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Impact of Higher Power PEV Charge Levels on Three U.S. Radial System and Field Trial Findings on ESB's Low Voltage Residential Network

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Abstract

As plug-in electric vehicle (PEV) adoption ramps up, utilities need to maintain grid reliability and safety for adoptors and their residential neighborhood. Quantifying the relationship between electric system distribution equipment capabilities and expected residential PEV charging demand becomes an important utility planning function. PEVs are expected to charge at a rate of 3.3, 6.6, 7.2, 9.6, and 19.2 kW. As a result, a substantial number of PEVs charging at various households will significantly alter the typical demand patterns of residential networks. Utilities are implementing notification programs to identify PEV charging locations and reinforce neighborhood distribution systems, as needed. Despite our readiness efforts, PEV adopters may not notify their utility about new charging locations. This will delay necessary upgrades to the distribution infrastructure. In light of these developments and needs, the Electric Power Research Institute (EPRI) initiated a multiyear project with 19 utilities to understand PEV system impacts in the United States, Canada, and Europe. As part of this overall study EPRI developed detailed distribution and behavioral models to characterize the impact of these new loads, characterize PEV adoption, electricity usage (charging demand) and conducted field trials on residential electric distribution systems. This paper presents the results relevant with regards to two aspects from this overall study: 1) Impact of high power charge levels on distribution assets, and 2) Key findings from a year long PEV field trial conducted on residential low voltage (LV) network (400V) in Ireland.

Keywords: Plug-in electric vehicle, distribution system, deterministic models, thermal loading, charge profile

1 Introduction

As customer adoption of plug-in electric vehicles (PEV) continues to grow so does the potential for adverse consequences to distribution system operations and assets; particularly across service transformers and/or secondary drops. These concerns are amplified considering that geographically clustering of PEV adopters within particular neighborhoods or socioeconomic regions can lead to significant concentrations of PEV on particular feeders even though overall adoptions may be relatively small.

Traditionally, residential neighborhoods were designed based on typical customer demands. This includes the maximum predicted household demand, as well as a certain level of coincidence that could be expected to occur between the feeder loads throughout the day. The introduction of PEVs to distribution networks could potentially alter the way we plan our distribution assets. It is also unrealistic to expect customers to uniformly notify their utilities of PEV ownership, leaving open the potential for unexpected localized risk to the system.

Recognizing the unpredictability in identifying specific customer adoption, vehicles types, and charging patterns, a proactive risk mitigation strategy is recommended to mitigate system-wide and localized risk to the distribution system. Potential stresses on power delivery systems can be mitigated through asset management, system design practices, controlled charging of PEV, or some combination of the three. But again, given the likely variability in customers' PEV choices, car types, varied charging patterns, varied charging speed preferences, and variable participation in utility-centric time-of-use (TOU) charging options, the utility might not be able to manage this risk in an ex post fashion. In many cases, the utility will likely not be notified or aware of an EV addition, or a unique charging pattern. As such, a proactive risk mitigation strategy is recommended to remove localized risk to the distribution system. Controlled charging can significantly reduce PEV loading impacts on the distribution system, but is not likely to be universally adopted. Tariffs and rates which encourage nighttime charging (e.g., load management, valley-filling, etc.) can also help to avoid or postpone upgrades.

The strain on power delivery systems requires adjustments in asset management, system design practices, or even application of advanced controls which properly account for the particular nature of the newly emerging load.All of these factors can be taken into account in the analysis of potential risk as a function of distribution system conditions and geographic factors.

This paper presents in detail some of the findings from this ongoing research related to the impact of high power PEV charge levels on distribution system and overall finding from a PEV field trial in Ireland that was commissioned in order to determine the extent of any such potential effects on Ireland's LV distribution network.

2 PEV Adoption

PEVs entered the commercial market in late 2010 and are 30 months into their initial launch and offer enough of a time lapse to get an idea as to the initial adoption; and the future looks bright. In US during May 2013, a significant benchmark of over 100,000 vehicles on the road was passed. The cumulative PEV sales in the U.S. as of June 30th, 2013 surpassed 116,000.

While modest, PEV sales over this initial period, as plotted in Figure 1, have grown at a steady rate – nearly 163% times that seen for hybrid electric vehicles over a comparable period. The staying power of the PEVs is also reflected by the automotive industry themselves with 10 different vehicle manufactures offering 15 different PEV models.

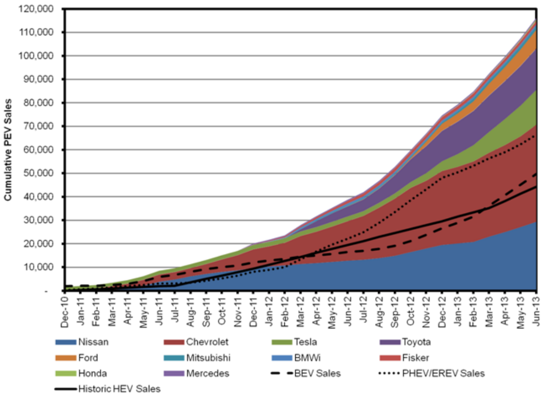

Figure 1: Cumulative PEV Sales as of April, 2013 (Source: Data is from Automotive News and HybridCars.com)

As PEV adoption continues to grow so does the need to accurately assess the distribution system's ability to reliably and effectively serve this unique and changing demand and per-capita load growth. While initial research, demonstrations, and engineering assessments have successfully demystified the operation of these new system loads, distribution utilities require additional analytical tools which can perform comprehensive analyses of the system asset impacts under various PEV adoption, control, or business case scenarios.

3 PEV Impact Assessment Challenge

PEV electrical charging characteristics have quickly evolved since the initial offerings in 2010. The first mass-produced PEVs charged at relatively low rates (up to 3.7 kW), traveled between 35 and 75 miles per charge, and there was little public infrastructure. Over the course of the first few years a host of additional PEV models had been introduced including a battery electric vehicle offering a range of up to 265 miles as well plug-in hybrid electric vehicle (PHEV) offering an electrical range of 10-15 miles.

Charging rates in new vehicle models have also increased dramatically from 3.7 kW to upper ranges between 7.0 – 19.2 kW. In order to provide context for these demands, several PEV charging rates are compared graphically in Figure 2 against average peak summer demand of number of typical household appliances.

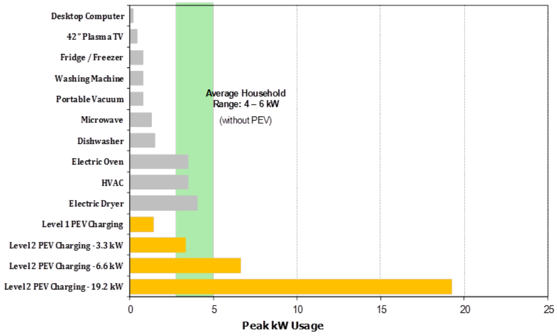

Figure 2: Comparison of PEV Charging and Household Demand

Accordingly, increased customer adoption of PEVs with the distribution system has raised a variety of potential system impact concerns as well as need for future advanced operations such as controlled charging strategies and providing ancillary services. However, traditional deterministic distribution assessment techniques focus solely only on the peak demand case and hence do not sufficiently capture the effects of temporal variations in PEV demand nor are they capable of evaluating advanced dispatch control methods. Furthermore, deterministic approaches are incapable of addressing the spatial uncertainties associated to where PEVs will be interconnected on the system. These difficulties are further exacerbated by general lack of accurate data for system assets located close to the customer which are also the first assets likely to be impacted by PEV adoption.

The ability of distribution utilities to continue to provide safe and reliable service, therefore, in part depends upon the development of new tools capable of fully capturing the characteristics of the system and this new load under various adoption scenarios while also providing results which can be readily incorporated into planning and management practices.

4 EPRI Phase I – Distribution System Impact Study

The first step in developing the needed planning tools is accurately portray the new load’s charging demand and patterns as seen at the point of interconnection. Secondly, the likely distribution system impacts likely to occur must be assessed along with underlying PEV characteristics and system design practices influencing the overall risk of impact occurrence. Recognizing that these goals could be best achieved through collaborative research, EPRI initiated a study which analyzed potential impacts for 41 distribution circuits located across 20 utility operating territories.

The circuits studied in this effort represent a wide diversity of voltage classes and loading levels. A summary of the peak demand by voltage class is provided in Figure 3. The circuits also represent a variety of the total number of connected residential customers, as provided in Figure 4, which were considered potential adopters of PEV in the evaluations.

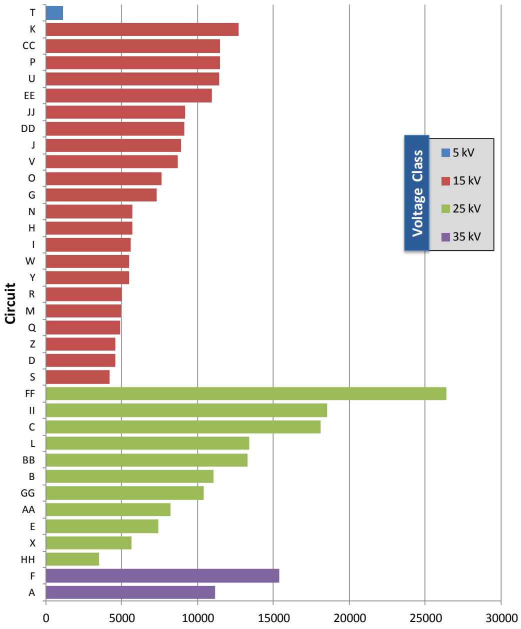

Figure 3: Peak Feeder Demand (in KW) by Voltage Class

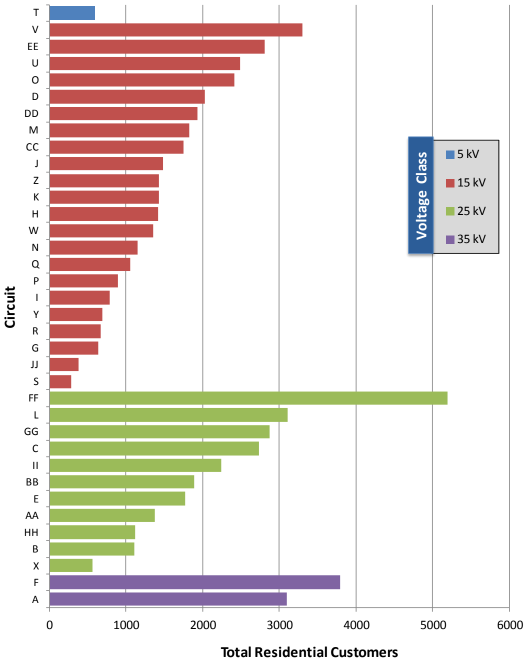

Figure 4: Residential Customer Count by Voltage Class

4.1 Study Methodology

In order to fully account for the various PEV charging scenarios and the unique temporal and spatial issues involved, a novel analytical framework was developed which incorporated both deterministic and stochastic analysis methods. A wide range of potential impacts were evaluated during the course of the study including total feeder load growth, steady-state voltages criteria, system losses, voltage imbalance, and thermal overloading of system assets.

A brief description of the three analyses employed when evaluating the potential impacts on the radial feeders follows:

- **Asset Deterministic Analysis –** examines each assets capacity to serve additional demand is compared to the worst-case projected PEV demand that asset is likely to see under the defined PEV scenario.

- **System Level Deterministic Analysis –** examines the system response to non-diversified PEV charging conditions across increasing levels of PEV penetration.

- **Stochastic Analysis –** projects likely impacts considering the full projected diversity of the PEV charging through randomly generated system scenarios which model PEV charging and system response over a full calendar year.

Detailed time-series distribution circuit models was developed by incorporating additional system data not typically included in most distribution models such as service transformers models and load profiles representing the sequential variation in each customer load. These load profiles were developed using actual system measurements taken over the course of a full calendar year. Models were derived for both individual and PEV fleets based on manufacture data, laboratory testing, customer behavior analytics, and adoption projections.

This information was used to derive random variables such as market penetration, electric vehicle portfolios, individual vehicle home arrival times, and the miles driven which were used to capture the temporal and spatial variations associated with the new load type. These models were adjusted as necessary to account for the specific regional characteristics.

The results of the simulations across different distribution systems were combined to develop summaries of general concerns, assets that are likely to be at most risk, conditions that may require additional monitoring to mitigate issues, and the impacts of different charging profiles including controlled charging and time-of-use rates.

4.2 Highlighting the Key Takeaways from the Analytical Assessment Experiences

While performing the detailed circuit studies, attention was also given on the application of the developed analytical techniques. One assessment method proved to be very effective in identifying the assets at risk and underlying factors influencing these risks.

The goal of this method was simple – calculate the ability of each asset to serve additional demand and compare this with a conservative projection the demand expected from PEV adoption. In this manner, assets could be quickly subdivided into assets which had either zero or non-zero risk under the specified PEV use conditions.
Results from one of the study circuits are provided in Figure 4 below. In this figure the remaining capacity for each asset is represented as individual points and the worst-case PEV demand for different PEV penetration scenarios is represented by the black lines. As can be seen, plotting the data in this fashion permits the quick assessment of which assets can safely serve the additional demand simply by is location with respect to the PEV demand projection lines.

Another benefit of this method is it permits direct comparison of different PEV scenario conditions as displayed by the change in the PEV demand projection lines plotted in Figure 5.

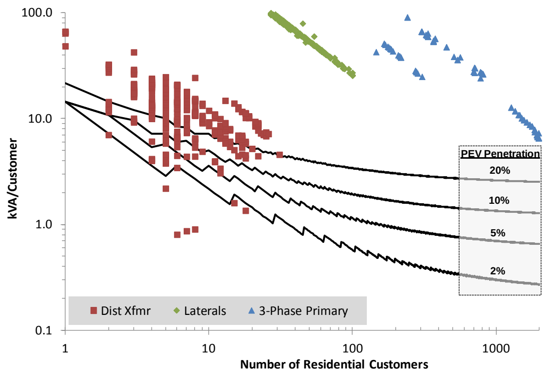

Figure 5: Asset Analysis for Example Study Circuit

4.3 Impact of Higher PEV Charge Levels on Distribution Feeders

This section evaluates the impact of high power charge levels on distribution feeders and illustrates the need for utility notification for EVSE tracking on distribution systems. The results from this analysis serves as a basis to support the 'early notification' process to that utilities can inspect specific areas of their distribution system for sufficient capacity. Examination of the number of assets vulnerable to the higher charging levels was examined in this study using three of the distribution feeders where significant levels of near-term PEV adoption are expected.

4.3.1 Thermal Overloads Analysis

Increasing PEV charging rates and larger battery sizes can increase customer demand and thus the likelihood of thermal overload occurrence. Service transformers, in particular, are determined to be the most sensitive asset type to this particular analysis. The resulting increase in overall demand magnitude and duration may significantly impact existing power system assets, such as distribution service transformers, which may not be sufficiently sized to serve such a large step-change.

Figure 6 illustrates the rate, or level, that a PEV charges versus time of charge. It is clear from this figure that the most dominant PEV characteristic influencing the overload risks posed to service transformers from PEV adoption is charge levels.

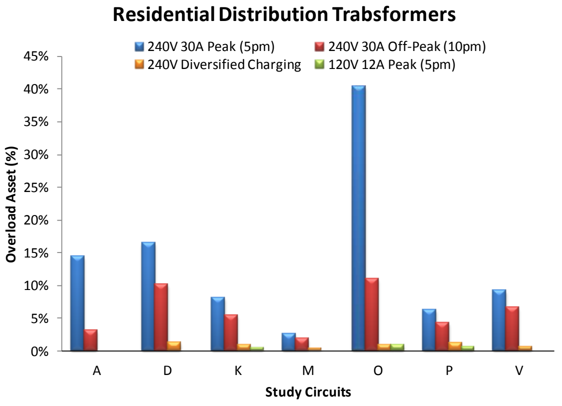

Figure 6: Impact of Higher Charge Rate versus Time to Charge

In this section we present the modeling results that evaluate the impact of high power charge levels on distribution feeders and illustrate the need for utility notification for PEV tracking on distribution systems. The results from this analysis serves as a basis to support the 'early notification' process to that utilities can inspect specific areas of their distribution system for sufficient capacity.

Examination of the number of assets vulnerable to the higher charging levels was examined in this study using three of the distribution feeders where significant levels of near-term PEV adoption are expected. The four PEV scenarios depicted in the analysis included the following PEV charge rates, charge duration, and battery capacity.

- Nissan Leaf – 3.7KW ~5 hour charging @20KWHR
- Nissan Leaf – 7.2KW ~3 hour charging @20KWHR
- Tesla Model S – 9.6KW ~10 hour charging @90KWHR
- Tesla Model S – 19.2KW ~5 hour charging @90KWHR

To illustrate, the potential change to the demand profile for an example 25 KVA service transformer serving 5 residence customers are shown in Figure 7. The existing loading, in this case, is based on actual AMI measurements onto which the addition of a single PEV's changing demand is superimposed – assuming different charging rates and battery sizes. The two dashed lines indicate metrics related to thermal loading capabilities; the Nameplate rating (which may be infrequently exceeded for a short period of time such as 1-2 hrs) and the Emergency rating (which if exceed indicates a significant reduction in the transformers expected lifespan). Hence, the potential impacts from the various charging levels can be quickly examined by comparing the amount of time each profile spends above the Nameplate rating and whether the Emergency rating was exceeded. Based on the utility's planning process, they consider 150% of the nameplate rating to be the emergency rating of their service transformers. AMI measurements revealed that the existing peak demand occurs at 5pm and is 72% of the emergency rating of the transformer.

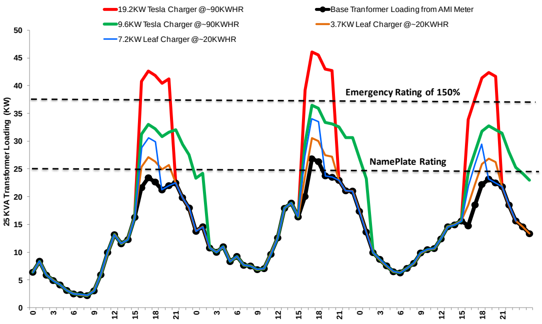

Figure 7: Sensitivity of Different PEV Charge Levels on Example 25KVA Distribution Transformer Loading

As shown in Figure 7, the longer charging durations at higher charging rates – associated with the larger battery sizes – naturally increases the potential for violating one of these two metrics (normal rating and emergency rating). When this occurs, the transformer is not able to dissipate the heat built up in its windings fast enough to avoid undesirable decreases to the asset's total lifespan. Service transformer upgrades are necessary in these cases to mitigate potential impacts to power system assets and to reduce potential customer interruptions. The ramifications of the duration and magnitude of increased loading from PEV charging can also be examined in details in terms of thermal insulation loss-of-life analysis. However, results of loss-of life analysis are not presented here.

Increases in charging magnitude and duration will intrinsically increase the likelihood that a transformer will need to be upgraded to serve this additional load. Examination of the number of assets vulnerable to the proposed charging levels is examined next for the three circuits in order to illustrate the degree of assets potential impacted.

4.3.2 Asset/Component Analysis

The first stage of the thermal overload impact analysis uses the Asset Analysis procedure to provide a deterministic comparison of asset remaining capacities against projected PEV demand. By ensuring the estimates are conservative in nature, the method identifies which assets are highly unlikely to experience thermal overloads at particular PEV penetration levels. In this fashion, the assets which may be at risk can be identified by default and the process can be used to quickly evaluate the influence of underlying risk factors.

The assumption used in this analysis includes:

- Peak hour PEV demand projection
- Temporal diversity of 30% coincident charging. This imply that there is a 30% chance that a PEV charges during the peak hour
- The change in the projected worst-case PEV demand given increasing PEV market penetration was derived for the 99.9th percentile demand
- 99.9th percentile lines were calculated assuming the PEVs are composed of only a single type – with a line for each potential charging rate/battery combination
- Charge duration is not factored in this analysis. The battery size and charging for 5-10 hours may influence the probability of charging at peak but this estimate will likely not change greatly.

Example asset analysis results are provided in Figure 8-10 where different PEV demand projections are plotted to evaluate sensitivities to different PEV charging rates namely: 3.3 kW, 6.6 kW, 9.6 kW, and 19.2 kW. Figure 8-10 shows projected worst-case demand at 8% penetration with different charging rates. Three circuits were evaluated to understand the high power charge level impacts.

- Circuit EE – 358 potential PEV customers out of a total of 2803 utility customers
- Circuit U – 318 potential PEV customers out of a total of 2482 utility customers
- Circuit V – 426 potential PEV customers out of a total of 3325 utility customers

In these figures, remaining capacities are denoted by transformer nameplate ratings. Each point in these figures indicates the estimated remaining capacity for an asset in each of the three study circuits – based on the individual asset peak demand and specified thermal rating. The solid lines represent the projected PEV demand as a function of number of residential customers served off the assets. Thus, assets unlikely to be impacted – where the asset's remaining capacity exceeds the projected PEV demand lines – can be quickly identified for different PEV penetration levels.

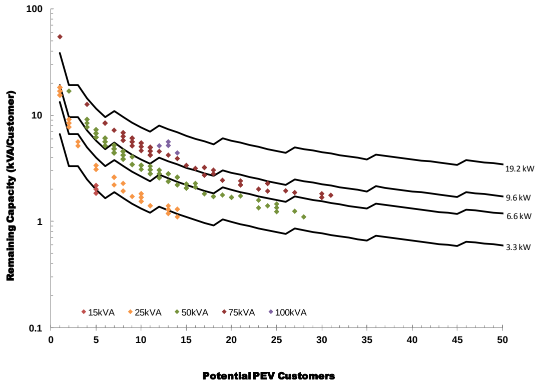

Figure 8: Asset Analysis Results for Circuit EE – Sensitivity of PEV Charge Levels

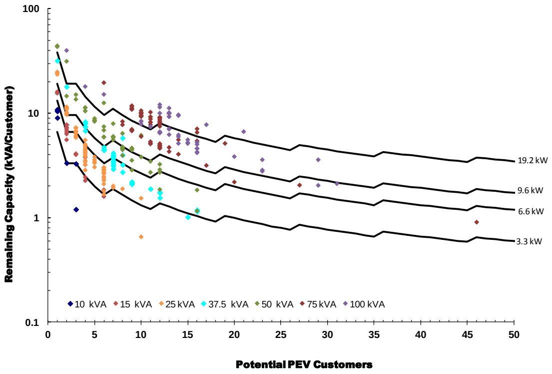

Figure 9: Asset Analysis Results for Circuit U – Sensitivity of PEV Charge Levels

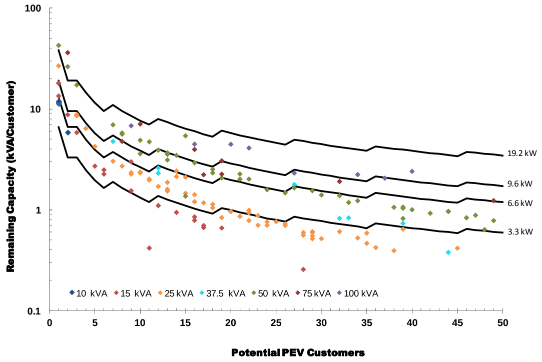

Figure 10: Asset Analysis Results for Circuit V – Sensitivity of PEV Charge Levels

In order to evaluate sensitivities to different PEV penetration, different PEV demand projections are plotted in Figure 11, using data from Circuit U. A key conclusion is that, doubling and tripling the assumed vehicle charging rates (from 3.3KW to 6.6KW to 9.6KW to 19.2KW) has a much more dramatic impact on the number of potential transformers at risk as compared to increasing the penetration level from 8% to 32%.

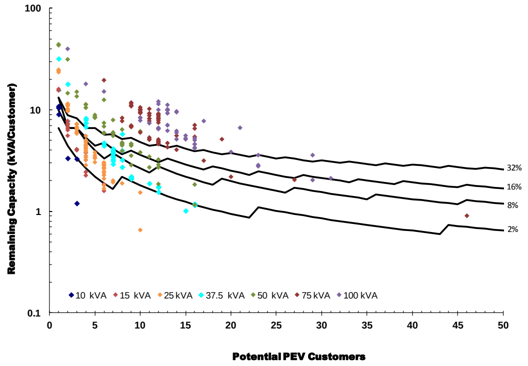

Figure 11: Asset Analysis Results for Circuit U – Sensitivity of PEV Adoption Rates for 6.6KW PEV Charging

As seen for each of these three circuits, smaller transformer sizes tended to be the most sensitive to PEV charging. The number of service transformers determined to have remaining capacity less than worst-case projected demand by the Asset Analysis is plotted in Figure 12 against the total number of transformers deployed in each circuit. As shown, the service transformers potentially at risk from PEV charging on each circuit dramatically increase with increasing PEV charge levels. This is clearly illustrated in Table 1. Comparison of the three circuits also indicates the increased number of potential transformers at risk which is impacted at the higher charging rate.

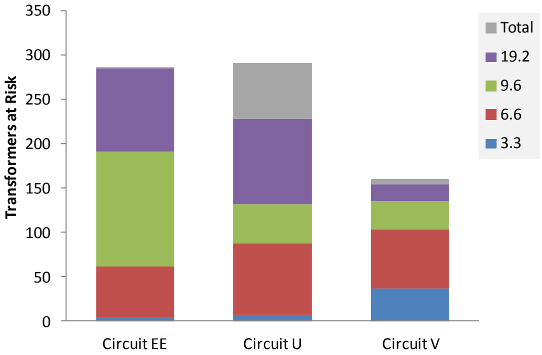

Figure 12: Overall Asset Analysis Summary – Sensitivity of PEV Charge Levels

Table 1: Overall Summary – Sensitivity of PEV Charge Levels

Charge Rate	Count of Transformers at Risk (% of Transformers at Risk)		
	Circuit EE	Circuit U	Circuit V
3.3	5 (2%)	7 (2%)	37 (23%)
6.6	62 (22%)	88 (30%)	103 (64%)
9.6	192 (67%)	132 (45%)	136 (84%)
19.2	285 (100%)	229 (78%)	155 (96%)
Total Xfmrs	286	292	161

The deterministic evaluations of the defined Asset Analysis procedure are useful in quickly screening which circuits (and assets) may have a high degree of sensitive assets to PEV charging. This clearly shows how strongly the impact aggregate with high PEV Charge levels. A Stochastic Analysis procedure can also be applied to identify likely risks for these circuits indicated in Asset Analysis to have potential impacts. However, these results are not presented here.

4.4 General Findings

Conclusions from study include:

- **Impacts are likely to be seen first on the service transformers and secondary service lines.** The likelihood that these assets are impacts is highly dependent upon the specific configuration, asset sizes deployed in the field, and existing load conditions. The likelihood also depends upon the assumed PEV adoption and charging assumptions; however, nontrivial risks may exist even at low penetration levels.

- **Customer behavior strongly dictates the temporal nature of PEV demand.** In particular, home arrival time – which is assumed to correspond directly with the start time for uncontrolled vehicle charging – is the dominant factor in determining when the majority of PEV demand will occur.

- **Service transformer thermal overload risks are highly sensitive to PEV charging rates.** In some case cases, doubling PEV charging rates –to facilitate shorter charging times – was shown to increase the overall thermal overload risks significantly more than tripling the number of PEVs operating at the lower charging rate.

- **Simple feeder level metrics are not sufficient indicators of overall system risks**. Over time, deviations in the type, size, and configuration of assets deployed will occur in response to the evolving system needs. These variations are highly specific to the realities in the field and can vary greatly between utilities, circuits, and even at different portions of the same utility feeder. Additionally, the risk associated with each asset is a function of asset specific factors such as customers served, asset size, and existing demand which are not accurately represented by feeder level metrics.

  For example, the count of the total deployed service transformers that were determined to be sensitivity to thermal overloading due to PEV charging is summarized in Figure 13 for each of the study circuits. As shown, the service transformer sensitivities vary greatly between the circuits and are not correlated with the total number transformers deployed on the circuit.

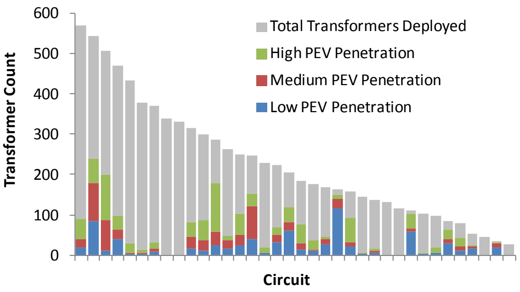

Figure 13: Service Transformer Fleet which is Sensitive to PEV Adoption Levels

5 Field Trial Findings from ESB Networks

The ESB Networks in conjunction with EPRI and ECAR Energy Ltd conducted an electric vehicle field trial in a suburb of south Dublin, Ireland that was aimed at assessing the potential impact of EVs on residential low voltage networks (400V) in Ireland. The electric vehicle field trial commenced in January 2011 and ran until March 2012. Figure 14 shows a sample residential load curve over a day with and without electric vehicle charging. A power quality meter was installed at the head of the feeder. The corresponding voltage and current profiles from a smart meter located at the remote end of the feeder are provided in Figure 15. It is evident from this figure that the voltage experienced by this customer around the time of the maximum feeder loading is close to the lower acceptable limit of 0.9 pu (207 V). The actual recorded minimum voltage for this customer was 0.912 pu (209.8 V).

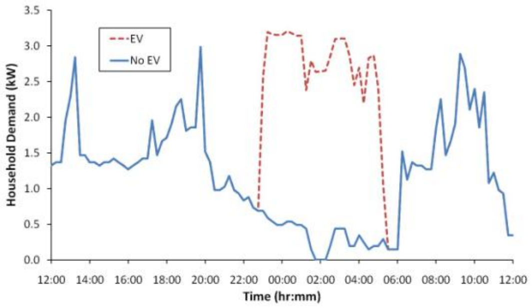

Figure 14: Residential Demand Profile over a Sample Day with and without Electric Vehicle Charging

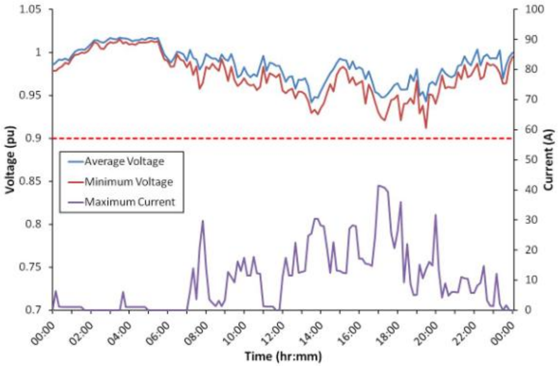

Figure 15: Voltage and Current Profiles for a Household at Remote End of Feeder for the 24-hour Period shown in **Error! Reference source not found.**

A modeling exercise was also undertaken to study the effect of voltages on the feeder with PEV loading. Figure 16 shows the 3-phase voltage along the feeder. In the first case, electric vehicles are added incrementally from the start of the feeder (red line) and in the second case, they are added from the end of the feeder (blue line). If placed at each house from the end of the feeder, the lower 3-phase voltage limit of 0.92 pu is almost immediately reached given the initial high loading on the network, with the 0.9 pu voltage limit hit at approximately 8%. When vehicles are added from the start of the feeder the 0.9 pu limit is hit at 20%.

Utilities will not be able to control where vehicles are connected but awareness of the sensitivity of the network parameters to vehicle charging is valuable.

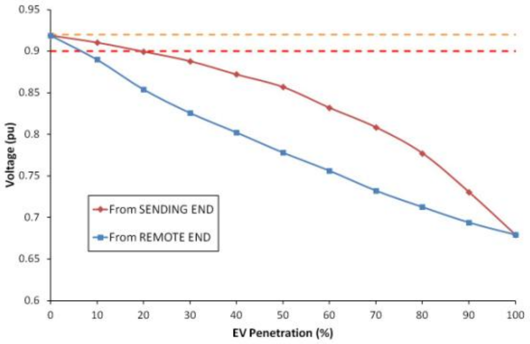

Figure 16: Three-phase Voltage with Increasing Levels of Electric Vehicles

Figure 17 shows the single-phase voltage at a customer point of connection. This voltage is recorded at the end of the single-phase service cable which connects the house to the network. The same effect as shown in Figure 16 is evident again here. The reconfiguration to 74 customers results in very low voltages (sitting on the limit) at the maximum demand scenario. The voltage profile obtained is not as smooth as the 3-phase voltage due to the phase interdependency and slight load unbalance which occurs in the system.

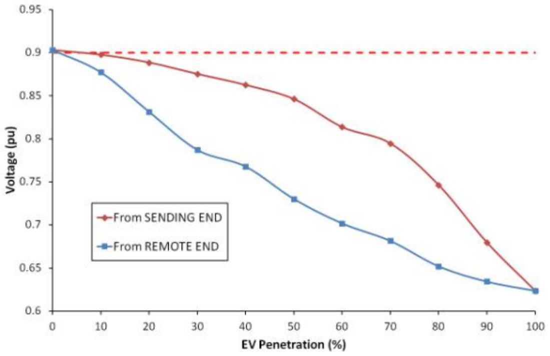

Figure 17: Single-phase Voltage at Customer Connection Point with Increasing Levels of Electric Vehicles

The results shown in Figure 16-17 indicate that it is at the remote end of the feeder where the most noticeable network impact will occur.

The field trial of electric vehicles described here has revealed a number of points of interest for distribution system operators. The field trial measurements provide high quality data at points on the network that generally have little or no data recording capability. The secondary circuits are typically not modeled in distribution planning studies as very little system-wide secondary data is available. Therefore, customer level impacts from EV charging are often not quantified by utility planners in great detail in most of the distribution models. Field data highlights that even within a ten minute period there can be a significant variation in demand. In particular, the average loading or voltage recorded within a ten minute period may indicate that it is comfortably within standard, but there may be short term loading spikes which push the voltages below the lower limit for a short time.

6 Next Steps – Territory-Wide Screening Tool

Utilities have asset upgrade policies in place related to the distribution system in response to naturally occurring load growth. This has typically tracked the population growth and growth of load resulting from increased penetration of air conditioners, electric appliances and consumer electronics. As PEV adoption grows, utilities will need to create updated asset upgrade policies based on PEV growth forecasts around their most capacity-constrained distribution system segments. In response to the overall need, a screening tool is proposed which is capable of performing system wide evaluations of individual asset capacity against projected PEV per-capita demands. The Phase II effort is focused on developing a screening tool capable of projecting and quantifying potential impacts due to PEV adoption across entire service territories.

While the methods developed during the initial study provided significant step forward in impact assessments, desirable advancements were identified during the course of the study to enable a screening tool which utilities could use to gauge system impacts as well as mitigation strategies. Additional functionalities for this screening tool include the:

- Ability to assess the risks across the entire service transformer fleet for multiple potential PEV scenarios,
- Account for geographic clustering and variations in PEV conditions across the utility operating footprint,

- Quantify the overall risk to system assets using individual asset information utilizing existing system data, and
- Incorporate planning and business practices necessary to express impacts in terms of costs as well as provide the ability to evaluate mitigation options.

This tool will link electric vehicle portfolio and customer behavior projections with utility databases containing system asset information, customer demand/consumption measurements, and business costs specifications. Additionally, the tool will provide sufficient flexibility when defining and altering PEV projections and/or system data as deemed by the user.

While the screening tool will identify the associated risk for each asset, it will more importantly providing data mining of this information to reveal and report actionable statistics for asset managers and system planners. Some of the key features of the proposed screening tool are depicted in Figure 18. One unique feature is the potential to diagram geographic "hot spots" in order to quickly identify regional factors and issues in addition to utility defined reporting functions.

Additionally, the screening tool permit utilities to perform fast reassessments as system conditions and PEV projections change over time. Impact of different utility pricing schemes and their sensitivities on distribution level load shapes may also be evaluated. Finally, the probabilistic assessment based tool is not only expected to facilitate future system planning and asset management related to PEV adoption but also serve as a foundation for the integration and design of other emerging technologies.

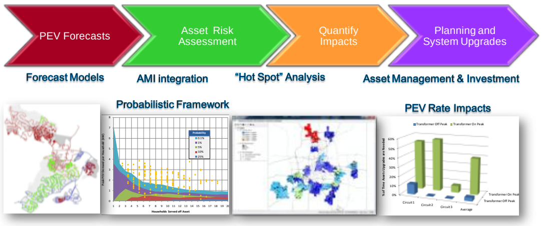

Figure 18: Key Elements of PEV Impact Screening Tool Development Initiative

References

[1] *Understanding the Grid Impacts of PEV – Phase 1 Distribution Case Studies*. EPRI, Palo Alto, CA: Dec 2012. Product ID 1024101

[2] J. Taylor, A. Maitra, M. Alexander, D. Brooks, M. Duvall, *Evaluation of the impact of PEV Loading on Distribution system operations, IEEE Power Engineering Society, Calgary*, July, 2009

[3] P. Richardson, J. Taylor, A. Maitra, E. Diskin, A. Keane, "Electric Vehicle Field Trail: A Distribution Network Impact Study, submitted to IEEE Transactions in Power Systems 2012

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