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Conceptual Study on Renewable Energy and Electric Vehicle Integration in Smart Grids

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ABSTRACT

Smart grid technology plays an important role in the efficient use of distributed energy resources. With the increasing global CO_2 emission rate and reduction in cost of renewable energy power systems, opportunities for renewable energy systems to address electricity generation seems to be increasing. To achieve commercialization and adoption for the local independent user, an understanding of the technologies involved as well as their implication is necessary. This paper presents a study on the smart grid challenges, technologies involved, and the integration of renewable sources. This explores the challenges and technologies used in integrating smart grid with renewable energy sources so as to achieve the demand side management. The introductory section provides a brief overview of the smart grid system. Subsequent sections cover the applications of smart grid as well as benefits, Issues and renewable energy integration in smart grid systems. This study would be useful to smart grid developers and practitioners of renewable energy systems and policy makers.

Keywords: *Smart Grid, Renewable energy Integration, Micro-grid, Electric Vehicles, PV.*

1. INTRODUCTION

A Smart Grid (SG) is an electricity network that leverages on Information Communication Technology to enhance the operation of conventional electricity grid. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce energy consumption and cost, and maximize the transparency and reliability of the energy supply chain. All components of SG are capable of two-way wireless communication to allow rapid exchange of information signals among themselves. These signals are relayed to the control centre, and analyzed to take suitable decisions. This enables rapid restoration of power in case of outages, adding a self restore feature to the grid. It also provides information to the consumers about their energy consumption, and tariffs. This empowers them to manage, and efficiently use energy. SG technology, thus, leads to a sustainable energy system with minimum wastage, and maximum utilization of clean energy. Thus, SG can provide an uninterrupted power supply to the end users by striking a balance between demand, and supply [1].

A smart grid's key features include:

- **Load Handling**: Smart grids are equipped with technology that can advise consumers to temporarily minimize energy consumption in situations where heavy loads are connected to the system. This is due to the instability of grid load over time.
- **Demand Response Support**: This provides automation that enables users to reduce their electricity bills by guiding them to use low-priority electronic devices when rates are lower.
- **Decentralization of Power Generation**: A distributed or decentralized grid system allows the individual user to generate onsite power by employing any appropriate method at his or her discretion

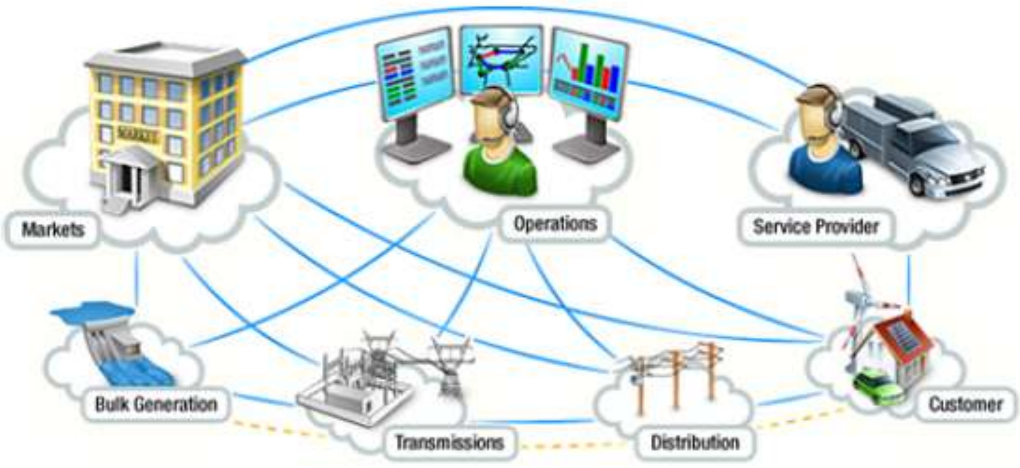

Figure 1: Image of a smart grid Network [2]

The Smart Grid is designed to be user centred, market-based, reliable, interactive, flexible, and sustainable. Its deployment dates back to 2010 and improvements are continually made, resulting to the following [2]:
• Increased hosting capacity for renewable and distributed sources of electricity.
• The integration of national networks into an only market-based European network.
• A high level of quality of electricity supply to all customers.
• The active participation of users in markets and energy efficiency.
• The anticipation of new developments such as a progressive electrification of transport.
• An economically efficient deployment of future networks, for the benefit of grid users.
• The opening of business opportunities and markets for new players in the smart grids arena. [3]
The demand for electric power is continuously increasing. This poses a challenge to the existing grid to minimize the demand-supply gap. But, increasing the power generation faces global climatic constraints. The world faces a serious threat posed by the carbon footprint and the Greenhouse Gas (GHG) footprint, resulting in adverse climatic changes. To overcome this issue, there is a need to switch over to Renewable Energy or green energy [1]. Electric Vehicles (EVs) have been seen as an effective way to reduce carbon emission by many countries. However, EVs need to be connected to the electric power grid for charging and this does not come without cost. Indirectly, EV's still contributes to global emission rate especially if the energy grids housing the charging stations are dependent on energy sources that emit a high amount of carbon to the atmosphere. Secondly, they need to be more investment to expand the capacities of generation, transmission and distribution due to the boosting charging requirements of EVs [4]. In the construction of a smart grid, EV charging station incorporated with PV systems will play an important role. The integration of PV with EV charging station in a micro-grid or distribution system is a possible way to effectively improve the emission reduction of EVs, meet the daytime charging demand and reduce the dependence on the power grid [4].

2. SMART GRID APPLICATIONS

Smart grid technologies find application across the world. This ranges from isolated islands to very large integrated systems. In the developed world, smart grid technologies enable the upgrading and extension of existing grid systems, while providing opportunities for the incorporation of innovative solutions. In developing countries, smart grid technologies are essential to avoid lock-in of outdated energy infrastructure and attract new investment streams. This creates an efficient and flexible grid system that accommodates the rising electricity demand and a range of different power sources. Smart grid technologies offer a long list of benefits, below are some of the benefits:

- It enables end-users as well as energy suppliers to decrease the number and the duration of high demand periods.
- Smart grids help to reduce grid maintenance costs, energy losses and also reduce the need for stand-by generators thus offering a qualitative and reliable service would to end-users.
- Smart grids enhances the energy efficiency of the grid to the benefit of the end-users by both coordinating and scheduling low priority home devices, so that their power consumption takes advantage of the most appropriate energy prices and/or energy sources at a given time.
- Smart grids enables power outage anticipation as well as service perturbation detection through real-time information transmitted over communication networks.

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- Smart grids rapidly detect and analyze data coming from the distribution network so as to take corrective actions and restore power stability when needed.
- Smart grids lower CO2 emissions by reducing end-user energy consumption during peak hours, when electricity is generated through power plants that produce a lot of CO2 emissions.
- Smart grids can also optimize capital assets: power production from a large number of small power providers using renewable energies (PV panels and small wind turbines) which can be synchronized, leading to arrangements at local levels, and power production from centralized power plants which can be optimized. End-users benefits from the lowest-cost generation sources, as well as from centralized renewable energy sources (wind turbines). [5] [6]

Beyond these benefits, smart grid technologies interestingly enable a high level of inclusion of renewable energy source in an electricity system. With renewable power shares sure to continue increasing, smart grid technologies in combination with appropriate supporting policies and regulations will be essential to transform the electricity system and create the grid infrastructure to support a sustainable energy future [7]. Harmonizing both ICT (information communication technology) with energy renewable sources can generate new ways for achieving energy savings and lowering CO2 emissions [6].

3. SMART GRID ISSUES

Before exploring how smart grids are supporting variable RE integration around the world, we first examine the challenges facing RE grid integration. Two distinct categories of challenges can be identified, which are:

1) Energy management Challenges:

The Energy demand has been constantly growing over the last few years, partly because of the emergence of new electrical applications and the integration of new technologies for transportation (EV's), requiring increasing investments in the energy producing sector. Also, during certain periods, the electricity distribution network usually comes under stress, because of high power demand. In order to face the rising electricity demand, a number of solutions for efficient energy consumption are sort after. Variable Renewable Energy (RE) sources are both more *uncertain* and more *variable* than conventional generators. For instance, prediction of reliable power generation for Wind farms provide a useful illustration of uncertainty, while it might generate a reasonable percentage of power in a year, yet it is not easy to predict far in advance when generation will occur. A rooftop solar installation provides a useful illustration of variability: transient events such as cloud passage can reduce output quite rapidly. Generally, solar PV output is more variable than wind (changing faster on a minute-to-minute basis), but it is less uncertain. Techniques have been developed to tackle these issues [8]. Figure 2 illustrates how spreading solar photovoltaic's (PV) over a larger geographic area tends to reduce aggregate variability.

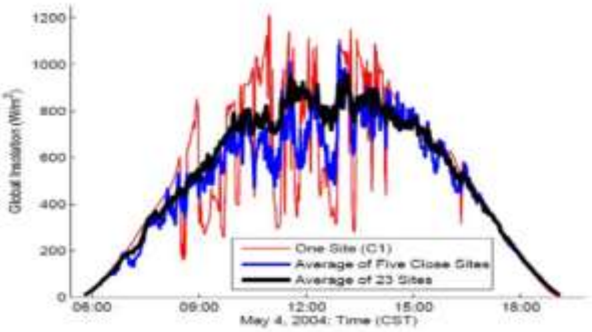

Figure 2: Illustration of how spreading solar Photo-Voltaic (PV) cells over a larger geographic area tends to reduce aggregate variability [8]

Energy management systems are being developed to optimise energy consumption. According to [9] smart grid energy management systems are classified according to the following objectives: Energy efficiency, Demand profile improvement, Cost Optimization and Price Stabilization, and Emission Control. Researchers have adopted various methods and tools to solve these objectives. Currently, researchers mainly use optimization approaches, game theory and machine learning to tackle these objectives. [9]

2) Economic, Policy, and Regulatory Challenges:

In addition to energy management challenges, institutional challenges also arise with increasing shares of variable RE. Two specific challenges are identified by [8], which are: Capital-intensive grid upgrades and uncertain project costs and cash flows.

➢ Capital-intensive grid upgrades

Grid upgrades may be required to accommodate wind and solar power. For example, to the extent high quality wind and solar resources are located far from demand centers, new transmission lines or upgrades to existing lines may be required. At the distribution level, rooftop PV may accelerate the fatigue of distribution components, such as low-voltage transformers, moving forward the need for grid upgrades. Minimizing the cost of upgrades, while ensuring system reliability, translates to greater value from RE investments [8].

- **Uncertain RE project costs and cash flows**

Smart grid solutions are emerging to two specific issues that historically have negatively impacted RE project economics: grid upgrade costs allocated to RE project developers and energy curtailment when full RE production cannot be readily integrated into the power system. Both issues may cause cash flows of the project to diverge further from expectation. To the extent upgrades become costly or curtailments increase, the investment landscape for variable RE becomes more uncertain and can slow overall deployment. In cases where policy measures and subsidies insulate project investors from these risks—for example to further enhance the investment environment for RE—costs and risks may be socialized. Smart grid investments can also play an important role in reducing those costs and risks. Smart grid solutions emerging to address the economic, policy, and regulatory challenges of variable RE include [8]:

• **Dynamic line rating**: Real-time information about transmission line capacity can allow grid operators to extract more value from existing lines, reducing the need for costly upgrades.

• **Demand response**: Enabled by smart meters and intelligent loads, customer demand response solutions can help absorb excess RE generation, reducing the need for distribution upgrades.

• **Smart inverters and other advanced power controls:** Smart inverters and other power controls can reduce the need for significant grid transmission and distribution upgrades, thus reducing costs that may otherwise be levied on RE projects or socialized.

• **Grid-scale storage:** Large-scale storage of various types can help to reduce the need for additional transmission capacity.

• **Behind-the-meter storage:** Customer storage solutions can help absorb excess PV generation, reducing the need for distribution upgrades.

• **Advanced energy management systems:** Advanced energy management systems that provide real-time, high-resolution visibility and control of power systems, can allow grid operators to defer more costly capital expenditures.

• **Better forecasting:** System-level forecasting can help system operators operate their grids more flexibly, allowing more production to be accepted. [8]

4. SMART GRID TECHNOLOGIES

Smart grid technology is generally seen to include a wide range of communication, information management and control technologies that contribute to the efficiency and flexibility of an electricity system’s operation. Smart grid technologies vary widely in cost, applicability, and market maturity. These technologies can be put into four functional categories [7].

- **Information collectors:** These sensors generally measure performance-related characteristics of electricity system components. Examples include meters that continually measure the power and electricity output of a distributed renewable generator; sensors that track temperature, vibration and other characteristics of a transformer; and meters that measure electricity characteristics (voltage, current, etc.) of a distribution line.
- **Information assemblers, displayers, and assessors:** This category includes devices that accept information and display and/or analyse it.
- **Information-based controllers:** These devices receive information and use it to control the behaviour of other devices to achieve some goals, such as reduction of electricity expenditure or stabilisation of a voltage.
- **Energy/power resources:** These include technologies that can generate, store, or reduce demand for electricity.

The smart grid technologies commonly deployed includes:

a. Advanced Metering Infrastructure

These are smart electricity meters and incorporates the communications and data processing equipment needed to collect smart meter data and deliver it to the grid operator [10] [7]. AMI facilitates the integration of renewable power sources; it enables advanced electricity pricing schemes, which can improve the economics of distributed PV. AMI also serves as the communication link that enables (Demand Response) DR, which is synergistic with PV.

b. Advanced Electricity Pricing

It is a common experience to observe that most electricity consumers are charged the same price for every kWh they consume. In such conditions, what consumers pay do not reflect the true costs of production. Advanced electricity pricing refers to a broad range of approaches and pricing programmes that try to make consumer prices more accurately reflect real-time production costs so that customers shift consumption toward times when electricity is less expensive. [7] Some of the approach includes:

- **Time-of-Use Pricing**

Generally, electricity usage typically peaks around the same period of time every day for a given area. A time-of-use (TOU) price schedule is usually used to discourage electricity usage during peak times. This is such that electricity is least expensive when loads are low (typically at night) and most expensive during peak times (usually afternoons). TOU pricing is typically advantageous for solar PV, which produces power during the daytime, when the price is usually high.

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- **Critical Peak Pricing**

Critical peak pricing (CPP) is a dynamic pricing programme in which utilities signal customers when loads are approaching (or are expected to approach) annual peaks. Customers who respond by reducing loads are compensated. Often, customers are notified a day in advance based on demand forecasts [11]. As with TOU pricing, CPP customers may adjust loads manually or use BEMS/HEMS to manage loads automatically. [11]

c. Demand Response

This refers to techniques for reducing electric system loads during times of peak electricity usage or when renewable output drops [12].The benefits of DR include avoiding the use of the most expensive bulk generation plants, avoiding construction of additional generation and transmission capacity, and avoiding brownouts and blackouts. DR programmes can also be configured so that grid operators can turn *on* customer loads during times of low system load to avoid having to cycle central generation plants below minimum values.

d. Distribution Automation

In general, "DA" refers to various automated control techniques that optimise the performance of power distribution networks. In contrast to transmission networks, electrical distribution networks have historically not included much sensing and control outside the substation. It is now becoming more common to implement smart grid DA techniques. Some of these techniques include:

- Volt/Volt-Ampere Reactive Control and Optimisation
- Automated Fault Location and Restoration

Distribution networks use switches and breakers to isolate faults from the rest of the circuit, limiting the number of customers affected (for example, when a branch from a tree falls on power lines). Devices called reclosers, which can open temporarily and then re-close after a brief time, can reduce the impact of temporary faults. Historically, breakers, switches, and reclosers are not monitored or intelligently controlled. Adding sensing to these devices and controlling them using intelligent algorithms can reduce the frequency and duration of outages even further by locating faults more accurately and isolating smaller sections of the grid. Feeders can be reconfigured automatically to route power around fault locations. Intelligent control of switches and reclosers also helps ensure they operate properly in cases of reverse power flow that may occur with distributed resources. [7]

e. Renewable Resource Forecasting

Accurate forecasting of power output from wind and solar resources can alleviate many of the cost and operational challenges related to their variability and increase the value of RE, because power predictions become more certain. Solar power forecasting is expected to mature quickly as grid penetration levels increase [7]. Wind forecasting providers are beginning to expand into solar forecasting. Solar forecasting is already in use by utilities that have large PV plants, but because most solar power variation is due to visible clouds, satellite imagery can be used in addition to traditional weather prediction methods. Wind plant power forecasting has become a priority for grid operators as utility-scale wind plants have come to make up a significant portion of grid capacity in some areas. With wind penetrations around 25%, studies have shown that wind forecasting can save tens to hundreds of millions of dollars per year in operating costs over several states in the U.S. [13] [7]

f. Smart Inverters

Inverters are electronic devices that connect most RE sources and energy storage devices with the electric grid, including PV, wind turbines and battery systems. Early inverters were designed to inject only real power (no reactive power) onto the grid. This causes the grid voltage to rise whenever RE output is high and to fall when RE output drops. This problem is easily fixed by employing inverters capable of providing reactive power (VARs) to regulate the grid voltage at their point of connection. Injection of VARs to control voltage is called volt-VAR control [7]. RE sources have several drawbacks from an electricity grid operator's point of view. They can cause transient grid voltage fluctuations ("flicker"), steady-state grid voltage problems and frequency deviations. However, when smart inverters are used to interface RE sources with the electric grid, these problems can be mitigated [14]. In some cases, renewable sources employing smart inverters can even improve grid power quality beyond what it would be in the absence of renewables through for example, providing reactive power when the grid needs it. [7]

g. Microgrids

The microgrid can be seen as the building block of smart grids. It comprises low voltage (LV) system with distributed energy resources (DERs) together with storage devices and flexible loads. The DERs such as micro-turbines such as, fuel cells, wind generator, photovoltaic (PV) and storage devices such as flywheels, energy capacitor and batteries are used in a microgrid. The microgrid benefits both the grid and the customer. [15]

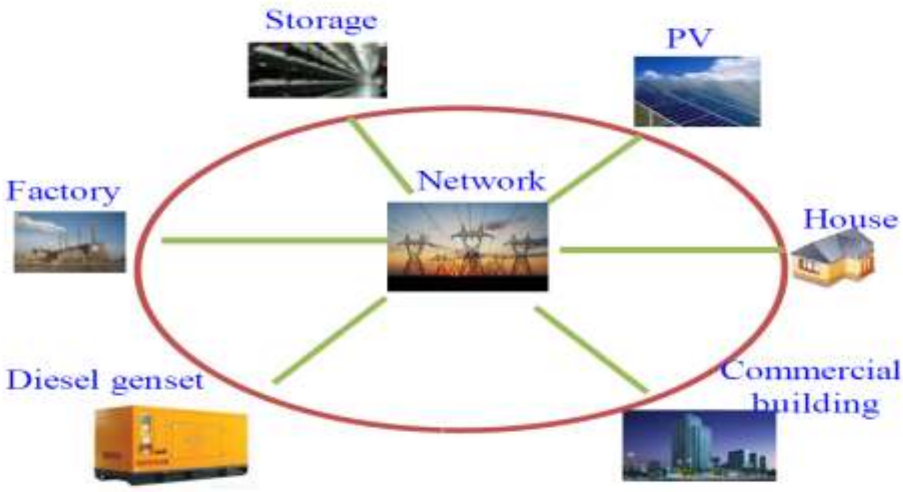

Figure 3: Micro-grid concept

A typical micro-grid includes:

- An intelligent micro-grid switch to handle connection and disconnection from the central grid.
- Internal energy sources (often including energy storage).
- A micro-grid controller to control and optimise micro-grid resources. [7]

A microgrid has two modes of connection:

- **Grid-connected Mode**: The micro-grid (MG) is connected to the upstream network. The MG can receive totally or partially the energy by the main grid (depending on the power sharing). The excess power generated can be sent to the main grid (when the total production exceeds consumption).
- **Island Mode**: when the upstream network has a failure, or there are some planned actions (for example, in order to perform maintenance actions), the MG can smoothly move to islanded operation. Thus, the MG operate autonomously,this is called island mode, in a similar way to the electric power systems of the physical islands. [15]

h. Distributed Storage

Electricity storage is extremely useful for adding flexibility to electric grids because it helps to deal with the variability and unpredictability of renewables. Electricity storage can be divided into bulk storage, which can output large amounts of power (multiple megawatts) over long periods of time (hours), and distributed storage that can output smaller amounts of energy (kilowatts to megawatts) over shorter periods of time (milliseconds to minutes). Some of the technologies used (or proposed for use) in distributed storage include lithium-ion batteries, lead acid batteries, some types of flow batteries, thermal storage, flywheels, super capacitors, and hydrogen storage.

5. RENEWABLE ENERGY INTEGRATION

Renewable energy sources typically have higher first costs and lower operating costs than fossil-fuelled electricity generating technologies. Even though renewable energy sources may be "cost-effective" on a lifecycle basis, yet some electricity systems particularly in developing countries simply do not have access to sufficient capital to invest in renewables. This challenge can be mitigated through innovative means or options such as those proposed by [7]. These include:

- Supply-side options, such as distributed generation.
- Demand-side options, such as demand-side management
- Storage options, such as EVs, batteries, and thermal storage.

Smart grid technologies can allow for optimal use of these alternative technologies, and thus avoid the need for new large power plants. This eased integration can help enable both utility-scale renewables (such as multi-megawatt wind farms) and smaller distributed renewable generation. Integrating renewable energy sources into the smart grid system would enable the reduction of the cost of sources required for building extra generators, improved power quality, reliability and achieve customer satisfaction.

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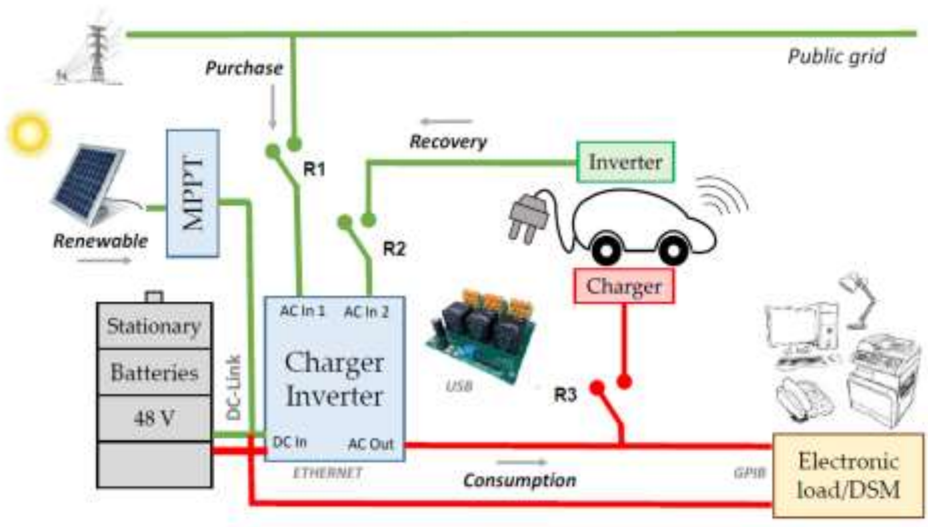

Figure 4: A micro-grid comprising a photovoltaic system with storage, an electric vehicle, and a Demand-Side Management (DSM) system.

➢ PV Integration

Solar energy is an infinite energy source derived from the environment and has an intermittent supply. Its availability is less than predictable and is beyond human control as compared to conventional power plants. PV systems are plagued with high initial cost, variability, requirement of space for PV panel installation, less efficient energy conversion, etc. Solar power is also not always available where and when needed [16]. Unlike conventional sources of electric power, solar resources output cannot be controlled. Daily and seasonal effects and limited predictability result in intermittent generation. This poses many challenges for the Grid integration [17]. Some of the difficulties encountered include:

- Intermittent Generation as a result of the intermittent nature of solar resource.
- Transmission System issue resulting from the proximity of existing solar plants from transmission lines. Planning for transmission expansion to support increasing level of solar generation in dispersed areas is essential to the growth of the solar power sector. Planning and system studies are required to determine seasonal requirements for up -regulation, down – regulation and ramping capacities. Long term resource adequacy issues also need to be addressed. The interconnection protocols and standards may needed to be modified to address greater level of power factor control and low voltage ride through to mitigate any transient stability issues.
- Distribution system issues as a result of increasing penetration of institutional and residential solar generation. Grid operators are facing shifts in peak demand and load pattern resulting in a scenario where in generators are being called upon to ramp up their output more than before and for which they may have not been designed.
- Integrating Energy storage as the percentage share of PV generated energy is increasing the total energy basket.

The integration of PV systems to smart grids will add value to utilities and customers through improved reliability enhanced power supply and economic delivery of electricity. The applications most likely to benefit from PV storage and integrating it with grid are peak shaving, load shifting, micro grids, outage protection and demand responds [16].

➢ Electric Vehicle Integration

An Electric Vehicle (EV) is any kind of vehicle which uses an electric motor for propulsion powered by rechargeable battery packs, ranging from cars, motorcycles, trains, trucks, etc. until boats, aeroplanes and even spacecrafts. However, these vehicles might be powered only by electricity or they may also have an internal combustion motor, becoming part of the hybrid technology [18].

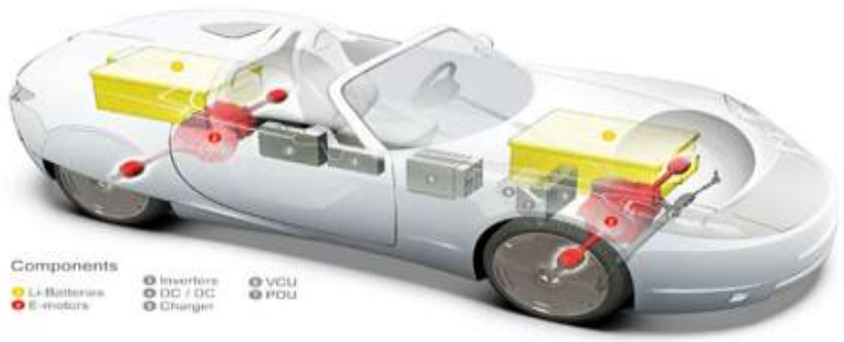

Figure 5: Image of an Electric Vehicle [18]

Electric vehicles employ the Vehicle-to-Grid (V2G) technology to provide power back to the grid while being connected. It does not matter if this power comes from a battery, a fuel cell or a plug in hybrid electric vehicle. The concept is basically to make the electric vehicles supply back electricity to the grid and not just pull from the grid. This allows the stored energy in the batteries to be fed again into the distribution system network. EVs batteries can be charged during low demand periods and discharged when more power is needed or if some economic profit can be made. The V2G concept is simply based on the fact that an average EV is used for just a few hours each day, hence, the batteries of the EVs could be used during the rest of the day by energy distribution companies as a storage media in case of high production and as a source in peak power demand periods. The Vehicle to Grid (V2G) concept is based on the energy storage in the electric vehicles but it is the price of the electricity which is the key factor for this concept. Whenever the energy consumption is low and the electricity price is accordingly cheap, EVs are expected to charge. When the demand gets higher and the price of the electricity rises, the energy stored in the batteries might be used both to support the electric grid functions and to earn some money.

More so, this technology also helps to buffer the constantly fluctuating balance of power in the power systems. Today the active power is produced and consumed simultaneously as there is no great storage facilities present in the power systems. This means that the supply must match the demand at every time. Otherwise, voltage rises and drops, overloading of some of the transmission lines, brownouts and even blackouts might occur [19].

Due to the behaviour of the final customers, constant fluctuations are always present in the grid. The vehicles with the ability of giving power back while connected can be used to match those small instantaneous variations of power rather than using any other generation source.

V2G technology also allows for the integration of intermittent renewable energies into the power systems. With this feature, the excess power produced during periods of high wind or high solar irradiation are not wasted but stored for a later use. This also eliminates the need for building renewable energy plants with back-up fossil-fuel generators [20].

For a proper implementation of the V2G technology, each vehicle must have at least these three required elements: a connection to the grid for electrical energy flow, control or logical connection necessary for communication with the grid operator and controls and metering on-board the vehicle [19]. Figure 5 shows the connections between the electric vehicles with V2G technology and the electric power grid. Lines represent the power flow, so electricity flows from the generators to the end users through the transmission lines and the distribution system. Notice power also flows back from the connected EVs to the grid.

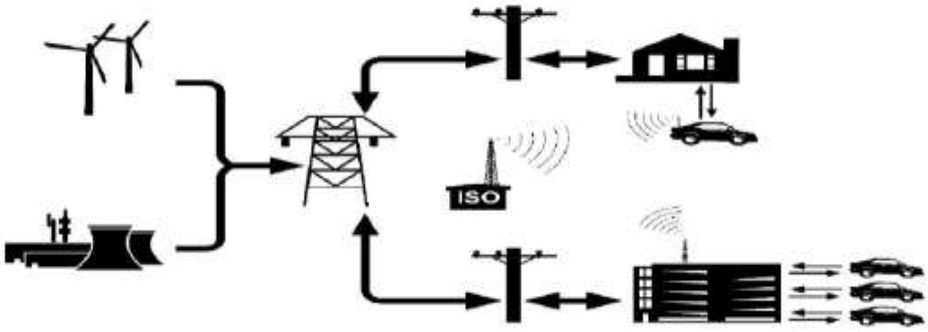

Figure 6: Connections between the electric vehicles with V2G technology and the electric power grid [19]

The maximum capacity of any typical EV technology battery is insignificant at system distribution levels. A standalone EV would simply appear as noise in the power system at the grid level. With the integration of V2G technology, many electric vehicles are aggregated and managed together so that they can have an impact into the grid.

The Smart Grid will provide the control needed to mitigate the load impacts and also to protect components of the distribution network from being overloaded by EVs thus ensuring electricity generating capacity is used most efficiently. With a Smart Grid, utilities can manage when and how EVs charging and discharging occurs.

6. CONCLUSION

If renewable energy sources are given an integral role in smart grid systems, it would promote the use of sustainable sources and open up a niche in the market that focuses on the integration of alternative energy. Smart grid incorporates multiple technologies to form an intelligent system aimed at optimizing and providing an efficient energy demand and supply balance. Due to the potential importance of smart grid, this paper did a survey on the smart grid challenges, technologies, optimization and the smart management system. It also explored the challenges and technologies used in integrating smart grid with renewable energy sources so as to achieve the demand side management. Electric vehicle integration with distributive storage feature was also reviewed. In summary, there is no doubt that within the advanced framework of smart grid, many challenges, services and

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applications which are tricky to be achieved in existing power grids are made clearer for smart grid developers and planners which will lead to a more environmentally sound future, better power supply services, and full improvement in our daily lives.

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