World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

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Modelling and system impact of large-scale electric vehicles charging at the medium voltage transmission system

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World Journal of Advanced Research and Reviews, 2026, 29(01), 807-813

Publication history: Received on 02 December 2025; revised on 10 January 2026; accepted on 13 January 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.29.1.0073

Abstract

The rapid increment of electrical vehicles along with faster charging capabilities impact the transmission of electric power in the National grid. It increases the power demand, causes voltage disturbances, line overloading, imbalance in power systems, higher power losses, transients, and causes larger current flow in the grid at the specific time intervals. This reduces the power quality in the grid and causes significant impact on lifespan of the electric power equipment. While most existing studies focus on low-voltage distribution networks, the impacts of large-scale electric vehicles integration on medium-voltage power networks remain insufficiently explored. This paper analyses the power flow on the 132KV medium voltage transmission systems due to increment in electric vehicles charging at the faster rate. It analyses the voltage quality and harmonics effects on the grid. The research is carried out on the MATLAB/SIMULINK and mathematical modelling.

Keywords: Electric vehicles; Transmission network; Power quality; Voltage drops

1. Introduction

Electric vehicles are increasing every day to minimise the carbon emission and to improve the environment. The increment in electric vehicles can have severe effects on the transmission grid such as high-power demands. It also increases the harmonic content due to large number of power electronic components in the charging stations. This severely impacts the voltage flow and leads to power disruption on the network [1]. In this paper, various numbers of electric vehicles are connected to analyse the power flow on the grid. There are three types of electric vehicles such as hybrid electric vehicles, Plug-in hybrid electric vehicles and battery powered electric vehicles. All these types of vehicles operate in different mechanism [2].

Hybrid electric vehicles operate by an electric motor and internal combustion engine together. These combinations reduce the consumptions of fuel economy and better economically than conventional vehicles [3]. The efficiency of these vehicles is further improved by implementation of supercapacitors and regenerative breaking which converts kinetic energy to electrical power and store in the battery storage systems [4]. These types of vehicles are less noisy and produces less carbon emission compared to conventional vehicles. As of April 2020, more than 17 million hybrid electric vehicles were sold [5]. Plug in hybrid types of vehicles operate by electric motors and internal combustion engine. The electric motors are powered by batteries storage system and internal combustion engine operate by using gasoline fuel type. The batteries of these vehicles can be charged by wall sockets, internal combustion engine or by regenerative braking system [6]. The vehicle normally operates by electric motors powered from batteries and switches over to internal combustion engine when batteries are depleted.

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The research focuses on the steady state and transients' conditions before and after connection of electric vehicles to the grid. The simulation is carried out by applying the time varying electric vehicles at the load side as shown in Fig.1. It also analysed how many electric vehicles can be connected to the system at a time to not impact the power flow parameters. The electric vehicles can have severe impact at a peak time on the transmission network. It also disrupts the power flow parameters on the transformers and cause voltage transients. The research was performed to compare the benefits of electric vehicles on the human health, environment, and its impact on the transmission grid. Transmission grid consists of several voltage level but in this research the medium transmission voltage level 132kV was investigated.

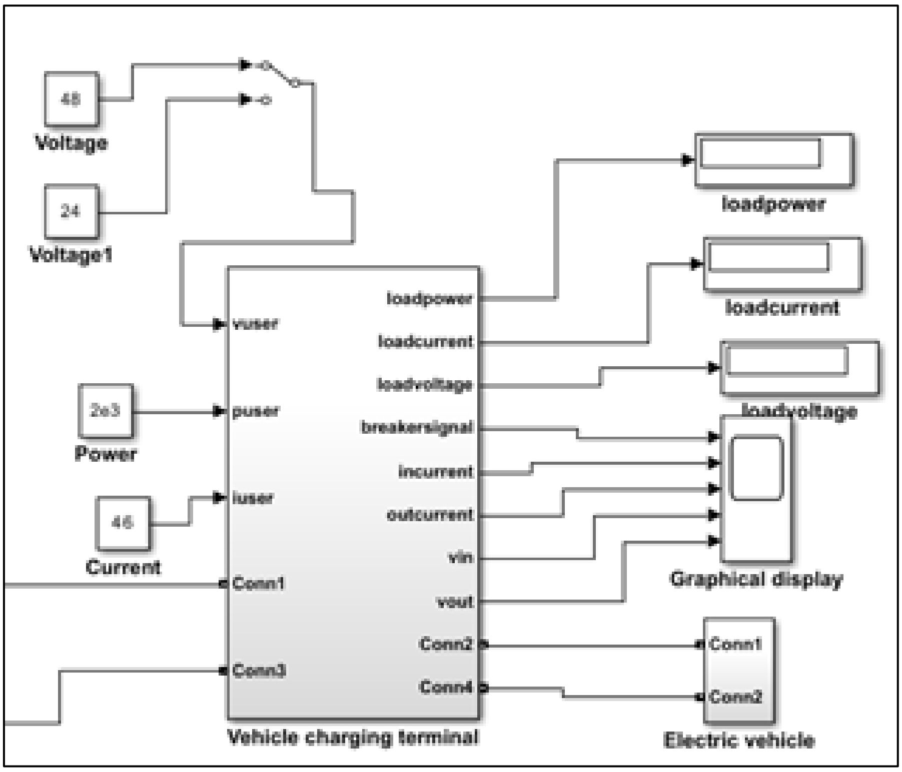

Figure 1 Electric vehicle charging terminal

2. Methodology and electric vehicles energy conversion procedures.

Plug-in hybrid electric vehicles and battery power vehicles draw power from the National grid. The charging of these vehicles create increment in current demand and cause voltage transients at the grid [7-8]. The research is carried out by creating a complete power network on a MATLAB software by following a National standard system. Electric power is generated at 23KV at the power generation station. The power parameters such as inductance, resistance and capacitance for the grid are taken from the type of Araucaria AAAC type conductor used [9]. These parameters are applied as per kilometers by following the conductor standard. The voltage is then stepped down from 132kV at a substation to a distribution level of 400V/230V to connect the electric vehicles as shown in Fig.2.

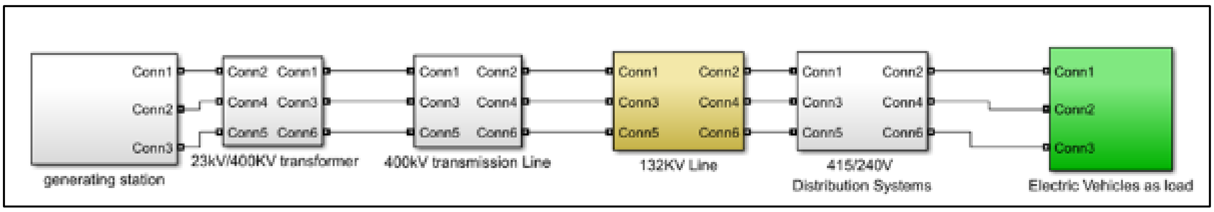

Figure 2 Complete network model to analyse electric vehicles impact on the 132kV grid

The model of electric vehicles is simulated and then connected to the distribution Network. There are different loads of electric vehicles loads are connected to analyse the power on the grid shown in Fig.3. It was concluded that charging large numbers of electric vehicle types creates voltage drops and transients at the 132kV National grid system. There are three of charging applied to read the power flow at the grid.

- Regular charging at the home.
- Regular charging at the charging stations.
- Fast charging at the stations.

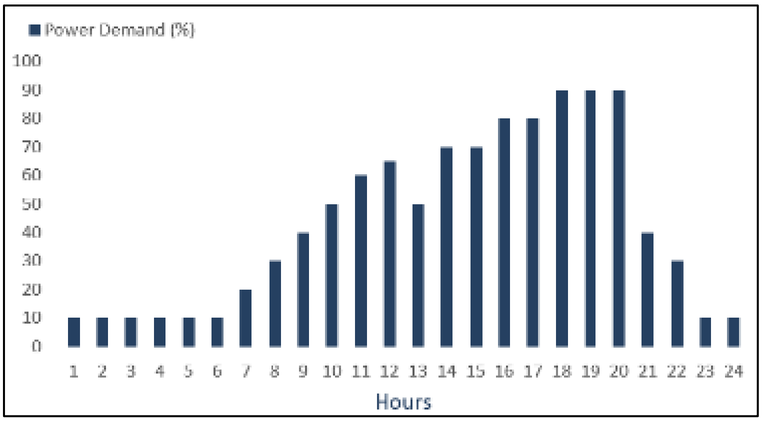

Figure 3 Expected power utilisation by electric vehicles during variable hours

The normal voltage level noticed at the 132kV grid is before connecting the electric vehicles. By connecting the vehicles at a regular charging, the voltage level drops to above 8.5% and further voltage drops observed when high power drawn at the load side. Specifically, voltage drop tend to severe at the peak demand times. It is also noticed that voltage drops are incrementing by connecting the fast-charging electric vehicles that draws massive power in a short amount of time. This increases the power losses and cause the over current flowing in the national transmission network. So fast charging of electric vehicles tends to cause higher fluctuations as compared to normal charging.

Table 1 Increment in electric vehicle loading on the grid.

Number of EV connecting to grid instantly	Individual EV capacity	Total power consumed (MW/hour)
10000	10kWh	100
20000	10kWh	200
35000	10kWh	400
50000	10kWh	500
75000	10kWh	750
100000	10kWh	1000

2.1. Energy conversion assessment

The energy conversion in electric vehicles is achieved by means of power electronic components such as IGBT switching elements and control mechanisms shown in Fig.4. 48VDC is converted to three phase 400V AC to run the three-phase induction motor. The speed control of induction motor is very important parameter in electric vehicles. Constant V/f control mechanism is used to control the speed of the induction motor. This maintains the constant flux between the stator and the rotor of the induction motor [10]. As voltage is directly proportional to maintain the torque and frequency relates to control the synchronous speed of the motor. The battery is considered as the ideal voltage source which provides constant voltage throughout the running process.

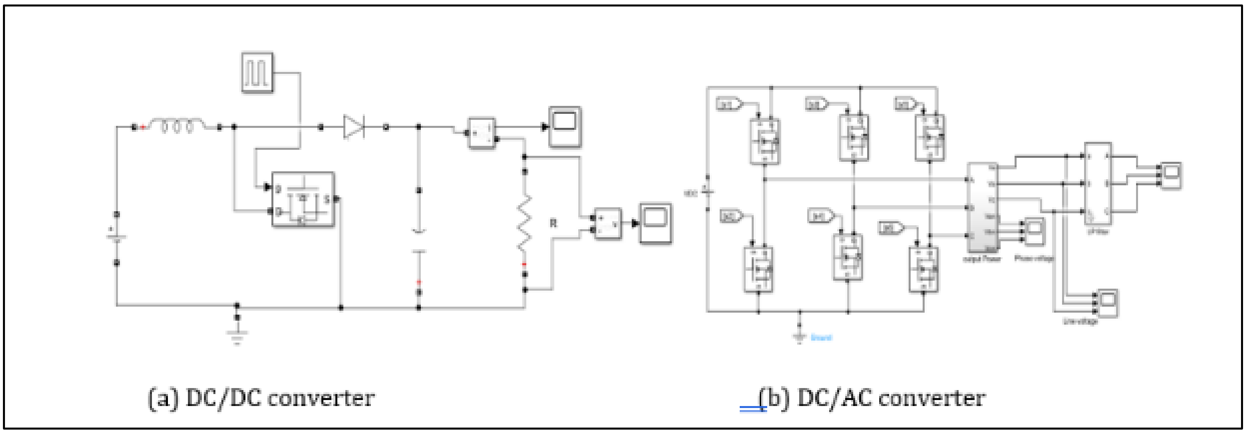

Figure 4 AC/DC/AC power conversion mechanism

SPWM is applied to achieve the voltage regulation in the output. This type of modulation technology can also control the speed of thee phase induction motor [11]. The output of waveform consists of highly switching elements hence a low pass filter is designed to smooth the output and achieve the sinusoidal output. The switching losses are calculated by using the below equation [12].

$$P_{ON} = \frac{V_{CE} \times I_c \times T_{ON} \times f_s}{6}$$

$$P_{OFF} = \frac{V_{CE} \times I_c \times T_{OFF} \times f_s}{6}$$

Where V_{CE} is the collector emitter voltage, I_c is the collector current, f_s is the switching pulse frequency applied to the gate, T_{ON} is the switching ON time and T_{OFF} is the switching OFF time. The average output voltage can be calculated by using the applied duty cycle.

3. Power flow study on the 132kV grid.

The simulated model consists of 132kV transmission grid along with distribution network systems of 400/230V. The electric vehicles loads are connected to all the three phases. The variations in the loads side were conducted to analyse the power matching with the source side.

Firstly, the uncontrolled charging is observed where user charge the electric vehicles when reach home. This is called uncontrolled charging. If they start charging at the peak times, then they are adding extra load demand on the system. This can be the worst-case scenario where massive power fluctuations are noticed in the grid. The second way of charging is at the off-peak times where the vehicles can be charged for a longer hour in a timed controlled manner. This showed the less impact on the grid and does not impact the power flow parameters. The third way is the fast charging where electric vehicles draw very large amount of power in a short period of time. The faster charging creates harmonics and transient on the grid. This way of charging is also harmful to the distribution transformers [13]. The smart control system is needed to balance the power flow on the grid due to increment in load demands at the peak and off-peak time. The voltage level at different sections of the grid are shown in Fig.5. The voltage level is observed for the three scenarios such as uncontrolled charging, controlled charging and fast charging at the peak and off-peak times. The voltage level is 5% lesser at the peak demands, while it remains stable at the off-peak times. The faster charging reduces the voltage by 10% than standard voltage. The three-phase system also noted imbalance by connecting the maximum vehicles loads to one phase. This caused imbalance current flow and leads to short circuited of the one phase.

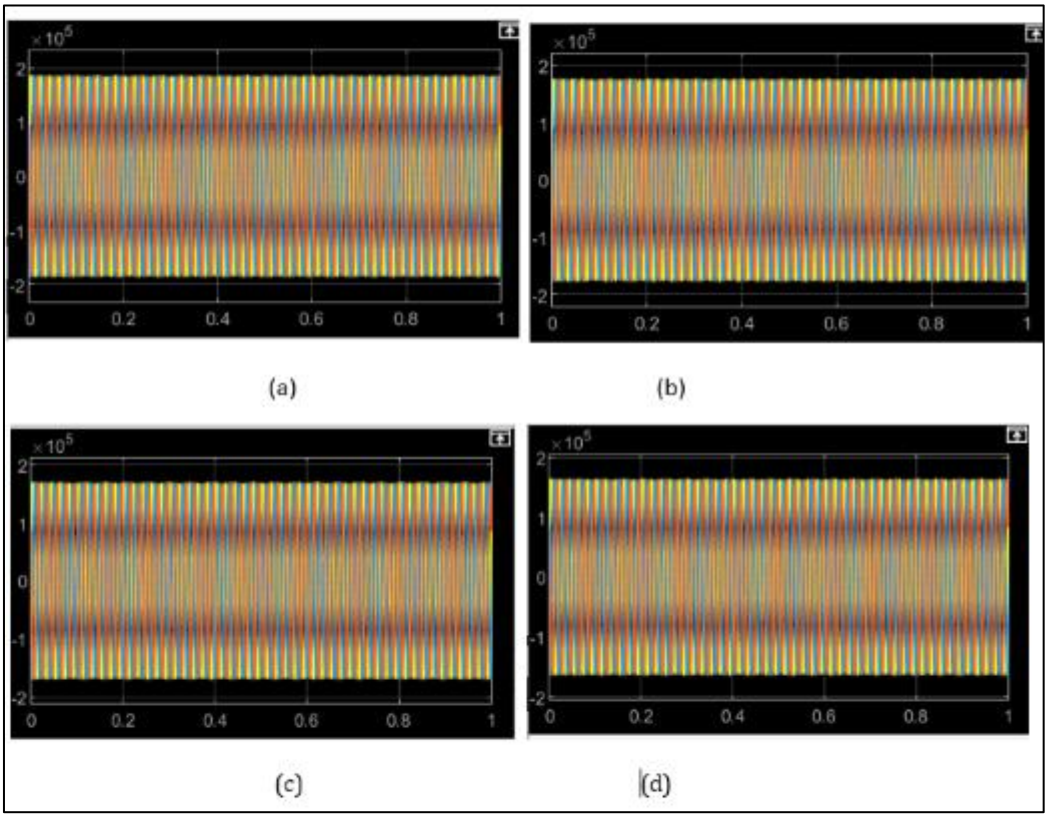

Figure 5 Voltage analysis on the 132kV transmission system by connecting variable load electric vehicles. (a) 132kV standard transmission (b) 125kV voltage on the grid (c) 120kV on the grid (d) 116kV on the grid

The power electronic components and switching devices in the electric vehicles are non-linear components that cause an impact on the entire power system. These components create large number of harmonics and are regulated by using filtering and pulse width modulation control systems [14]. These power electronic components severely impact the power flow during the faster charging of the electric vehicles at the peak power flow times. It also creates imbalance between the reactive power and active power flow in the systems. Fig.6 shows the voltage by the charging the different types of a load parameters of the electric vehicles. Current flow is distorted that can impact the power flow on the network. This also creates complexity for the power protection systems. It resulted that the large deployment of electric vehicles at the peak time violates the power supply and consumption demand that creates variation in the voltage standard limits [15]. This reduces the power quality in the grid that reduces the life span of consumer equipment's. It can be minimised if the electric vehicles loads are equally distributed to all the three phases and with smart harmonics filtering system. It is also possible to design electric vehicle parameters in a way that has lesser impact on the grid and draw lesser power at the peak times. The power quality can also be improved by installing additional features on the network that makes a smart network.

Voltage level is compared by connecting electric vehicle as a various load from slow charging to faster charging. The result shown that the voltage is reduced from the standard level after connecting the faster charging vehicles at the peak energy consumption times. This caused extra loading in a short period of time on the grid. There is about 10% voltage drop occurred on the grid. But lesser effect is noticed on the voltage level at the off-peak times.

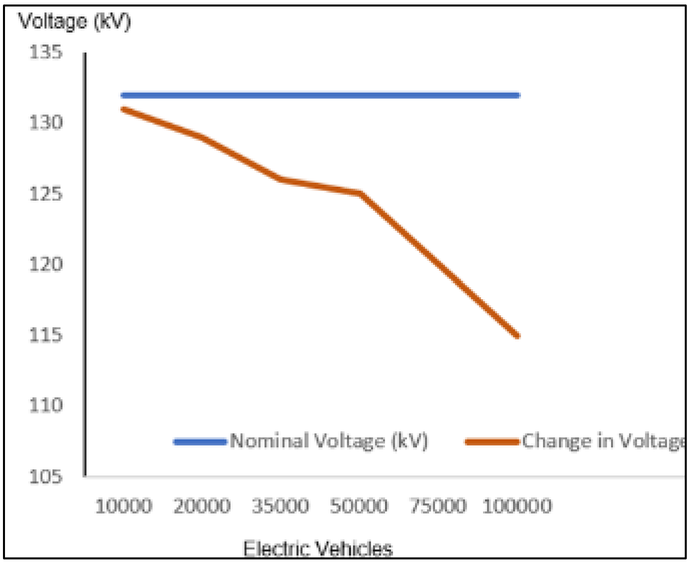

Figure 6 Voltage drops due to increment in electric vehicles load

4. EV Battery degradation due to faster charging

The parameters that relate to the battery degradation are temperature, state of charge, charging timings, rate, depth of charge and storage capacity. It needs to be determined how much energy left in the battery and average withdrawing periods of power from the battery. The charging and discharging of the electric vehicle are another important feature that needs to link with degradation of the battery. If the charging and discharging rate is higher, it will cause the rise of temperature in the battery that leads to battery damage and limit the battery life cycles. It is also required to analyse the sensitive parameters of the electric vehicles such as efficiency in storage capacity, type of manufacturing, material used to construct battery and consumption losses. These factors contribute very important role in the long-term usage of the battery for a better gain. Driving distance also impact the battery life because continuously withdrawing large amount of power degrade the battery life as well. Long driving draw large amount of power and hence increase the battery temperatures. There are many battery manufacturing plants that design and build the batteries at different specifications.

The slow and faster charging are compared to examine the parameters investigated for the battery gradation are charging time, battery temperature, current flow, voltage standards, rate and depth of battery charging. Energy flow is measured by examining energy remaining, energy storage and energy drawn from the battery. Charging and discharging are analysed by timing features and faster charging. The sudden drawn of high power from the battery increase the battery temperature and caused battery degradation. The model of battery degradation is given by.

$$B_c = 1 - (1 - i)e^{-cd}$$

Where B_c is the battery capacity degradation after the charging events, 'i' is the current decrement of the battery, 'cd' is the battery degradation components due to charging and discharging cycles. 'cd' can be defined as follows.

5. Conclusion

The research is performed at a 132kV National grid by connecting different ranges of electric vehicles. It is concluded that electric vehicles charging from grid cause voltage drops, over current production and power losses at the grid. This also minimises the lifespan of equipment at the power network system. It is observed that charging electric vehicles at peak time cause more disruptions in power flow as compared to off-peak timings. The increasing numbers of electric vehicles in future can create massive issues to the power flow industry. The research performed in this paper shows the impact of growing electric vehicles to overcome the power flow challenges that can lead to power quality problems. It is also investigated that connecting larger electric vehicles loads to one phase will create imbalances in the three phase power systems. Hence it is necessary to distribute the electric vehicles loads equally in all the three phases. This can be achieved by connecting the modern electronic communication system that interact with substation controlling systems to auto heal the power fluctuation.

Compliance with ethical standards

Acknowledgments

Authors would like to thank the research facilities support provided by the London South Bank University. This research is self-funded and did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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