

Impact of Plug-In Electric Vehicles on the Distribution Grid

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Abstract-Pollution due to greenhouse gas emissions in urban areas and excessive dependence fossil fuel has been a huge threat in the sustainable development of the transportation sector. So, there is a need for a solution that can tackle this situation. Electric vehicles can be one of the most promising remedies to tackle this problem. They provide energy conservation and environmental protection. Electric vehicles are propelled by an electric motor powered by rechargeable battery packs. They have both positive and negative impact on the power grid. For instance, in order to evaluate the impact on electric vehicles on demand profile, one needs to know about 1)charging process of electric vehicles, 2) amount of electrical energy required, 3) amount of power required, 4)state of charge of the battery. This paper extracts the comparison between the load profile of the distribution system without EV's and with EV's connected. Also it shows the voltage unbalance caused by EV's interconnection with the grid.

Keywords-Electric vehicles; load profile; charging process; voltage unbalance.

I. INTRODUCTION

Air pollution, greenhouse emission, climatic changes and excessive dependence on fossil fuels are the major issues for concern in today's world. All these issues have lead to the electrification of power train. Since most of the power plants are located in rural areas, personal automobiles are considered the main cause for air pollution in urban areas. Electric vehicles provide both energy conservation and environmental protection. Also electric vehicles have been considered as an effective solution over the negative impacts of conventional vehicles.

Electric vehicles run on electricity only. They are propelled by an electric motor powered by rechargeable battery packs. They have several advantages over conventional vehicles. EVs powered by super capacitors can run for more than 20 min by charging only for 30 s, recharging EVs will not be a major problem. In the future, EVs will be recharged via contactless power transfer [1]. However they do face several battery related challenges. Most EV's can only go about 100-200 miles before recharging whereas gasoline vehicles can go over 300 miles before refueling. Also the large battery packs are expensive and may to be replaced one or more times. One the other side, Electric vehicles are energy efficient, they convert about 59-62% of

the electrical energy from the grid whereas conventional gasoline vehicles only convert about 17-21% of the energy stored in gasoline [2]. Moreover electric vehicles emit no pollutant and provide smooth operation and strong acceleration. Electric vehicle serves as a distributed energy resource.

Electric vehicles play an important role in smoothening of the load profile. They provide the function of peak shaving. They reduce the difference of minimum and maximum of power load. Many studies have been undertaken to study its impact on the load profile. They are as follows:

1. Battery storage capacity
2. Cost of residential charging
3. Consumer driving habits
4. Local power demand curve

Battery of the vehicle plays an important role. Electric vehicle derives all its power from the battery and thus has no internal combustion engine. Electric vehicle batteries are different from other batteries as they deliver power for a given period of time. Flooded lead-acid battery is the cheapest and the most commonly used battery.

State of charge: Second most important term is the state of charge of the battery. State of charge (SOC) defines the current state of a battery in use. At each vehicle departure time, state of charge is expected to have a certain desired value. Beyond this value, it cannot be further discharged.

II. RELATED WORK AND BACKGROUND INFORMATION

Several surveys have been done for the study and analysis of energy consumptions of PEVs and the influence of PEVs on the electric grid.

Some of the latest and significant works done in this area are enlisted below:

Sumit Paudyal et al. [3] developed a mathematical model to study the impacts of uncoordinated charging and coordinated charging of the PHEVs on distribution system operations considering a 15-node distribution feeder with 10%, 20% and 50% PHEV penetrations in residential loads.

Power quality(PQ) is one of the issues which will be of great importance when many EV's are plugged to the grid either for charging or giving back to grid, since most of the electronic devices are non linear in nature. Paul S. Moses et al. [4] has studied the impact of PEV charge rate on voltage

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profile, fundamental and harmonic losses, transformer loading and total harmonic distortions.

The paper at hand presents a model of a distribution grid. A comparison is made between the load profile of grid with coordinated charging and without coordinated charging of EV's. This paper also gives an idea of the effect of EV's integration on the voltage unbalance.

III. SYSTEM DESIGN

A model of distribution grid is made on DigSILENT software. This software is power system analysis software for applications in generation, transmission, distribution and industrial systems [5].

The power factory is capable of simulating many events, some of the events are:

1. Load flow studies
2. Step wise variation of load
3. Switching events
4. Calculation of initial condition
5. Symmetrical short circuit studies
6. Change of any system parameter
7. Load events
8. Insertion of network element

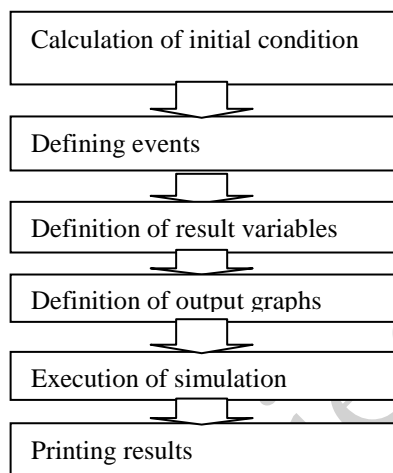


Fig.1. Flow diagram of simulation in DigSILENT

This model has six distributive loads of different rating. The power demand and the required time duration for PEV's are determined by the charging level. Three types of chargers are available for the charging of electric vehicles. Level 1, level 2, and level 3. Most of electric vehicles' charging might occur at the residential level. The common site for charging EVs is the garage where the vehicle is parked overnight and it is convenient to be plugged in.

A level I AC charger is suitable for home. Level I charger uses standard wall outlet of 120V/15A and the maximum power up to 1.8 kW. This kind of charger usually requires 6 to 8 hours to fully charge the EVs' battery pack [6]. Level 1 charger is highly cost effective as it does not require additional reinforcement of the existing residential

infrastructure. Hence in this paper we have considered level 1 charging of electric vehicles.

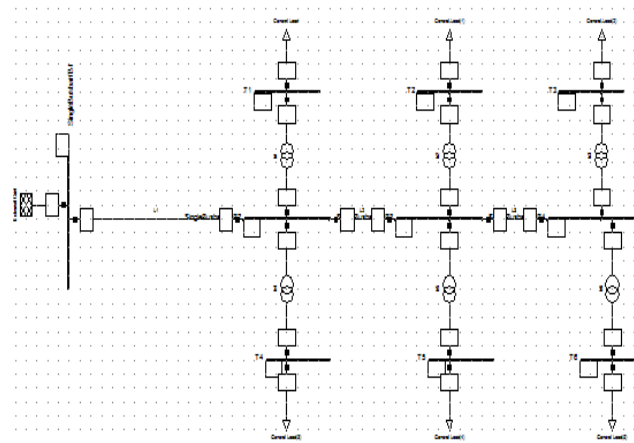
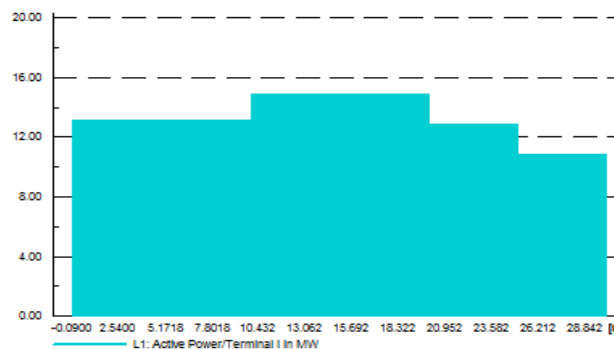


Fig.2. Model of distribution grid

Figure 1 shows the model of the distribution grid. The paper helps to analyze the interaction of EV's with the distribution grid. Three cases are considered in this paper. In the first case, load profile is obtained, when no PEV's are connected to the grid. In the second case, PEV's are connected but uncoordinated charging is there. Its impact on the load profile is studied. In the third case, coordinated charging of PEV's is done and its impact on the load profile is analyzed. It is seen that due to coordinated charging the load profile gets smoothed, and the number of peaks also get reduced. This section represents the impacts of unmanaged PEV's charging on load profile and voltage unbalance.

Case 1: Impact on load profile without PEV's

In this case no PEV load is connected to the grid. Load curve is obtained which shows that the peak load occurs between 10am to 6pm in the evening as this is the working hour of most of the industries. Load is at its base in the midnight. The following graph shows the load profile without PEV's.



FFig.3. Load profile without PEV's

X-axis denotes the time in hours

Y-axis denotes the load in megawatt (MW)

Figure shows that the peak load is around 15MW and is between 10am to 6pm. Whereas the base load occurs at midnight usually between 1am to 5am.

Case 2: Impact on the load profile with PEV's uncoordinated charging.

In the second scenario the effect of unmanaged PEV charging on the load profile is seen. In the second case it is assumed that (Based on the associated report, 2009 NHTS) [7], most of the drivers arrive homes between 5PM and 9 PM. Thus, evening at 6 PM as well as night at 10 PM are chosen to be the best times for the vehicles' owners to start charging their cars' batteries. With the help of load event, the load is increased in the evening. Now due to the charging of vehicles between 5pm to 9pm the peak load increases further and the load profile shows an increased peak. This is the case of uncoordinated charging, which means charging of the vehicles as soon as the owners reaches home. Following graph shown the load profile with uncoordinated charging.

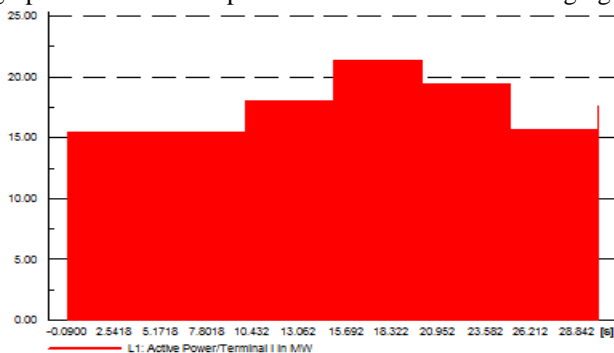


Fig.4. Load profile with uncoordinated charging of PEV's

From the graph it is clear that due to uncoordinated charging the peak load increased to 22MW. The peak load is shifting from 3 PM to 7 PM when consumers plug-in their vehicles in the evening. The peak load increases to 22 MW at compared to 14MW. Now in the third scenario we will analyze the effect of coordinated charging on the load profile.

Case 3: Impact on the load profile with coordinated charging of PEV's.

In scenario third we will see that how coordinated charging will help in peak shaving. In this scenario it is assumed that, the drivers charge their car during late night that is when there is base load. Due to coordinated charging of the vehicles, it has been observed that the peak gets shaved, the load profile gets smoothened. Following graph shows the effect of coordinated charging of PEV on the load profile.

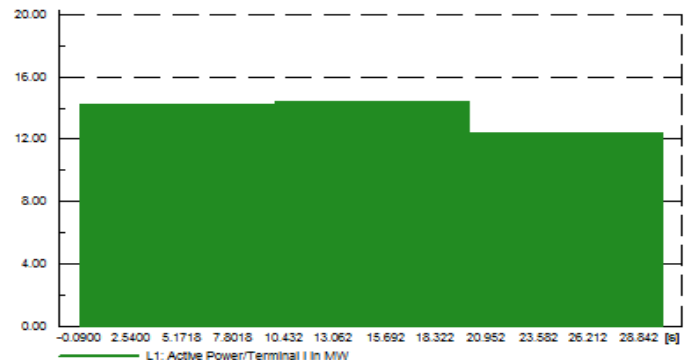


Fig. 5 Load profile with PEV's coordinated charging.

It can see from the above graph that peak load is around 16 MW. There is less number of peaks as compared to the uncoordinated load profile.

IV. VOLTAGE UNBALANCE

One of the power quality problems at the distribution level is voltage unbalance. It means that the magnitudes of line or phase voltages are different. It causes unequal voltage magnitudes at the system frequency and phase angle deviation. Voltage unbalance usually occurs in rural areas where the distribution lines are too long. It is mainly caused by uneven distribution of single phase loads over the three phase system. Uncoordinated charging of electric vehicles could significantly increase the voltage unbalance of the distribution system.

The voltage unbalance has negative impacts on the power system and its equipment. The power system will have heating effects and more losses in case of unbalanced conditions. Moreover, temperature and machine losses will be increased which result in reduced efficiency and decreased life of the machines.

National Electrical Manufacture Association (NEMA) defines the voltage unbalance in percent as the ratio of maximum voltage deviation from the average line voltage to the average line voltage (%LVUR). The same definition is used by IEEE and the only difference is that the IEEE uses the phase voltage rather than the line voltage [8], so the phase voltage unbalance rate (PVUR) is given by

$$\% \text{ PVUR} = \left[\frac{\text{Maximum voltage deviation from the average phase voltage}}{\text{Average phase voltage}} \right] \times 100$$

NEMA recommends that the maximum voltage unbalance of the electrical supply system must be restricted to 3%. According to the standers of "NEMA Motors and Generators" and International Electro technical Commission (IEC), the permissible maximum voltage unbalance for the induction motors is one percent [8].

Voltage unbalance can also be defines as the ratio of negative sequence component of the voltage and the positive sequence component of the voltage multiplied by 100.

$$\text{Voltage unbalance} = \frac{\text{negative sequence component}}{\text{Positive sequence component}} \times 100$$

On the basis of this formula various graphs have been obtained at various nodes showing negative and positive sequence component of voltage. Hence voltage unbalance is found out at terminals and transformers of the distribution grid.

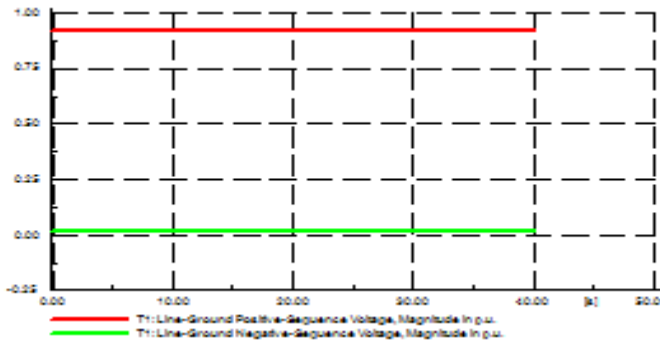


Fig. 6 Positive sequence component and negative sequence component at terminal 1

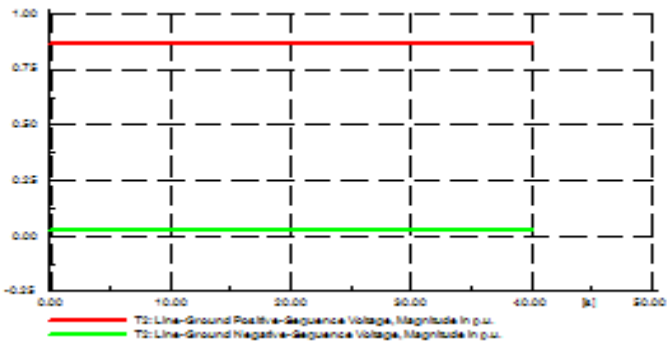


Fig. 7 Positive sequence component and negative sequence component at terminal 2

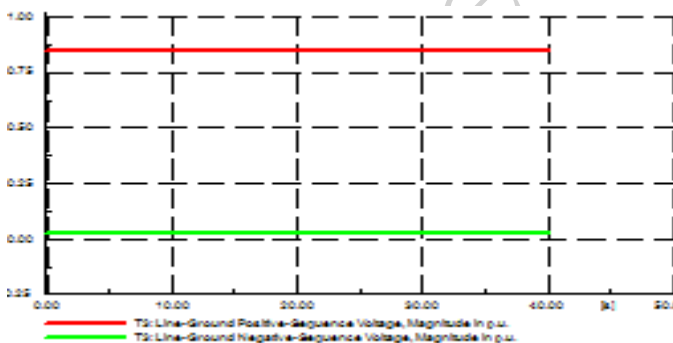


Fig. 8 Positive sequence component and negative sequence component at terminal 3

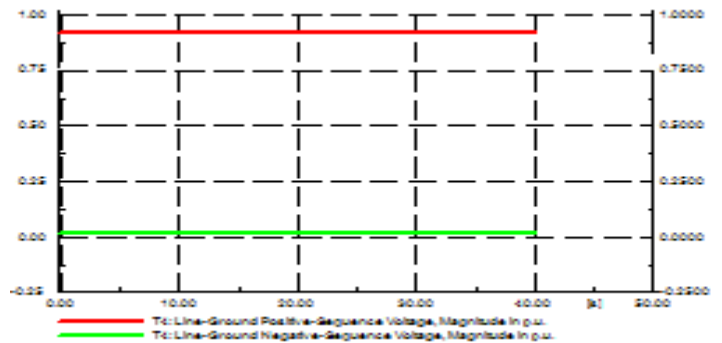


Fig. 9 Positive sequence component and negative sequence component at terminal 4

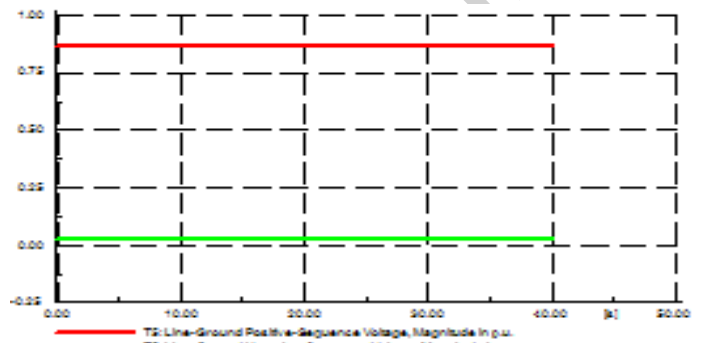


Fig. 10 Positive sequence component and negative sequence component at terminal 5

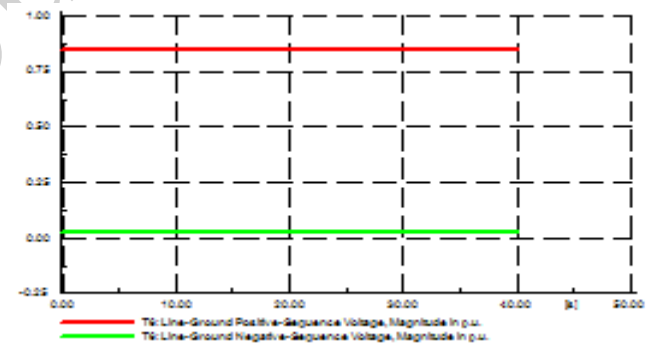


Fig. 11 Positive sequence component and negative sequence component at terminal 6

From the values obtained, table is formed showing voltage unbalance caused by the uncoordinated charging of PEV's at various nodes.

Voltage unbalance at various terminals of the grid are shown below in the table

Table 1 voltage unbalance at terminals

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Nodes / Terminal	Positive Sequence Voltage(V+)	Negative Sequence Voltage(V-)	Voltage Unbalance (V-/V+)
T1	0.9620064	-0.02714366	-0.028215675
T2	0.9073417	-0.01494187	-0.016467743
T3	0.8920338	-0.01234928	-0.01384396
T4	0.9122158	-0.02760368	-0.030260033
T5	0.9071508	-0.01577571	-0.017390394
T6	0.8926602	-0.01420449	-0.015912539

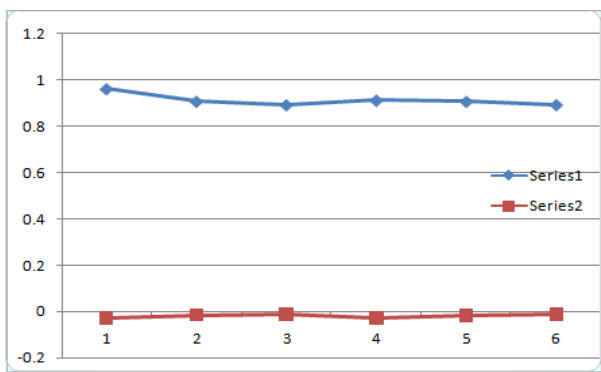


Fig.12 VOLTAGE UNBALANCE AT ALL THE SIX TERMINALS

Y axis showing voltage in per unit (PU)
 Similarly voltage unbalance is calculated at various transformers of the distribution grid.

Similarly following graphs shows the positive sequence component and negative sequence component at various transformers.

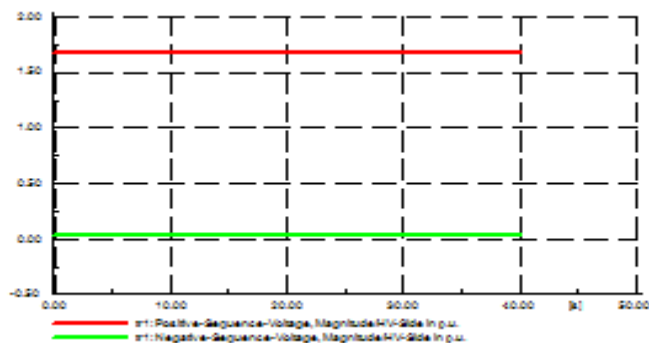


Fig.13 Positive sequence component and negative sequence component at transformer 1

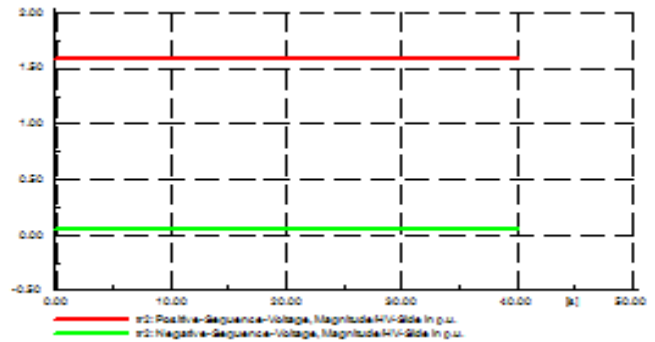


Fig.14 Positive sequence component and negative sequence component at transformer 2

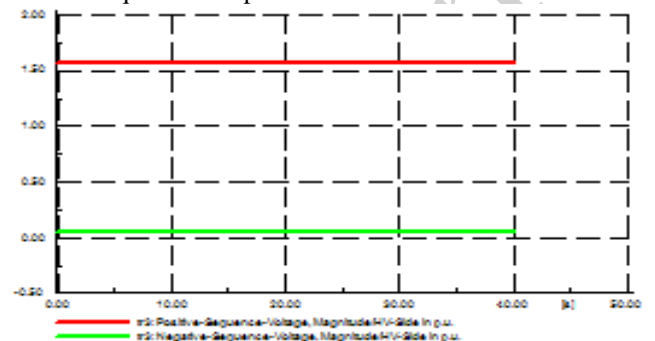


Fig.15 Positive sequence component and negative sequence component at transformer 3

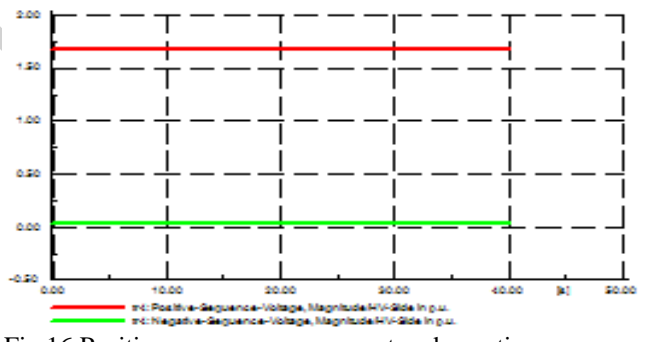


Fig.16 Positive sequence component and negative sequence component at transformer 4

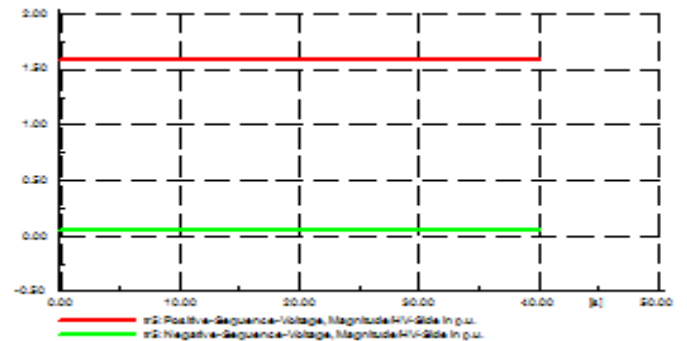


Fig.17 Positive sequence component and negative sequence component at transformer 5

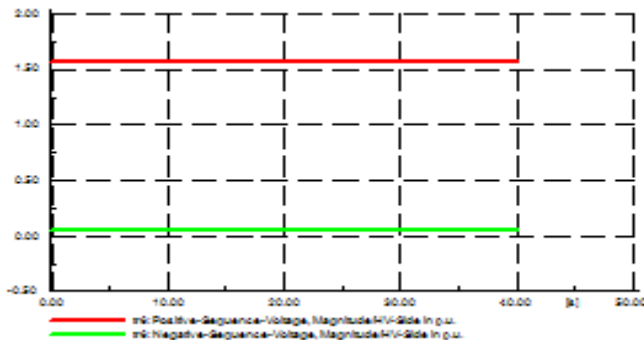


Fig.18 Positive sequence component and negative sequence component at transformer 6

Table 2 voltage unbalance at transformers

Nodes/ Transformer	Positive Sequence Voltage(V+)	Negative Sequence Voltage(V-)	Voltage Unbalance (V-/V+)
TR1	1.763678	-0.04976337	-0.028215678
TR2	1.663461	-0.02739342	-0.016467726
TR3	1.635395	-0.02264034	-0.013843958
TR4	1.764062	-0.05060674	-0.02868762
TR5	1.663111	-0.02892214	-0.017390385
TR6	1.636544	-0.02604156	-0.015912533

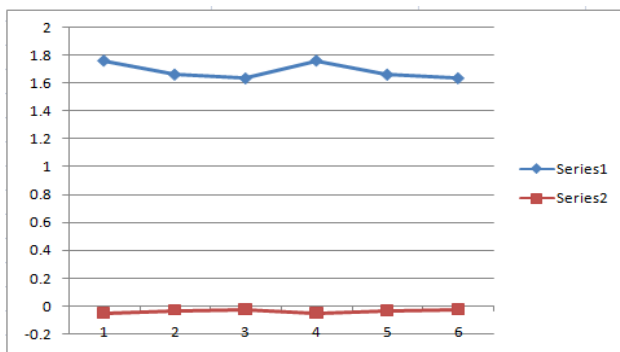


Fig. 19 Voltage unbalances at all the six transformers

V. CONCLUSION

Large-scale penetration of plug-in electric vehicles in distribution system will undoubtedly influence the design and the operation of the distribution network. The increased adoption of electric vehicles has a huge impact on some specifications of the distribution system such as voltage quality at load points and the load curve.

It could be assumed that the number of electric vehicles will increase over next few years. They can provide ancillary service which includes peak power, spinning regulation etc. In the future, they could bring huge social and economic value to the grids as well to the vehicle owners

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