or the mounted solar panel and allows inter-connectivity of the electricity grid with renewable energy systems. The GTI is capable of providing electric power to a house while simultaneously re-routing the excess into the main grid and in so doing potentially lower the house electric bill. GTI circuits can be one, two or three stages, depending on the wattage and voltage levels.

(ii) **The Stand Alone Inverters** are used in isolated systems. This inverter is structured in such a way that it draws DC from PV charged batteries. They are designed for remote stand-alone applications or off grid power systems with a battery backup. In this design set up, the inverter draws its DC power from batteries charged by a PV array and converts to AC power. The Stand Alone Inverter comes in a variety of size and output, the Pure Sine Inverter is most suitable for Solar Home Systems, and rural electrification systems in areas without utility grid.

(iii) **Battery Backup Inverters** are designed in such a way that they draw energy from a battery, and while managing the battery charge, move the excess energy to the grid. The battery backup inverter have anti-islanding protection and is capable of supplying AC energy to select loads during an outage.

A **Solar Battery** is a device containing, or that stores energy received directly from the solar panel. Solar batteries serve as the 'arteries' of an efficient solar panel system. Solar batteries store energy originally transmitted by the sun through the solar panel, enabling the inverter to convert it to Alternating Current (AC) for use, [17]. In choosing the best Solar Battery for use, it is important that specific variable are initially established like the Capacity, Power, Depth of Discharge (DoD), Round Trip Efficiency, Battery Life/Warranty and Manufacturer, are important variables in the whole solar battery and system efficiency mix, and a pre-purchase tick off on all these variables will guarantee efficiency and user satisfaction.

Storage batteries are popularly of three types, namely lead acid, lithium ion and salt water.
Lead acid batteries are popular and have been mostly associated with off grid energy systems for many decades, they have a relatively short life and low DoD, although least expensive. Lithium ion is popularly used in solar panel systems, and widely regarded as the best of the options. They are lighter and more compact than the lead acid batteries. They also have a higher DoD and life span, but more expensive, [17]. Saltwater batteries are not made of the usual heavy metal compositions which make up the last two, they comprise of salt water electrolytes and are easily recycled. They are however relatively untested and unproven hence very minimally used when it comes to solar panel systems.

METHOD

This section describes the methodology behind the presentation of this paper - the influence and framework behind its approach. It underlines critical reasons for adopting its design. It explains in details the philosophical approach adopted and with the aid of references backs up this choice. It spells out the methods used in gathering secondary data used and the reasons behind the choice. The methods adopted in this research, were chosen because it proves to be the best alternative in aiding the realisation of the paper's objectives and adequately providing the most effective means through which the papers submissions are tested and questions answered.

Research method is defined as, 'a systematic and orderly approach taken towards the collection and analysis of data so that information can be obtained from those data', [12].A research design provides the direction needed to carry out the research paper, and if correctly chosen, the right design will help provide relevant data or information in response to research questions, [4]. Three types of research designs exist, i.e. the exploratory, descriptive and explanatory research designs. The exploratory design is adopted when there is the need to investigate 'what is happening', gain new insights, assess phenomena, ask questions and clarify understanding of a problem' – [21]. This design adopts literature review and case studies as means of conducting research. The descriptive research design is an extension of the exploratory design and is adopted if the research objective is to 'have a clear picture of the phenomena on which you wish to collect data prior to the actual collection of data' – [21]. The explanatory or causal design is applied when there is the need to establish or describe the relationship between variables, and this is usually achieved by means of qualitative or quantitative data gathering and analysis, **[21].**

This paper is of exploratory research design. This design was adopted considering the papers objective, which was to 'clarify' understanding around Solar PV as an alternative source of clean and sustainable energy, and how it works or operates as a system. The exploratory design is used when there is the need to, 'gain new insights, assess phenomena, ask questions and clarify understanding of a problem, **[21]**. The exploratory research design adopts literature review as a means of conducting research, clarifying gaps, boosting knowledge, understanding and awareness around a specific area or topic, **[4]**. This has been done in the course of producing this paper; specific and related literature have been reviewed in coming up with the necessary informative and educative resource. Literature review is, 'a critical evaluation of the existing body of knowledge on a topic, which guides the research and demonstrates that the relevant literature has been located and analysed', **[3]**. In writing this paper, specific literature in the form of journals, articles, research papers and publications have been reviewed to obtain the necessary information and data needed to satisfy and fulfil the objectives.

SOLAR PV POWER GENERATION PROCESS: DISCUSSION

Solar electricity, also known as Photovoltaic technology, is the process through which sunlight is directly converted to electricity. Solar as a source of electric power has been put to use for decades in rarely mentioned areas like space programs. In the last decade, the advances in solar PV technology has meant the emergence of a stronger electricity power market which has provided viable alternatives in powering both grid and off grid homes. Despite the existence today of various

types of Solar electric systems, three components that make up each of these individual systems are at the core of their operating systems; these are namely - the module, inverter and battery (depending on the type). The solar modules convert sunlight into electricity, the inverters convert the same electricity (DC) from the modules into Alternating Current (AC) making it safe for domestic and household use. The batteries store up excess electricity produced by the solar PV system. Other components which are equally important include equipment such as circuit breakers and wirings. With the advance of Solar PV technology, sunlight converting modules are now built into glass roofs, walls, car roof tops.

A process called Net Metering ensures additional electric power produced by the PV system (which is in excess of that being used by the building and stored in the battery), can be fed back into the grid, allowing the customer to pay only for the net electricity consumed - which is the power consumed by the consumer from the grid minus (-) the power generated by their solar PV system. With the metering system, consumers are able to realize good value for the electricity produced by their PV systems. Solar PV systems, as will be further expatiated, differ slightly with specific regards to the presence or not of battery storages within the system. Grid connected (On grid) PV systems do not require batteries, save for some in which they are used for backup power in emergency situations. The Off grid and the Hybrid PV systems both have the use of batteries considering their peculiar nature and the alternative power option they are conceptualized and built to provide.The Solar Energy Systems, come in various configurations and is basically a choice between staying completely Off grid or On grid. The figures below are illustrative of the three common Solar Photovoltaic (PV) power systems.

On-Grid Solar System

Also known as the Grid Tied system, is always connected to the grid as the name (grid tied) suggests. The excess energy that the solar panels produces is fed to the grid. During periods in the day when there is no sunlight, and the domestic load consumption goes up, it draws from the grid's electricity. For the Grid tied system, the use of a battery to store electrical energy is unnecessary as the grid serves as its means of storage - this has its benefits and disadvantages. The On Grid Solar system is relatively cheaper than the Off-grid or Hybrid systems. Its disadvantage lies in the fact that electricity cannot be stored within the system, hence, if the grid is down at anytime, there will be no alternate source of electricity.

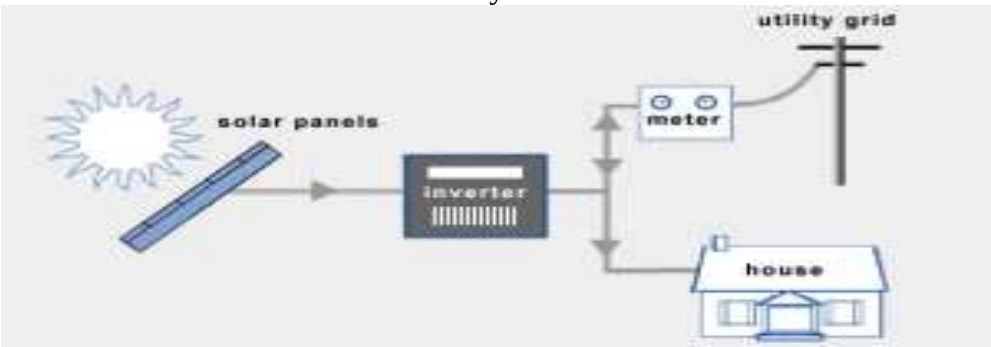

Figure 2: On-Grid Solar System, [20]

Figure 2 further illustrates the lack of battery within the On Grid Solar System, the arrow heads also indicate the working pattern as the sun rays from the solar panel are immediately fed to the inverter as DC, converted to AC and supplied to the house, the excess load of which is sent to the grid, having been measured through the meter.

Off-Grid Solar System

The Off grid solar system is also referred to as the Stand Alone Solar System. As the name implies, they are not connected to the grid, the solar panels produce electricity which is stored in the battery banks. Night time, the stored power is used to provide electricity. The Off grid solar system is popularly mostly used in remote areas with little to no grid connection or power supply. It's advantages lies in the feeling of energy self-sufficiency it gives, and the fact that grid failures and power down times won't affect system power supply. Its disadvantage lies in the additional cost that come with battery bank or generator installations, and the increased need for delicate care and maintenance services.

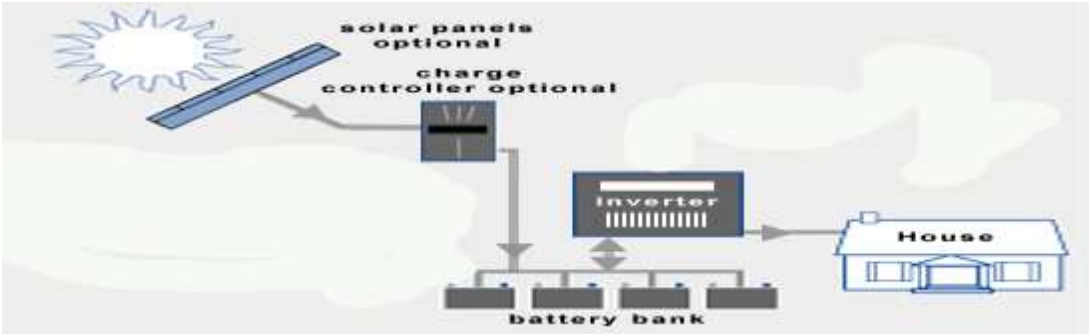

Figure 3: Off-grid Solar System, [20]

The Off grid Solar System as explained and illustrated above in Figure 3, is stand alone - completely separate and independent of the grid. It comprises the solar panel, a charge controller, inverter and then the house receiving the electricity supply. The solar panel receives the sun rays and sends to the battery for storage, there is an optional charge controller which serves the purpose of limiting the rate at which electric current is added or drawn from the battery. The inverter converts to AC current ready for residential supply and use.

Hybrid Grid Solar System

The Hybrid Grid Solar System is a combination of core aspects of the On Grid and Off Grid Solar Systems. The Hybrid Solar System does not require a backup generator. They can often also be referred to as, 'Off grid solar systems with a utility back up option'. It has advantages like the ability to switch between grid power and battery power at will. It is less expensive than a complete stand alone system and has no need for a backup generator as the possibility or option for grid connection serves as backup power. The downside or disadvantage to it is that it can hardly be used in remote areas which has no grid connection or power.

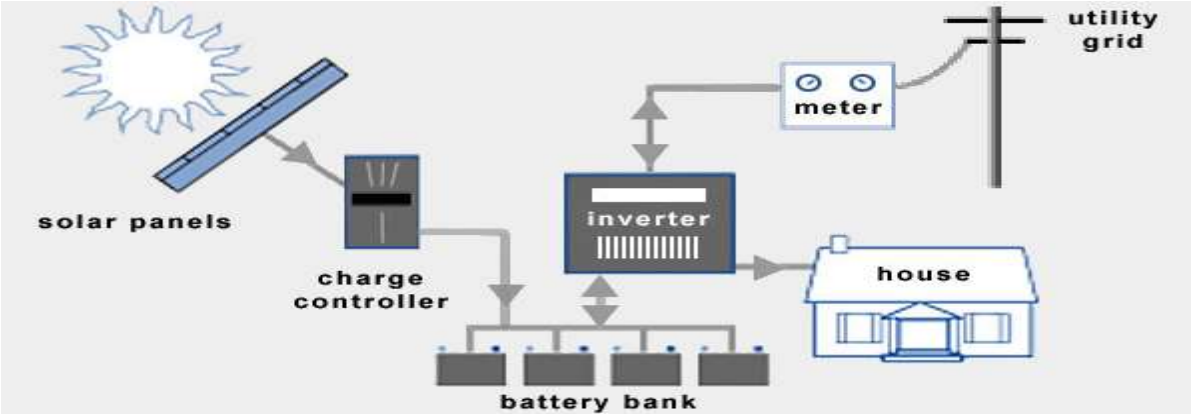

Figure 4: Hybrid Grid Solar System, [20]

As can be seen from figure 4 above, the Hybrid Grid Solar System consists of solar panels, charge controller, battery bank, inverter and meter - which are dual connected to both the house and the grid. The arrow heads in the figure above indicate the working pattern, right from the sun relaying its rays onto the solar panels and then through the charge controller to the battery banks and inverter.

Though relatively expensive, PV cells are easily maintained. They are environmentally friendly and produce no greenhouse gas emissions. Solar PV cells presents no noise pollution compared to hydropower stations and wind turbines which let off a large amount of noise. Solar cells have very minimal environmental impact as it does not emit or give off waste, neither does it deplete natural resources or endanger human or animal health. A Solar PV system has a minimal 20 year life-line, with little need for rigorous maintenance.

However, with Solar PV energy production primarily dependent on the sun, it can safely be said Solar power is a variable source of energy, meaning Solar PV facilities will produce little to no power during night time or long cloud spells etc. Solar batteries are however part of the Solar PV power system, to cater for this deficit, by mitigating this effect and the energy shortage that comes with it.
It is important to note that, potentially toxic chemicals like Arsenic and Cadmium are used in Solar PV production process; its environmental impacts are however minor, and any residual effects managed through proper material/waste recycling and disposal. Solar Energy is relatively more expensive to produce and this is due to the high cost of producing PV equipments, and the currently low conversion efficiencies of these equipments. However, manufacturing or production costs are currently dropping across global markets. A complementary increase of conversion efficiencies are also being witnessed. Solar PV technology promises, over the next few years of research, innovation and development (R&D) to become increasingly more cost competitive with fossil/nuclear fuels.

CONCLUSION

This paper set out to stimulate understanding, and knowledge around Solar PV, as a critical arm of Renewable Energy. Emphasis was paid to expatiating its concept, processes and components, and how these put together, enable the clean generation of electric power as a viable alternative to fossil or nuclear fuel.

The objective of the paper is premised on the hypothesis that there is a gap driven by relative dearth of literature disseminating basic knowledge around the topic area, i.e. a preponderant number of literature inadvertently focus on technicalities, technologies and other advanced and complex aspects of Solar PV. A poor primary understanding of Solar PV will stymie a competent grasp of the more complex technicalities and its associated technologies, besides, lack of knowledge influences lack of appreciation and patronage.

Accordingly, this paper comprises a critical evaluation that brings to the fore, defines and explains Solar PV, making understanding easier for the casual observer or 'lay man' who are primary energy consumer targets and key denominator in the ongoing paradigm shift from fossil fuel to clean sustainable energy.

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KEY TERMS AND DEFINITIONS

Solar PV: Solar Photovoltaic in full, is a solar powered system designed to receive sunlight energy, convert same to alternating current (AC), and supply outwards for either domestic or commercial purposes.

Renewable Energy: also referred to as sustainable or clean energy, refers to energy that is obtained from renewable resources. They are replenished naturally and non depletive. Tides, waves, sunlight, wind and geothermal heat are renewable energy sources.

Solar Panel: also known as photovoltaic panel or module, is designed to absorb sun light as a source of energy into the solar PV system where it is converted and generated as usable electricity.

Solar Cell: also known as the PV cell or photovoltaic cell, is an electrical device that converts light to electricity through a process known as the photovoltaic effect.

Solar Inverter: is an electrical converter which converts Direct Current (DC) sent from the solar PV panel, into Alternating Current (AC), which can now be used for both domestic and commercial purposes, or even fed back into the grid.

Solar Battery: is a device that is charged with electric energy from solar PV panels, and works to reserve this same energy for subsequent consumptions during grid power outages.

Grid: is an interconnected electricity delivery network comprising generating stations, high voltage transmission and distribution lines.

Alternating Current (AC): refers to the specific form in which electricity or electric power is delivered to, or utilized for domestic and commercial purposes. AC is what the solar PV system supplies to the building for domestic consumption, or the grid in excess.

Direct Current: refers to the unidirectional flow of electric charge. It is produced directly by PV cells and sent to the inverter for conversion to AC for safe domestic use.