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Impact of the Power Grid on Charging Stations of Various Power Rating and Sizes

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Abstract

Environmental energy issues are among the most common topics in modern world. The deployment of electric vehicles has been aided by the desire to reduce hazardous vehicular emissions and transition to alternative fuel sources. Electric vehicles offer the benefits which range from zero fumes gas discharge, decreased utilization of non-sustainable power like coal and oil. The advancement of electric vehicles indicates a move toward more efficient and cleaner electric drive systems. The charging infrastructure for electric vehicles should be safe, practical, and financially viable. The system should have the ability to handle electric vehicle charging requests. Different components of the power grid, such as voltage dependability, power efficiency, and power stream, would be affected when charging electric vehicles. The effect of EV charging system on the previously listed factors is evaluated in this paper.

Key-words: Energy Issue, Electric Vehicle, Power Grid, Power Quality, Power Stream.

1. Introduction

Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV), and Battery Electric Vehicle (BEV) are answers for air contamination and global warming. A lot of electrical energy is needed for charge these Electric Vehicle (EV) batteries. The genuine repercussions on power grid are heavy demand for energy. The most regular strategy to charge a BEV is to associate a cable to it when the vehicle is fixed [1]. Nonetheless, the charging time for this strategy is high. An option for this strategy is the development of battery trading stations wherein, a drained battery is supplanted by a completely energized battery [2]. A tale idea of wireless charging is simple level now and is under research presently [3-6]. Not withstanding the wide scope of benefits offered by Battery Electric

Vehicle (BEV), one of the prevailing purposes behind its lower acknowledgment is its restricted battery limit.

Regardless of the motivators offered by the public authority to advance Electric vehicles, India is as yet attempting to get more electric vehicles out. One thing to note is that India's own vehicle market is exceptionally portioned when contrasted with created nations. The market comprises of bike bicycles – the most well-known method of transport, three wheeler carts utilized for public transportation and Four wheeler vehicles and transports. The plans dispatched by the public authority embrace every one of these methods of transport with the point of getting more electrical variations to every one of them. The NEMMP which is the foundation of the electrification process pointed toward making India a pioneer in two and four wheeler electric vehicles on up coming years. Achievement, in any case, has been seen substantially more for two-and three-wheelers – that too in a restricted limit instead of 4 wheeler vehicles and could be credited to the absence of charging framework. In the 2 and 3 wheeler charging setting, there is an option accessible as battery trading anyway for the situation for four wheeler vehicles, on the other hand the electric vehicle charging framework. The charging foundation is as yet in its earliest stages disregarding the vision by the public authority henceforth this exploration intends to address the accompanying inquiries the current boundaries and difficulties impeding the execution of EV Charging stations.

Generally, the effect of EV charging on power grids has been a zone that has recreated by researchers. The foundation of charging stations forces an extra burden to the power grid. This can decrease the performance parameters of the distribution network. The uncoordinated charging of EVs may prompt expansion in peak load, introduction of increased harmonics as well deterioration of voltage profile. Numerous examinations led so far by the specialists uncovered the unfavourable effect of EV charging loads on various boundaries of the circulation network like voltage profile [8], harmonics and peak load [9]. The charging from distribution systems can greatly affect the characteristics and standards of the grid such as system stability, reliability, power flow, power quality and power loss.

2. The Impact of PHEV Charging on Various Power Grid Factors

The proposed charging model has two modes of operation. When the electrical grid is charging the storage, the charger modules are switched into the charging mode and the power flows from the electrical grid into the storage batteries. The grid current is filtered through the filtering circuit and then the rectifier is used for rectifying the input AC power [10-11]. The DC/DC converter in this mode controls the charging current into the storage batteries. During the discharging mode, the battery storage provides power to charge EVs. The charging system controls, the charging rate into the EVs which is controlled by the battery management system. In these regard two relays are used in the module to decide the mode of operation.

The proposed charging design for the individual charger modules is appeared in Fig. 4. The framework has two methods of activity. At the point when the electrical framework is charging the capacity, the charger modules are exchanged into the charging mode and the force streams from the power grid into the capacity batteries. The network current is separated through the filter circuit then the rectifier is utilized for amending the information AC power. The DC/DC converter in this mode controls the charging current into the capacity batteries. During the discharging mode, the battery ability to charge EVs. The charging system controls the charging rate into the EVs which is instructed by the battery management of the EV. Two relays are utilized in the module to choose the method of activity.

2.1 Voltage Stability Factor

Voltage stability can be characterized as the capacity of the system to hold system voltages inside worthy cut-off points under ordinary working conditions. Voltage stability can be nearby marvels or a worldwide wonder [12]. On the off chance that countless system buses face voltage stability issue, it is a worldwide wonder. Two factors to be specific Voltage Sensitivity Factor (VSF) and Voltage Stability Index (VSI) can be utilized for voltage steadiness examination.

The voltage stability is assessed dependent on the assurance of VSF from the PV curve [27-29].The PV curve is a graphical representation of active power and voltage.

- **The PV Curve**

Consider a two-bus system. Expect that one transport goes about as the sending end and the other as receiving is the voltage of the sending end and is the voltage of receiving ending. The transmission line is addressed with impedance $\bar{Z}_{\gamma}$. Assume that a load of impedance $\bar{Z}_{L}$. is associated at the receiving end.

Taking as the reference voltage, the magnitude of current in the transmission line is given as

$$I = \left| \frac{V_S \angle 0}{\bar{Z}_{\gamma} \angle \theta_{\gamma} + \bar{Z}_L \angle \theta_L} \right|$$

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$$\frac{V_S}{\sqrt{Z_\gamma{}^2+Z_L b^2+2Z_\gamma Z_L \cos(\theta_\gamma -}} \qquad (1)$$

The receiving end voltage magnitude is,

$$V_R = \frac{V_S Z_L}{\sqrt{Z_\gamma{}^2+Z_L b^2+2Z_\gamma Z_L \cos(\theta_\gamma -}} \qquad (2)$$

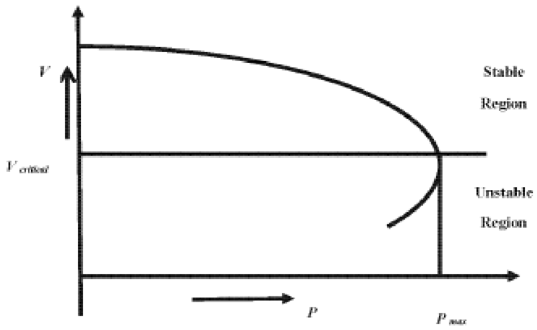
The active, reactive power consumed by the load is,

$$P_L = \frac{V_S^2 Z_L \cos(\theta_L)}{\sqrt{Z_\gamma{}^2+Z_L b^2+2Z_\gamma Z_L \cos(\theta_\gamma -}} \qquad (3)$$

$$Q_L = \frac{V_S^2 Z_L \sin(\theta_L)}{\sqrt{Z_\gamma{}^2+Z_L b^2+2Z_\gamma Z_L \cos(\theta_\gamma -}} \qquad (4)$$

The receiving end voltage is plotted against varying active power consumed by the load, to obtain the graph shown in Fig. 1 which is called as P-V curve.

Fig. 1 - Curve of Active Power Voltage (PV Curve)



This curve shows the course of voltage change with respect to active power.

From the PV curve, the critical point of operation for the system stability can be determined. As shown in Fig. 1, as the active power increases, the voltage decreases to a specific point where the active power is the highest.

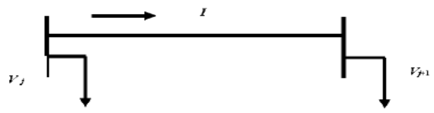
It can be expressed as,

$$VSF = \left|\frac{dV}{dP}\right| \forall P < P_t$$

A. Voltage Stability Index

The voltage stability index method, which was developed for a two-bus system is illustrated below:

Fig. 2 - A Two-bus System is Represented in a Single Line Diagram



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Consider j and j+1 be the two buses of the system. $V_j < \delta_j$ and $V_{j+1} < \delta_{j+1}$ be the voltages of j and j+1 respectively. The branch has resistance r and impedance x. I is the current flowing through the branch [12]. The equations for current and complex power may be written as

$$P_{j+1} - iQ_{j+1} = V_j \qquad (6)$$

Substitute the value of I in Equation (6), equate the real and imaginary parts, and simplify the equation:

$$V_{j+1}^4 + 2V_{j+1}^2(P_{j+1}r + Q_{j+1}x) - V_j^2 V_{j+1}^2 + (P_{j+1}^2 + Q_{j+1}^2 \quad |Z|^2 = 0. \qquad (7)$$

The transferrable active power may be written as

$$P_{j+1} = \frac{M \mp \sqrt{N}}{|Z|} \qquad (8)$$

and,

$$Q_{j+1} = \frac{P \mp \sqrt{Q}}{|Z|} \qquad (9)$$

The conditions for existence of transferrable active, reactive power is

$$N \geq 0 \text{ and } Q \geq 0 \qquad (10)$$

Substitute the values of N, Q and includes those leads to the inequality defining the stability criterion of the system is:

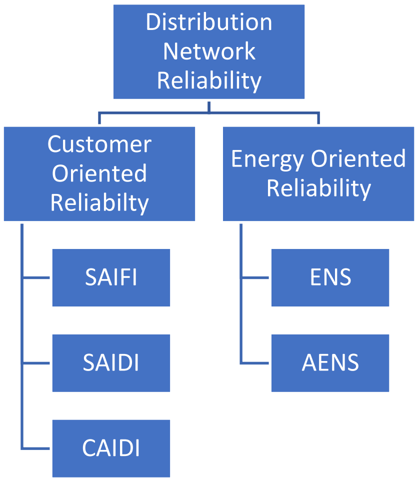
$$2V_j^2 V_{j+1}^2 - 2V_{j+1}^2(P_{j+1}r + Q_{j+1}x) - |Z|^2 + (P_{j+1}^2 + Q_{j+1}^2) \geq 0 \qquad (11)$$

The estimation of the Equation (11) is known as VSI. Regularly, the PEV battery limit ranges between 2 kW and 17 kW. Thus, these elements likewise choose the time needed to charge the battery. Vehicles with huge battery packs can put an appeal on current and voltage from the power grid, to get charged in a short timeframe. This would thus expand the active power demand. From Equation (11) as active power increases the value of equation decreases. In the event that the estimation of VSI decreases under 0, the system gets unstable [16]. Consequently, the effect of charging station on voltage stability is, charging stations demanding higher active power will make the system become unstable.

2.2 Reliability

Reliability of a system is characterized as the probability that the system will not fail throughout a theatrical span of activity, under the given arrangement of working conditions. Consumer loyalty levels give premise to estimation of Reliability of distribution networks.

Fig. 3 - Index of Distribution Network Reliability



For assurance of reliability for a network, a few boundaries, for example, measurable information of disappointment rate, fix rate, normal blackout span, and number of consumers of the network are required.

System Average Interruption Frequency Index (SAIFI) is connected with the frequency and term of interference of administration experienced by consumers. In, SAIFI is characterized as the occasions a system client encounters interference during a specific time-frame. It stresses the condition of the system as far as interference. It is determined as:

$$\text{SAIFI} = \frac{\sum \lambda_j N_j}{\sum N_j} \tag{12}$$

where λ_j is the failure rate and N_j is the number of customers for location *j*.

The measure of the system's energy shortage is Energy Not Supplied (ENS). It reflects the total energy that the device does not have. It can be calculated as:

$$\text{ENS} = \sum L_j U_j \tag{13}$$

where, L_j is the load factor.

AENS shows how much energy is not served during a given time span. The average machine load curtailment index is referred to as AENS. It can be calculated as

$$\text{AENS} = \frac{\sum L_j U_j}{\sum N_j} \tag{14}$$

AENS and voltage deviation above a threshold limit are crucial to the system's operation. Large deviations could put the device under a lot of stress. The power loss in the system can be aggravated by increased demand on the distribution network. It can also extend the time customers have to wait for those buses[20]. Finally increased the load, the system reliability could affect.

As an electric vehicle (EV) is linked to the power grid for charging, the grid's load demand increases. Per customer, the number of service interruptions and the length of each interruption is increasing. This will potentially have a bearing on the power system's reliability indices. When the system's reliability indexes fall below a critical value, the system becomes unreliable. This means that the power system does not sustain voltages within defined limits at all times when reliability indexes are less than their threshold value.

2.3 Power Loss

The equations below are based on a distribution system power flow analysis. The investigation is focused on distribution network modelling.

The relationship between power loss and load demand can be explained by the equation.

$$P_{loss} = L^2 \frac{R}{V^2 a_t^{2n}} \quad (15)$$

where L is the distribution network's load demand, R is the line impedance, V is the feeder voltage, and a_t is the transformer ratio n is transformer number.

Based on Equation (15) the power loss effect caused by PHEV charging can be represented by the equation.

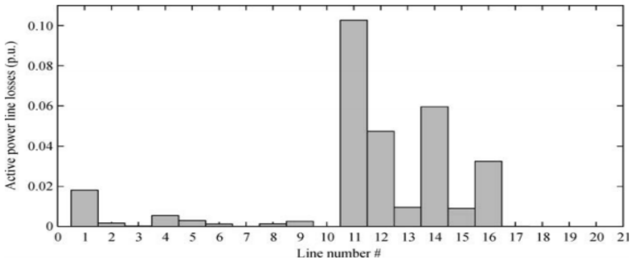
$$\Delta P_{loss} = (L_{PHEV}^2 + 2L_{Background})\left(\frac{R}{V^2 a_t^{2n}}\right) \quad (16)$$

Where, is L_{PHEV} load demand and $L_{BACkGROUND}$ is background real time load demand. It is obvious from Equation (16) that as the PHEV's load demand increases, so do the losses in the power systems. Equation dictates that charging a PHEV during peak hours would result in a significant increase in total power loss (16).

The effects of incorporating PHEV loads into an IEEE 14 bus system in order to determine the impact of PHEV charging on the power grid [23].

Figure 4 shows the active line losses profile before the PHEV load was added in the analysis.

Fig. 4 - Bus System Active Line Losses at Base Load



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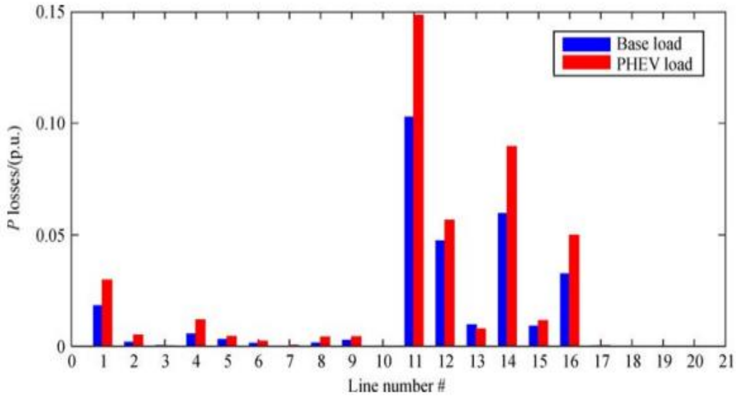
The active line losses profile plotted after the introduction of PHEV load is shown in Fig.6.

Fig. 5 - The Bus System's Active Line Loss Profile after the PHEV Load was Implemented



The graph illustrates a rise in active line losses as PHEVs are introduced into the distribution system. This is because PHEV loads increase the active power produced and the line current, resulting in excessive voltage drops. This leads to the increased loss of active lines.

2.4 Power Quality

Harmonic distortion in the power grid, voltage unbalance, current unbalance, and other issues all lead to harmonic issues. PEVs charge by drawing low voltage AC power is converting in to DC when they are connected to the power grid. The AC signal is first rectified before being sent through a DC/DC converter. Rectifier and the DC/DC converters are non-linear loads.

Harmonic distortion is generated on the distribution system by both the rectification and conversion processes performed by non-linear loads. Electric vehicle chargers include various non-linear devices. Present harmonics are considered to be caused by non-linear loads. When connected to the power grid, it generates a voltage that is not inherently sinusoidal. As a consequence of the non-linear load generating a sequence of sinusoids, fundamental frequency occurs at product of the fundamental frequency. Three-phase distribution systems are used. Each phase is 120º apart.

When the three phases have different harmonics, the total currents do not add up to zero. The three phases' different harmonics may either add constructively or destructively. Neutral currents can be generated if positive addition occurs. These currents have the ability to cause damage to power grids. Current harmonics are the most common source of voltage harmonics.

The voltage given by the power grid can be distorted by current harmonics induced by source impedance. The level of harmonic distortion in an electrical power system is calculated by total harmonic distortion (THD).

The power factor is related to THD as

$$\text{Power factor} = \frac{1}{\sqrt{1+(\frac{THD_v}{100})^2}\sqrt{1+(\frac{THD_i}{100})^2}}$$

THD_v denotes THD related to voltage harmonics, while THD_i denotes THD related to current harmonics. As shown by the above equation, an increase in THD will result in a decrease in power factor[18]. The apparent power, which is the actual power flowing in the network, is greater than the real power, which is the power consumed by the load, if the power factor is lower.

As a result of the high apparent power, more current is drawn from the grid, resulting in an increase in total energy lost. Increased harmonic current has a variety of effects, including overheating of power system facilities, interruption in the operation of safety and control equipment, and blackout.

Electric vehicles (EVs) are being introduced to the market, with charger structures that differ greatly. THD varies depending on the charger structure. The impact of certain charger systems on the power grid is already illustrated. High harmonic current is developed by a rectifier with a chopper and no control methods and result in high THD[27].

A rectifier with a DC/DC converter and control methods is found in another form of charger. Instead of a chopper, these chargers use a high frequency transformer. They selectively remove high frequency while reducing DC voltage ripples. These charges, on the other hand, introduce a lot of harmonics into the power system. As a result of the harmonics, high THD values are generated, affecting the power quality.

Since EVs with different charger structures introduce a large number of harmonics into the power system, an excessive number of EV charging, particularly during peak hours, can increase the introduction of harmonics. The voltage deviation and voltage unbalance in the device are also increased when a PEV is charged. The phase voltages of all phases in a balanced three-phase system should be equivalent. The voltage difference between the voltages at the three phases of a three-phase device is known as voltage unbalance. The load from EV charging is not uniformly distributed through the power system's three phases.

One phase's load could be higher than the load on the other phases. A phase's load may be zero, while the load on the other two may be non-zero. Uneven EV load distribution can result in different voltage drops between the system's phases, resulting in voltage unbalance. The overall bus-voltage deviation and voltage unbalance occur when charging is not coordinated.

Obviously, as the percentage of electric buses on the road increases, the voltage on each bus decreases. As a result, the load current rises and the voltage decreases even more, resulting in an unnecessary voltage drop and, as a result, voltage unbalances. Voltage unbalance, which often means unequal harmonic distortion levels, and phase angle variance, are power quality issues at the distribution level. The power system is heated as a result of the voltage imbalance.

The voltage unbalance (in percent) or Line Voltage Unbalance Rate (LVUR) is defined as the ratio of maximum voltage deviation from the average line voltage to the average line voltage, according to the National Electrical Manufacture Association (NEMA). However, because IEEE uses phase voltage rather than line voltage, the Phase voltage is used. so the Phase Voltage Unbalance Rate (PVUR) is given by

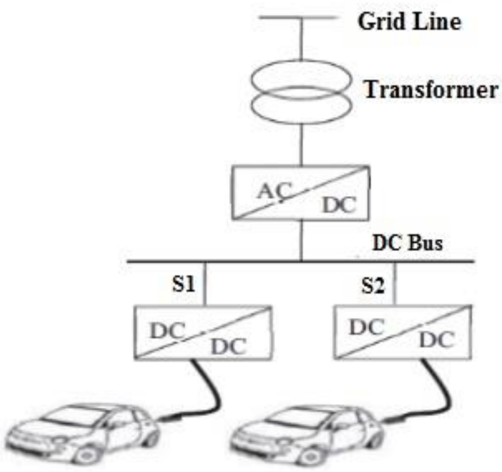
$$PVUR = \frac{Maximum\ voltage\ deviation\ from\ the\ average\ phase\ voltage}{Average\ phase\ voltage}$$

According to NEMA, the overall voltage unbalance of the electrical supply system is limited to 3%.

2.5 Power Flow

Electric energy from the distribution grid (AC Three Phase) is stepped down to the voltage level of the charging station using a transformer in a charging station. The three-phase AC/DC converter converts AC power to DC power and generates a DC bus. Electric vehicles are charged by connecting to the DC bus through a DC/DC converter that precisely matches the voltage required by the battery.

Fig. 6 - Charging Station Schematic Diagram



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The schematic diagram shown in Fig. 6 can be used to illustrate how a charging station operates and how electricity flows through it. A battery adapter (DC/DC converter) connects the electric vehicle to the charging station's DC bus. Constant Current-Constant Voltage (CC-CV) charging is the charging system used to charge the battery of an electric vehicle.

The battery current is kept constant at first, and the battery voltage is allowed to rise until it reaches a fixed value in this scheme. Constant Current (CC) mode is the term for this mode. When the voltage exceeds this level, current is allowed to decrease while the voltage is retained at the predetermined level it’s known as Constant Voltage (CV) mode. Constant Current (CC) mode is used for the bulk of the charging.

The DC/DC converter provides a suitable output for the battery. The voltage and current parameters of the DC/DC converter are regulated by a controller designed for CC-CV charging. The controller provides voltage and current rating feedback from the battery as input. The flow chart for the CC-CV controller software is shown in Fig.8.

Fig. 7 - Control Scheme for Electric Vehicle Chargers

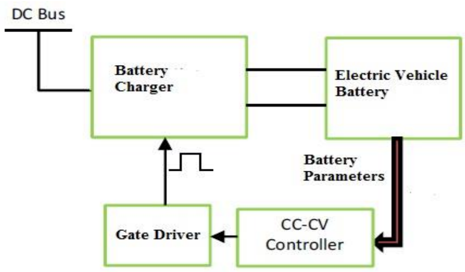
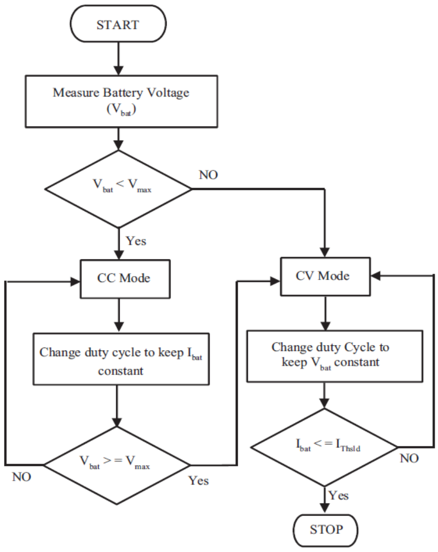


Fig. 8 - Charging Flow Map for CC-CV



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In power system analysis and design, power flow analysis is essential. Consider a structure made up of N buses. The following equations (17) to (21) was adapted from. The injection of net power into any machine bus k, which is complex in nature, can be described as

$$S_k = V_k I_k^* \qquad (17)$$

The current injected to bus k may be represented as

$$I_k = \sum_{j=1}^{N} Y_{kj} \dot{V}_j \qquad (18)$$

where, Y_{kj} is the element (y, k) of the admittance matrix Y.

Also, $Y_{kj} = G_{kj} + iB_{kj}$ where *G* denotes conductance and *B* denotes susceptance.

Substituting Equation (18) in Equation (17), we obtain,

$$S_k = V_k \sum_{j=1}^{N} Y_{kj}^* V_j^*$$

It is known that V_K has magnitude $|V_K|$ and phase angle. Hence the above equation may be written as

$$S_k = |V_k|\angle\theta_k \sum_{j=1}^{N} (G_{kj} - iB_{kj})(|V_j|\angle-\theta_j)$$

$$S_k = \sum_{j=1}^{N} |V_k|\angle\theta_k |V_j|\angle-\theta_j (G_{kj} - iB_{kj}) \qquad (19)$$

Substituting for $|V_k|\angle\theta_k$ as $|V_k|(\sin\theta_k + i\cos\theta_k)$ in Equation (20), we obtain,

$$S_k = \sum_{j=1}^{N} |V_k||V_j|(\cos\theta_{kj} + i\sin\theta_{kj})(G_{kj} - iB_{kj})$$

where,. $\theta_{kj} = \theta_k - \theta_j$ The above equation can be further simplified as

$$S_k = \sum_{j=1}^{N} \begin{matrix} |V_k||V_j|(G\cos\theta_{kj} + B\sin\theta_{kj}) + \\ i(G\sin\theta_{kj} - B\cos\theta_{kj}) \end{matrix} \qquad (20)$$

The complexities of control The active power is represented by the real part of S k, while the reactive power is represented by the imaginary part. It can be written as:

$$S_k = P_k + iQ_k \qquad (21)$$

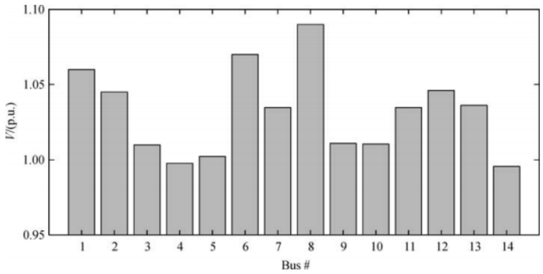
where, P_K is the active power and Q_K is the reactive power. Comparing Equation (20) and Equation (21), the equations for active power and reactive power may be written as

$$P_k = \sum_{j=1}^{N} |V_k||V_j|(G\cos\theta_{kj} + B\sin\theta_{kj})$$

$$Q_k = \sum_{j=1}^{N} |V_k||V_j|(G\sin\theta_{kj} - B\cos\theta_{kj})$$

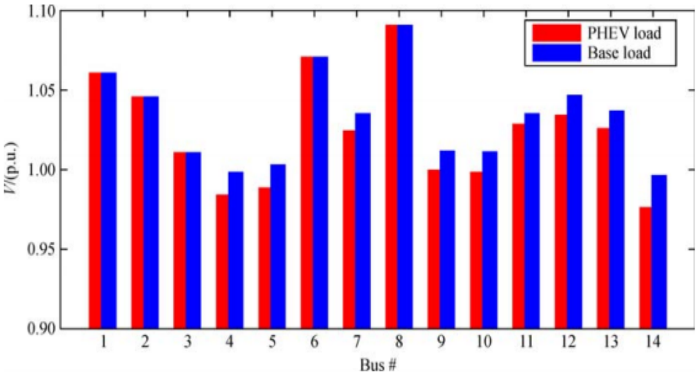
The authors conducted a study to monitor improvements in the power grid's voltage profile, active power profile, and reactive power profile after PHEVs were incorporated into the grid. The research was carried out using the IEEE 14 standards, which was generated in the Simulink Simulation Environment, and the results were plotted using the same. According to the study, the voltage magnitude profile plotted before the integration of PHEV load on to power system is shown in Fig. 9.

Fig. 9 - At Base Load, the Voltage Magnitude of the 1EEE 14 Bus System.



The Figure.10 shows that the voltage magnitude profile of the bus system after including of PHEV loads to all buses except bus numbers 1,2,3,6, and 8.

Fig. 10 - After the PHEV Load was Implemented, the Bus System's Voltage Magnitude Profile Improved



When comparing Figures. 9 and 10, it can be shown that the voltage magnitude of the buses where the PHEV loads were attached has decreased. The increased load demand imposed by PHEVs is to blame for this degradation.

Similarly, Figure. 11 represents the active power profile of the bus system prior to the incorporation of the PHEV into the power system. The active power profile after the addition of a PHEV load to bus number 1 is shown in Figure. 12. When comparing Figure.11 and Figure.12, it is clear that the active power produced by the penetration of PHEV load into the distribution network has increased significantly.

The increased active power produced can be attributed to the need to satisfy the PHEV load's increased charging demand. A higher line current is produced as more active power is generated.

Fig. 11 - At Base Load, The Bus System's Active Power Profile

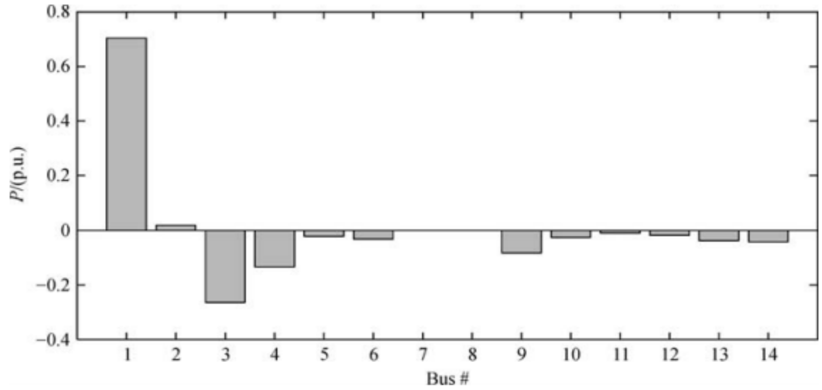
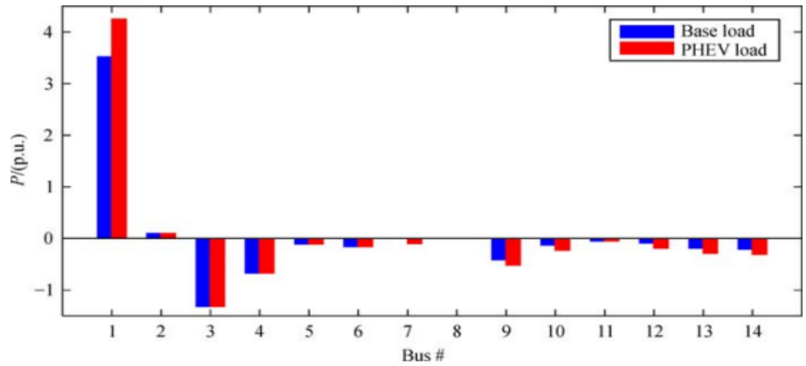


Fig.12 - PHEV Load was Installed on Bus Number 1, The Active Power Profile of the Bus System Improved



3. Miscellaneous Impacts

Other implications of incorporating PHEVs into distribution networks include:

3.1 Congestion

EV vehicle customers are free to charge their vehicle batteries at any time and for any span of hours. The power network may not be able to meet the demands of all customers in this scenario of uncoordinated charging. EV owners and residential consumers are among the customers. When many EVs are paid at the same time during peak load hours, the situation becomes even worse. The distribution network can become overloaded as a result of this uncoordinated charging.

3.2 Deterioration of Transformers

The life span of the transformer can be adversely affected over time as a result of increased PEV penetration, increased harmonic distortion, uncoordinated charging patterns, and increased temperature. These factors can contribute to the transformer's reduced productivity and lifespan.

4. Conclusion

In the current scenario, where EVs are rapidly becoming common, a study of the various effects of PHEV integration on distribution is an unavoidable necessity. Voltage instability, increased power loss, reduced system efficiency, and increased customer service interruptions result from the increased penetration of PHEVs into the delivery system. This integration has the ability to introduce both current and voltage harmonics into the power system, lowering its power quality. The high load demand imposed by PHEVs results in increased active power generation, which allows heating losses to accumulate in the power system.

Congestion in the delivery network may also arise as a result of an increase in the number of customers. All of these consequences would be compounded by the charging of electric vehicles during peak hours. It is imperative that charging time strategies be implemented in order to overcome the losses and negative impacts that have been introduced into the power system. To minimize the negative effects of EV charging on power systems, several load models and charging strategies have been developed, with more in the works.

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