# POWER QUALITY IMPACT OF ELECTRIC AND PLUG-IN HYBRID VEHICLES

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## *ABSTRACT*

*The continued increase of gas prices and concerns on greenhouse gas emissions in recent years have led to the steadily increasing acceptance of electric vehicles (EVs), especially the plug-in hybrid electric vehicles (PHEVs), by consumers. It seems that PHEVs are poised to become a serious contender for a noticeable share of the car market in the near future. As PHEV draws power through power electric circuits from the utility grid when it is being charged, utility companies are concerned with the potential power quality impact of mass penetration of PHEVs. This project was conducted to address this concern, i.e. to determine the collective impact of PHEVs on the power quality of primary and secondary distribution systems. The overall objective of the project is to provide technical information and assessment results to develop a proactive strategy to deal with the emergence of this new type of loads in residential areas of power distribution systems.*

## SUMMARY

The project was conducted through extensive computer simulation studies on sample primary and secondary distribution systems and by considering the market penetration of hybrid electric vehicles (PHEVs) [1,2,3]. Through surveying and analyzing various consumer market research data, the project has established the likely adoption trends of PHEV per household. This data was then used to establish the build-up of PHEV loads in a distribution system.

The simulation study further considered the random charging nature of the PHEVs. Factors considered included PHEV penetration level (deterministic), type of cars and chargers (semi-deterministic), PHEV location in a residential system (random), state of batteries at the end of day (random), start and end time of charging cycles (random), and charging strategy (uncontrolled, controlled, and smart - deterministic) [3,4,5]. The basic characteristics of a PHEV charger obtained and used by this project are shown in Table 1.

**Table 1: Basic parameters of PHEV charger.**

| Type | Power Level |
|---|---|
| Level 1: 120 VAC | 1.2-2.0 kW |
| Level 2 (low):208-240 VAC | 2.8-3.8 kW |
| Level 2 (high):208-240 VAC | 6-15 kW |
| Level 3: 208-240 VAC | >15 kW-96kW |
| Level 3:DC Charging: 600 VDC | >15 kW-240kW |

The level 1 and 2 chargers are the types involving residential customers. It can be seen that the power demand of level 1 charger is comparable with that of a microwave oven and the level 2 (low) is comparable with a dryer or a cooking range. In terms of power demand, the residential type chargers are comparable with other home appliances. The main difference is that the chargers can and will typically run for much longer periods of time. Figure 1 shows the harmonic spectrum of three chargers and they are compared with that of a desktop PC. The figure reveals that the chargers inject much less harmonics into the power system on a percentage basis. In fact, in term of harmonic current injection in amperes, one PHEV charger is roughly equivalent to 7.3 compact fluorescent lights (CFL) or 1.2 desktop PCs [6].

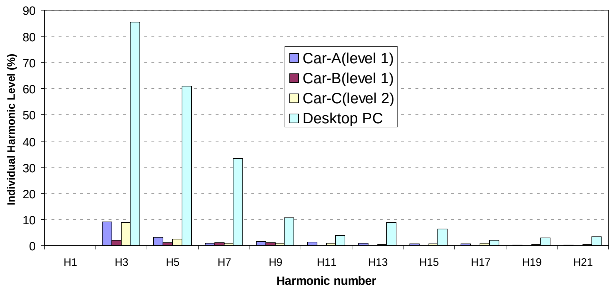
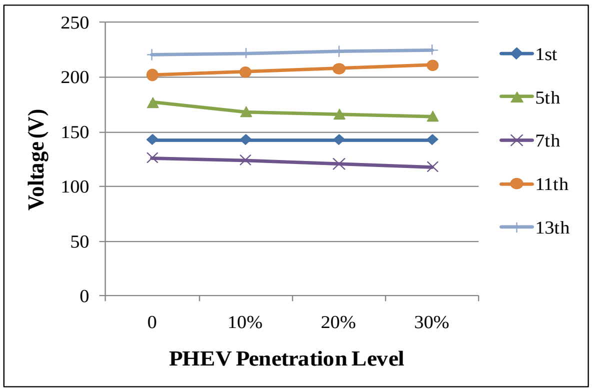



**Figure 1: Harmonic spectrums of PEHV and PC**.

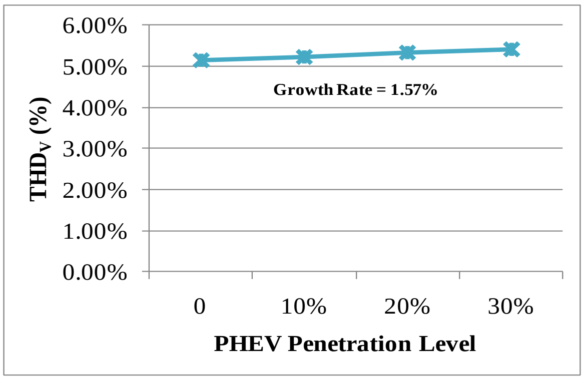
Two feeder models, one for the primary system study and one for the secondary distribution network study, have been developed for assessing the PQ impact of PHEV charger. For the primary system model, the service transformer was modeled as a random harmonic-producing load. For the secondary system model, the loads in each house vary randomly. The pattern of random variations was established based on the probabilistic characteristics of the loads. Various harmonic distortion indices such as the voltage THD, neutral current, harmonic-caused losses etc. were calculated from the models using a multiphase harmonic load flow program. The tens of thousands of results were then analyzed statistically to extract their mean and 95% probability values. A sample result is shown in Figure 2. The figure shows the growth rate of harmonic voltages in primary distribution system as a function PHEV penetration level.

The main findings of this study are summarized as follows:

- Modern PHEVs utilize a charging circuit that does not inject a large amount of harmonic currents into the supply system. The current THD produced by the circuit is around 10%. In comparison, the current THDs of compact fluorescent light and desktop PCs are approximately 145% and 115% respectively. As a result, the harmonic currents injected by one PHEV into the grid are comparable with those produced by 7.3 compact fluorescent lights or 1.2 desktop computers [6].




A) Individual harmonics




B) Total harmonics

**Figure 2: Growth rate of primary side harmonic voltages caused by PHEV (base voltage is 14,400V).**

- PHEVs do not create significant harmonic distortions in both primary and secondary systems. This is due to two factors. Firstly, the PHEVs don't inject a lot of harmonic currents into the utility systems in comparison with other home appliances such as desktop PCs and compact fluorescent lights. Secondly, the adoption rate of PHEVs is much lower than other home appliances. The growth of harmonic distortions due to PHEVs over the years is insignificant when compared with that resulted from other home appliances.

- The Society of Automotive Engineers (SAE) recently published a draft standard J2894 that covers the power quality requirements for PHEV and EV chargers [7]. This standard specifies that the current THD of a car charger shall be less than 10%. It also adopts the individual harmonic current limits of the IEC standard 61000-3-2 [8]. Since SAE standards are widely followed by automotive manufacturers, J2894 provides an assurance that the harmonics injected by future car chargers will continue to be low and will not be expected to be a problem. The project findings also demonstrate that if a load follows the IEC power quality limits, the harmonic impact of the load on power systems will generally be acceptable.

- PHEVs represent a large load increase in distribution systems. They can cause service transformer overloading, increased power losses and reduced service voltages. Such impacts have been known to utility companies. This report has quantified the growth rate of the impacts. For a 10% increase of the PHEV penetration level, the load of service transformer will grow by 8%, the service conductor losses will increase by 18% and the primary conductor losses increase by 2%. The impact of PHEVs on reducing service voltage level is not significant.

- PHEVs battery chargers are single-phase loads. When connected between phase and neutral, which is the case of Level 1 charger, a noticeable increase of neutral current in service conductor was found by this project, which in turn resulted in the increase of secondary neutral to earth voltage. The growth rate of neutral current was about 5% and neutral voltage was about 9% per 10% increase of PHEVs penetration. Increased neutral voltage could be a concern from the perspective of stray voltage management. The impact of PHEVs on the neutral voltages and currents of the primary systems are not significant.

- Many of the 60Hz impacts of the PHEVs such as transformer overloading and neutral voltage rise can be mitigated by using controlled and smart charging strategies where PHEVs are charged at different times. The use of level 2 chargers will significantly reduce the neutral voltage/current rise problem. However, level 2 charge will noticeably increase the loading of service transformers.

## CONCLUSIONS

In summary, the overall conclusion of this project was that the PHEV is not a significant harmonic-producing load in power distribution systems. Its impact on harmonic distortion is not a concern, especially in comparison with other home appliances with non-linear load characteristics. However, PHEV represents a major new load to distribution systems. It can create problems at the fundamental frequency such as service transformer overloading, increase in conductor electrical losses, the neutral voltage/current rise, etc. Fortunately, these impacts are mainly noticeable in the secondary distribution networks and can be mitigated by using smart charging strategies.

## RECOMMENDATIONS

Based on the project findings, the following recommendations are provided:

- Recommend customers to avoid the use of level 1 chargers. This type of charger can increase the neutral to earth voltage at the service entrance point, which might result in more stray voltage incidents.
- Use the low harmonic emissions performance of the PHEV chargers as a showcase to demonstrate the importance of adopting IEC harmonic emission limits for all home appliances.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] R. Lache, "Vehicle electrification, more rapid growth; steeper price declines for batteries," DeutscheBank Global Markets Research, 2010.

[2] A. K. Srivastava and B. Annabathina, "The challenges and policy options for integrating plug-in hybrid electric vehicle into the electric grid," The Electricity Journal, vol. 23, no. 3, pp. 83–91, Apr. 2010.

[3] K. Clement-Nyns, E. Haesen, and J. Dreisen, "The impact of charging plug-in hybrid electric vehicles on a residential distribution grid," *IEEE Trans. Power Syst.*, vol. 25, no. 1, pp. 371-380, Dec. 2009

[4] K. Qian, C. Zhou, M. Allan, and Y. Yuan, "Modeling of load demand due to EV battery charging in distribution systems," IEEE Trans. Power Syst., vol. 26, no. 2, pp. 802-810, May 2011.

[5] S. W. Hadley, A. Tsvetkova, "Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation," ORNL/TM-2007/150, Jan 2008.

[6] A. B. Nassif, J. Yong, W. Xu, and C. Y. Chung, "Indices for comparative assessment of the harmonic effect of different home appliances," European Transactions on Electrical Power, Feb. 2012.

[7] Power Quality Requirements for Plug-in Electric Vehicle Chargers, SAE Standard SAE J2894/1, 2011.

[8] Electromagnetic Compatibility – Part 3: Limits. Section 2: Limits for harmonic current emissions (equipment input current $\leq$ 16 A per phase), IEC Standard 1000-3-2, 1995.