Efficiency of Electric Vehicles and its Impact on Distribution Network

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1.0 Abstract

The advent and growth of Electric Vehicles are inevitable to fulfil the emerging sustainability mandates arising out of CoP 27 and other mandates. Although Electric Vehicles have inherent advantages over Internal Combustion Engine vehicles as an Electric Vehicle converts around 60% of the electrical energy from the grid to power at the wheels whereas Internal Combustion Engine vehicles convert only 17 to 21% energy stored in gasoline to power at the wheels, certain areas of enhancement of efficiency of EV are yet to be explored. This paper discusses various factors effecting Electric Vehicle efficiency and how same can be further improved considering various impacts of Electric Vehicle on the power grid.

2.0 Introduction:

Today Electric Vehicle adoption is increasing at an accelerated pace with 6.6 million Electric Vehicles sold in 2021 compared to just 0.12 million in 2012. Success of Electric Vehicle adoption is mainly due to sustained policy support as large number of countries have taken initiatives to phase out the Internal Combustion Engine vehicles. This has led to sustainability push by various governments, stakeholders leading to framing of policies and subsidies being offered to mitigate the impact and limit global temperature rise to 1.5 degree C. The global Electric Vehicle fleet consumed about 55 terawatt-hours (TWh) of electricity in 2021 and is projected to reach almost 780 TWh in stated policy scenario by 2030 as per report by International Energy Agency (IEA) i.e., Electric Vehicle shall account for 2% of global final electricity consumption.

In coming years growing number of Electric Vehicle fleet shall be an important factor which have implications for peak power demand and transmission and distribution capacity being key considerations. Planning and promoting smart charging including mix of fast and slow charging is critical to avoid contribution to the peak load and shall help in smooth operation and resilience of power system.

Keywords: Electric Vehicles, EV efficiency, EV charging, peak load, power grid.

2.1 Aim of the study:

This aim of the study is to conduct high quality study analysing the potential impacts of large scale integration of electric vehicles into the power grid. Large scale Electric Vehicle integration shall lead to the increase in the peak load. Meantime, the increased peak load may also cause some detrimental effects on the transformer in the distribution system. Out of total 318 million vehicles, India currently has 1.8 million electric vehicles but this number is going to increase as India has targeted to have 30% of vehicles sold as electric vehicle by 2030.

2.2 Objectives of the study:

The purpose of this work is to assess the potential impact on the distribution network due to the charging of Electric Vehicles. The maximum system demand is usually determined from the historical load data and demand side management. Detailed study is conducted based on review of EV charging infrastructure and its grid integration of the countries who have taken lead in early EV adoption with main objectives to understand planning and operation of grid with EV integration, technologies, policies and standards for EV charging infrastructure integrated with grid.

3.0 Electric Vehicle Drive Train:

An Internal Combustion Engine vehicle consists of engine, fuel tank and other auxiliaries. Desirable Torque or speed can be obtained through engine control. There is a hydraulic or battery-operated power brakes, power steering, and air conditioner. Engine drives a dynamometer which generates electricity to charge small battery used for auxiliary power. Whereas in EV instead of engine there is motor and controller through which desirable torque or speed can be obtained. Battery current through controller controls the drive. DC-DC converter is provided to convert battery voltage to the desired level to drive auxiliary including power brakes, steering, and air-conditioning. Vehicle performance is characterised by Vehicle Torque, speed and power. Gears can multiply torque at the expense of speed. Vehicle has to overcome rolling resistance, aerodynamic resistance and in case of ascending gradient slope it has to also overcome gradient resistance and thereafter provide acceleration or pick-up for the vehicle. An Electric Vehicle would need to have the following:

a. **Electric Motor**: High performance Electric motor for propulsion.
b. **Motor Controller**: Motor controller for motor drive with closed loop feedback system. Both motor and controller required to drive the vehicle as per drive train requirement so as to meet the required torque.
c. **Battery Pack with BMS**: Reliable battery pack with battery management system is provided in Electric Vehicle. Battery is designed to provide energy over a range as well as peak power. Bulk of the Electric Vehicle cost comprises of battery pack resulting in high upfront cost. The life of battery mainly depends on Charge-discharge rate also called C-rate, temperature of charge, discharge and storage and Depth of discharge i.e. extent to which battery is emptied and filled up in each cycle. Batteries generally last from 700 to 3000 cycles depending upon the battery chemistry, driving conditions and other factors. When the Electric Vehicle batteries are at the end of its life their capacity reduces to 75 to 80% of the initial capacity as it will limit

the vehicle range. Battery management system monitors the health of each cell, ensuring safety as in case of any malfunction it cuts off the cell module.

d. **DC-DC Converter**: DC-DC converter to convert battery voltage to desired level to drive vehicle auxiliaries.
e. **IoT**: IoT for vehicle data collection combined with remote monitoring (telematics) and data infrastructure to monitor and manage vehicle. It collects data during drive.
f. **Vehicle Control Unit**: It communicates with battery and with controller for vehicle management and safety. It may have external wireless interface and other interfaces/ Sensors.

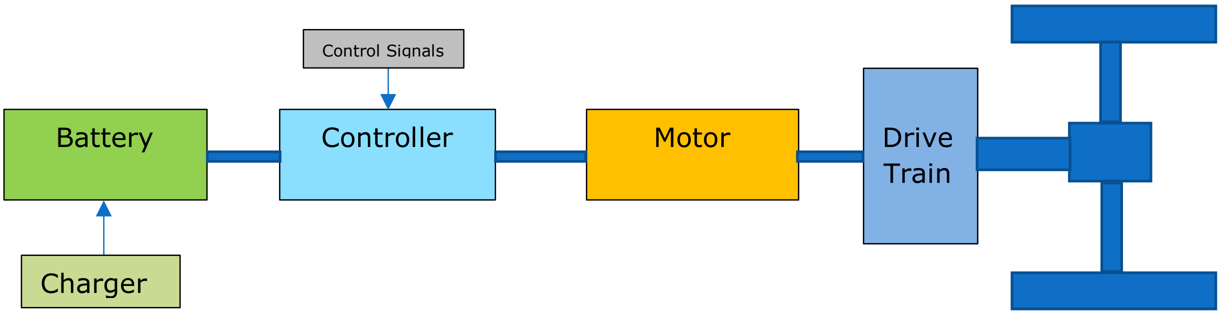

Figure 1: Electric Vehicle Schematics

Motors with controllers as well as battery determines the performance of the electric vehicle. They have to be designed carefully taking into account energy losses, auxiliary energy usage and lifetime deterioration. Motor, Battery and Vehicle control unit all have the powerful processor and memory which communicate with each other. These can store data during drive and charging, this data can be uploaded to a server which is useful in analysing the behaviour of every aspect of the vehicle. The data so collected with the help of the data analytics, helps in improving the sub-systems, driving behaviour and warns of potential faults.

In Internal Combustion Engine vehicles, gasoline is used as fuel which has energy density of 12500 Wh/kg whereas in Electric Vehicle, energy density of battery comprising of different chemistries, the energy density ranging between 120-300 Wh/kg. An Electric Vehicle has around four times higher drive efficiency compare to an Internal Combustion Engine vehicle. Even considering the above fact, battery weight per km is 10 to 12 times higher than of petrol and its size per km is 5 to 6 times higher. Cutting edge research on different battery technologies is ongoing at advanced research laboratories of the world which is expected to find solution to increase energy density of the batteries thereby reducing battery weight and size. Primary objective of the above research is to enhance energy density in the battery so that the gross dead weight of the Electric Vehicle reduces there by reducing the rolling resistance, faster pick up increasing Electric Vehicle efficiency and performance.

To push up Electric Vehicle adoption, standardisation and interoperability of Electric vehicle supply equipments will majorly help in integration of Electric Vehicle with grid. Large scale adoption of Electric Vehicle will help in mitigating climate change concerns as renewable energy shall be used to power batteries and same Electric Vehicle shall also help for managing the demand response by having vehicle to grid connection to balance peak load demands.

4.0 EV current scenario and future impact on Grid distribution:

Out of total 318 million vehicles, India currently has 1.8 million electric vehicles but this number is going to increase as India has targeted to have 30% of vehicles sold as electric vehicle by 2030.

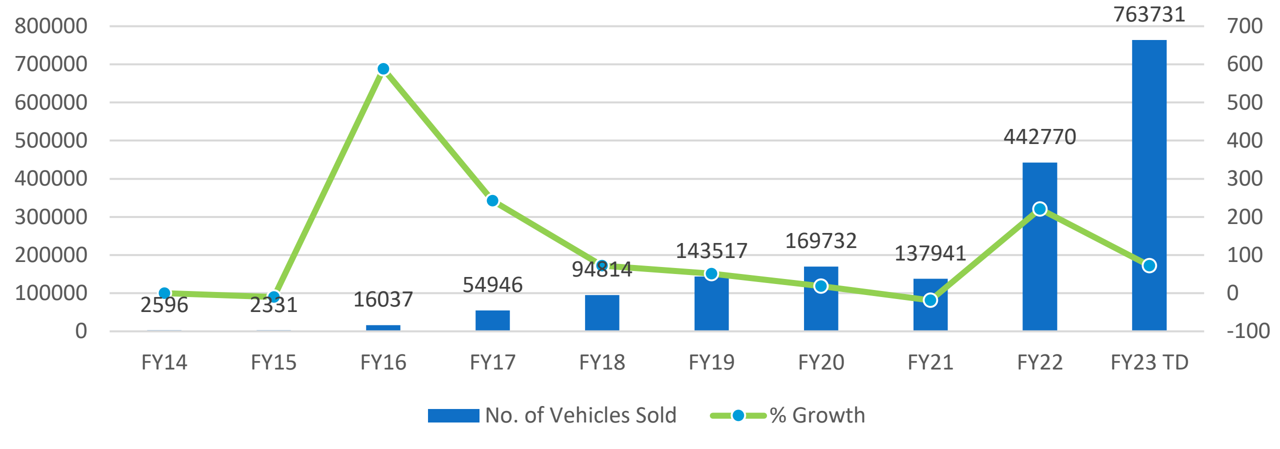

Fig 2: EV Vehicle Sales from FY'14 to Nov'22

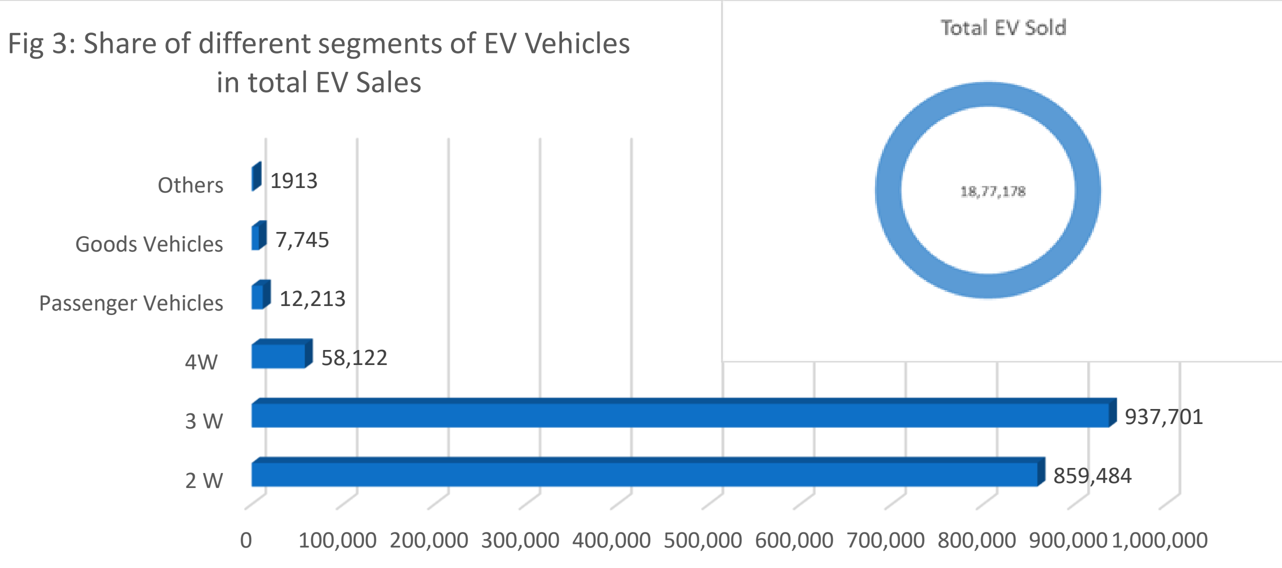

Fig 3: Share of different segments of EV Vehicles in total EV Sales

An emerging area of concern in the context of Electric Vehicle charging is to examine if the power systems are robust enough to withstand and sustain electricity demand as electric vehicles are deployed simultaneously in greater numbers. Currently annual demand for electricity is around 1300 Twh, with increased demand for Electric vehicles and with objective of 30% all vehicle to be electric by 2030, the demand for the additional electricity to power the electric vehicles is projected to be around 100 Twh. According to the government of India's Energy Efficiency Services Limited, which is the world's largest public-sector energy service company, India will have 79 Mn electric vehicles will be on the road and 8 Mn public charging stations (slow and fast) will be installed by 2030. For 1 Mn electric vehicles, assuming an average battery capacity of 30 kWh, India needs about 15 Mn units (kWh) of electricity per day, based on EESL's findings. Considering an average of 15 units of electricity is consumed per day to charge EVs, the charging price would be around INR 75 per day based on the average battery size of 30 kWh assuming ₹5/ Kwh electricity unit.

Fuel-wise vehicle stock by 2030 (estimated), Fig: 4

Vehicle	Electric	Petrol	Diesel	CNG	Ethanol	Biodiesel
2W	5,82,80,133	21,43,11,384	X	X	0	X
3W	26,95,640	40,54,744	41,90,319	21,36,116	0	0
4W	44,49,324	2,64,61,655	1,78,62,972	5,10,522	0	0
Others	4,73,530	50,06,216	1,06,42,958	1,69,652	0	0
4W (Commercial)	35,73,672	3,40,219	1,82,75,159	9,19,753	0	0
Bus	4,36,299	X	23,40,342	56,606	X	0
Total :	**6,99,08,598**	**25,01,74,218**	**5,33,11,750**	**37,92,649**	**0**	**0**

Source: https://www.ceew.in/cef/vehicle_calculator

At present, the electric vehicle charging infrastructure is predominantly categorised into two categories — slow chargers (3-4kW) and fast chargers (50-100 kW). On average, a public charging station will require almost 100 kW of load. So for a million EVs, the collective cost will be close to INR 75 Mn (7.5 Cr) per day, and about INR 27.37 Bn (2737 Cr) per year only for charging electric vehicles. And that's just for a conservative estimate of 1 Mn EVs with average battery capacities.

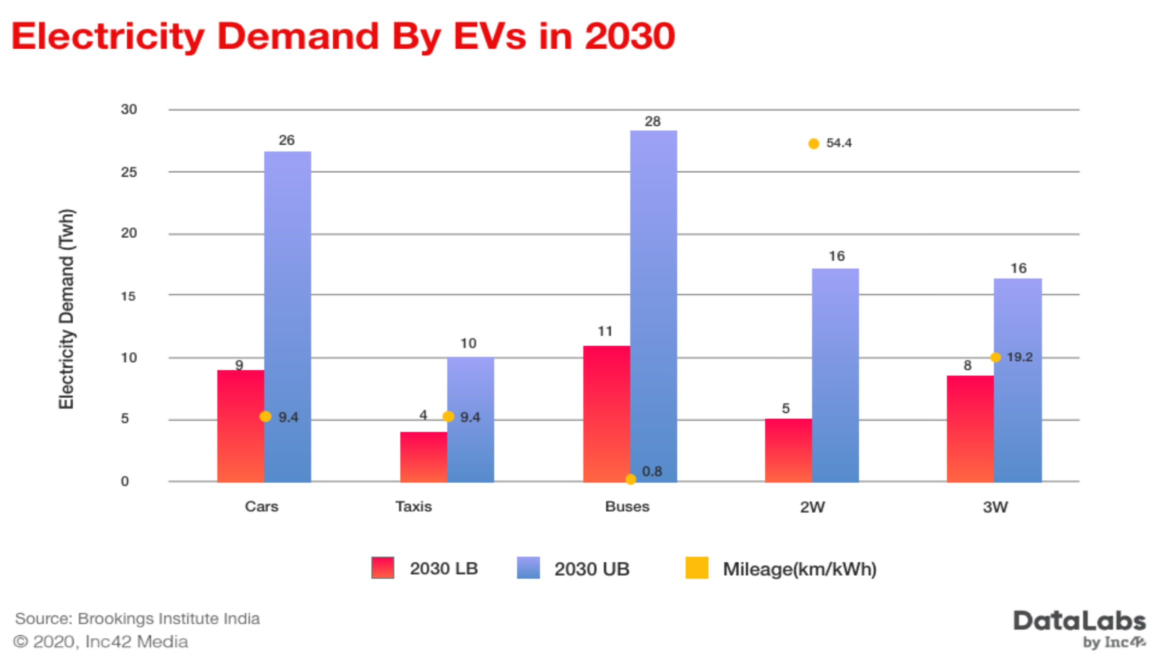

Figure 5

In India currently the number of charging stations are too less of the order of 135 EV per charging station compared to 6 in China and 19 in USA. By 2030 India shall be requiring over 2 Mn EV charger.

This integration of Electric Vehicle with grid for charging can impact the stability of the grid due to reactive power consumption and current harmonic injection. Electric Vehicles those are connected to power networks may lead to higher short circuit currents and voltage level, may not be within the regulated limits as the power demand is higher which can impact the lifecycle of equipment's and also cause false tripping in the case of protection equipment's. With sustainability push for faster transition to Electric Vehicles there is a stronger possibility that local distribution grid, transmission systems and generation infrastructure may not keep pace with eventual Electric Vehicle adoption. However smart control systems that can coordinate the timing of charging of individual Electric Vehicles potentially balancing the load and offsetting the peaks.

In Electric Vehicles batteries are the source of power which are supported on the wheels and this energy can be stored and used during vehicle drive. In order to manage peak power demand, smart charging can solve these problems. As soon as smart charger is plugged, it will establish communication with the grid and examine parameters related to load profile, pricing (time of day), battery charge state and battery conditions, charging preferences. Smart charging informs the preferred time for charging for optimal use of energy. Customers who are flexible and accommodate for this probably have to pay lower price compared to those who want to immediately require to do so at a higher price.

During day time when renewable energy generation is mostly available, this energy can be stored in Electric Vehicle batteries and during evening when there is peak demand this energy from batteries can be released to grid to ease load on the grid which is also known as Vehicle to grid (V2G). This also benefits the Electric Vehicle owners as the services they provide can be suitably remunerated. With more and more Electric Vehicle integrated with grid the form and timing of Electric Vehicle charging will be more stochastic. Smart charging helps in reversal of role of Electric Vehicle in the distribution network from passive load to the active control of Electric Vehicle in order to reduce the peak load, minimise the losses and generation costs. With integration of renewables peak demand and system cost can further be reduced which can be achieved with controlled charging to balance the supply and load demand. Vehicle to grid technology helps in creating new business model as it allows Electric Vehicle owners to store the energy and act as distributed generators thereby providing ancillary services which helps in integration of renewable energy in the power system for supporting the grid. Such futuristic grids have more focus on bi-directional power flow. Power grids should be reliable and has to balance supply and demand as well as maintain reactive component of power round the clock. Power system reliability is important as it should deliver power continuously with acceptable service quality. This requires a great amount of work in the field of power management, load flow studies and grid discipline, necessitating a deeper relook in the following areas:

4.1 Increased demand for energy: Adequate power reserves need to be maintained and allocated to cater to the increased demand due to Electric Vehicle charging. Nations like United States, China, some of the Scandinavian nations and other European countries (like Germany, France, UK) are forerunners in the race for the Electric Vehicle deployment. Going by their examples it is expected that 5% of the total electricity consumption shall be by Electric Vehicles by 2030. Currently the studies which has been undertaken anticipates uncontrolled charging can exacerbate the peak load problem with all users charging in the evening upon return from work. This uncontrolled charging can cause major congestion in already heavily loaded grids, low voltage problem in predominantly radial networks, increase in the peak load and load imbalances between phases in Low Voltage grids. In such a scenario, adoption of the smart charging technology with controlled charging using Time of Day (ToD) can minimise the impact on peak load and help in sustenance of power system. This will minimise the grid infrastructure cost considerably. The impact of Electric Vehicles on local grid needs to be studied for each system considering the existing infrastructure loading, load profile and renewable energy generation (Solar & Wind) and expected Electric Vehicle profile.

4.2 Robustness of the Network: A very interesting study has been carried out in the case of simulation of grid studies by German distribution Grid. This study reflects that up to 20% population of EVs (out of total population of vehicles), necessity of up-gradation of distribution grid is not significant. However up-gradation of transformers is required to address voltage control (switching from passive to active transformers that can control voltage levels on the low voltage side). This is also known as on-load tap changing transformers also called intelligent transformers. In the rural sectors, which has comparatively weaker grid infrastructure would require the up gradation on first priority. This simulation study further unfolds that strengthening of grid infrastructure becomes significant beyond 20% Electric Vehicle population, as transformer up-gradation shall be up to the tune of 10% in city areas and around 25% in the rural areas. Further this study shows that Line upgrades shall be limited to less than 2% of the total line asset even with 40% Electric Vehicle population as line up-gradation is cumbersome activity demanding large capital expenditure.

In any residential locality there are typically two types of areas in terms of power demand and supply

a. The ones having low load demand and low load growth forecast.
b. Others having higher load demand and higher load growth forecast.

In order to ensure better overall sustainability of the grid network it is suggested to mix and match the clusters by performing a load stability study to avoid clustering effects which can lead to grid disturbance and problems even at low Electric Vehicle uptake and maximising network utilisation round the clock.

It is observed through the experiences of nations which have earlier adopted and witnessed the issues related to the impact of mass Electric Vehicle charging that:

a. Wholesale up-gradation of the network infrastructure could have been a solution
b. But option a is restricted for adoption because of the difficulties associated with the process and need of high capital expenditure.
c. The other solution emerging out of the situation is to develop discipline of power use at the customer end.
d. In India there is absence of Time of Day (ToD) metering system for the end customers. However, its various impacts are borne by the Distribution and Transmission utilities. In one hand the Distribution utility needs to shell out higher amounts of energy charges to the

Generation utility at the peak hours. On the other hand, the Transmission utility is responsible to maintain the grid health at all situations and therefore needs to look out for the solution to the issues arising out of congestion at particular hours and lean demand at other times.

e. In order to address the two issues described above and to spare the expenditure and inconvenience going through the wholesale refurbishment upgrading the total infrastructure, one alternative can be conveniently adopted i.e. disciplining the customers by spreading the consumption on a 24 hour basis. This is also known as demand side management which has helped in demand side management under various critical situations, one being the demand side crisis face by the Japanese power distribution network post the disaster at Fukushima nuclear plant.

f. Technology like smart grid implementation can balance the demand and supply side response management and hence can avoid peak loads. It uses information & communication technologies to have two way flow of both information and electricity. Smart grid deployment helps in the improvement of the energy quality and acts as a barrier to the cyber-attacks.

Three factors determine the need for up-gradation of grid capacity at moderately low levels of EV penetration:

1. Generally, the load of an EV is higher compared to typical household loads. Not all loads are coincident when several EVs are in a system. The effective maximum load is only a fraction of the maximum possible load when adequate number of users are considered,
2. It is estimated that by 2030 the distribution grids need to be strengthened and requires expansion in order to cater to the additional loads coming from the renewable energy installations like PV solar system, increased demand for building HVAC requirements to cater to heating and cooling requirements
3. Third, in advanced countries, there is spare capacity available in distribution grids as same has been historically designed to cater to future requirements.

As EV charger which have higher power ratings, increase in number of charging stations can result in the strain on grid. This can be mitigated by adoption of a mix of fast and slow chargers with proper distribution of charging stations to cater to wide population. However, large fleets which is stationed at depots (where these vehicles need to charge simultaneously) do not have this flexibility and therefore in such cases it becomes necessary to upgrade distribution grid.

In India studies have been conducted on the impact of Electric Vehicle on the peak load on transmission lines. These studies indicate the impact of EVs on bulk energy by 2030 is within the existing generation margins. However, it is the distribution system which is facing the burnt due to low network capacity and no significant up-gradation undertaken in last few years and hence it is very important to upgrade the distribution grid irrespective of EV loads. Distribution companies in low and medium voltage do not have necessary capabilities to project real time load data. Further they do not have demand response technologies on a large scale to balance the grid demand. Coordination between distribution, transmission and generation companies is required to cater to the load congestion and system balancing.

It is pertinent that necessary distribution side grid is strengthened in order to accommodate increasing loads. Effective demand-response measures related to EV charging will be necessary to avoid extreme peak load events and disproportionate investment in grid upgrades.

4.3 Impact of large scale integration of EVs into the grid on power system reliability:

The power system reliability is often defined as the probability of power system that could deliver electric power to the end user on a continuous period with acceptable service quality. Power system mainly consists of 3 levels i.e. generation system, transmission system and finally distribution system.

The power system has used the deterministic methods for the planning and operation for decades. However, the system nature is stochastic, this characteristics is more evident in recent years with an increasing integration ratio of intermittent renewable energy and electric vehicles, which brings a lot of challenges on the safe and reliable operation of power system. So more and more utilities have switched to the statistical and probabilistic methods. With valid data collected by the utilities, such as the system availability, the number of hours of interruption, the probabilistic methods can offer a more precise model of the stochastic system, then help the unities achieve the delicate balance between the reliability and cost.

In order to keep the safe and reliable operation of power system, the production and consumption of electric power must be instantaneously balanced all the time. However, with the increasing integration ratio of renewable energy, the stochastic nature of renewable energy makes the generating system faces great uncertainty. Meantime the demand of electric power is also uncertain. The most reasonable method in counter with the uncertainty is to keep some level of margins between the generating capacity and expected load. So the system can deal with the uncertainty and unexpected contingencies in both generation and load side. This margin is often called operating reserve, which is usually provided by stand by units.

With the increasing integration level of electric vehicles into the grid, this research shows the uncoordinated charging of EVs will greatly increase the system peak load, which will have a significant effect on the safe and reliable operation of the power system. The existing smart charging control algorithms are analysed in detail and categorized as distributed and centralized methods. Based on these categories, two smart charging algorithms are put forward and evaluated in this research. The distributed smart charging algorithm is based on the multi-agent system. Each EV agent optimizes its own charging schedule according to the charging price signal from the aggregator agent. The smart charging pricing and sequential price update mechanism have been proven useful and can greatly decrease the computation complexity and communication burden.

The smart charging control of electric vehicles could also be coordinated with the renewable energy integration, especially with the wind power. The energy storage ability and the flexibility in charging scheduling might become the solutions for renewable energy's intermittency. Meantime, the system operator and planner can have a more precise knowledge about the reliability status of the system by adding both the renewable energy and electric vehicles into the power system reliability analysis, which can not only ensure the safe and reliable operation of the system but also help make more economical investment decisions.

5.0 Conclusion:

Through the research conducted to prepare this paper, based on the inputs received from the subject matter practitioners, two important aspects have emerged. The first is the need to improve the Electric Vehicle efficiency which can be achieved by prudent design so as to achieve higher efficiencies. There are losses associated with motors, DC-DC converters then there is charging efficiency. With ongoing advance battery chemistry research which shall be helpful in near future to get higher range with enhanced safety and at an economical cost. The second aspect which has emerged out of the research is the impact of battery charging on the power grid. It is observed that up to 20% Electric Vehicle population out of total population of all vehicles by 2030 there is minimal strain on the grid but beyond same, the grid infrastructure needs to be strengthened. Technologies like smart grid implementation along with controlled charging timing the Electric Vehicle charging during off peak hours can balance demand and supply side response management and hence can avoid peak loads. It is recommended to study the impact of Electric Vehicles on local grid considering existing infrastructure loading, load profile, generation from renewables and expected EV profile.

Declarations

- **Ethical Approval:** All ethical principles have been followed while preparing this manuscript
- **Consent to Participate:** NA
- **Consent to Publish:** NA
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- **Authors' contributions:**
  Anil Kumar: Conceptualization, Investigation, Supervision.
  M Siddiqur Rahman: Conceptualization, Data curation, Investigation, Writing- Original draft preparation.
  Rohit Gupta: Conceptualization, Writing- Original draft preparation, Editing.

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