Electric Vehicle Impact Studies for Utility Power Systems

Electric vehicle utility impact studies determine the changes in demand and energy needs that increasing penetrations of electric vehicles (EVs) will have on a power system, and these studies identify the changes required in the power system design, equipment, and operation to most effectively accommodate EVs. Two major issues present the greatest challenges to performing these studies. First, only limited information is available on EV demands and market penetration as so few are in use (roughly 40,000 nationwide at the end of 2011). However, the increasing production and sale rates of EVs and the societal trend toward an increasing use of electric transportation requires planning despite these uncertainties. Second, most utility power distribution systems are composed of thousands of circuits and hundreds of thousands of components that could be affected. Quanta Technology’s EVIS method combines two unique but proven analytical techniques to provide an effective way to obtain comprehensive, dependable, but affordable answers.

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The Challenge Presented By EVs

Increasingly, there are higher numbers of Plug-in Hybrid Vehicles (PHEVs) and Battery Electric Vehicles (BEVs) on American roads and highways ... and plugged into America’s electric grids. The total number of these vehicles operating in the US is projected to reach 15% of all vehicles in service within 20 years, perhaps within only 12. As a general rule of thumb, every two EVs, whether hybrid or pure battery, will increase uncontrolled peak demand on an electric utility system by roughly the same amount as a new residential customer.

PHEV and BEV loads are different from existing utility system demands in several profound ways, including:
their electrical characteristics,
their daily and seasonal load curves,
their amenability to various types of load control,
regulatory policy with regard to their electrical service and its pricing,
their owners’ attitudes about pricing and reliability

Regardless, expansion of a utility’s T&D system’s capacity to handle large numbers of EVs without a form of demand control, is in almost all cases going to be very if not prohibitively expensive. By contrast, various scenarios involving demand control, time-of-use or real time pricing rates or “cooperative-dynamic” control policies can optimize utility customer value and minimize cost. Given the magnitude of potential load increase, the importance owners attach to reliable and stable electric service for their personal transportation needs, the level of potential investment in new facilities and technology required to handle those load increases, an electric utility would do well to study EV impacts on its system today, in order to develop a great strategy for how it plans to handle them. This is particularly important, because often in the power industry the initial decisions on strategy, approach, and policies become locked in and cannot be changed once the utility has begun.

**Purpose of an EVIS Study**

The purpose of an EVIS study is to provide dependable answers to the key questions a utility needs to know. These questions are:

- How will EV’s affect our system?
- What and Where will the greatest impacts and sensitivities be?
- What types of changes and revisions to operating policy will need to be made on our system to best handle the introduction of EVs?
- How does what we do not and cannot know currently affect these answers?
- What is our overall best strategy for accommodating both the impacts we think are likely on our system. Does the uncertainty in our knowledge affect our decision, and if so, what is the best way we can mitigate risk?

**Unique Aspects of EVIS Studies**

Quanta Technology has funded its own R&D, and worked closely with several utilities on Electric Vehicle Impact and Strategy (EVIS) studies that both examine the expected range of impacts the utilities could potentially see with increasing use of EVs in their service territories, and assess the viability of various strategies they could employ to handle the impacts well.

Electric vehicle charging loads represent the most significant increase in utility customer electric usage since the advent of widespread air conditioning use in the 1950s and 1960s. (Quanta Technology studied this period of rapid load growth and change for lessons learned that can be applied to EVs. EVIS studies have the following important requirements.

**PHEVs and BEVs**

The type of vehicles studied has evolved considerably in the two years since EV studies became an industry interest area. Initially, studies focused on PHEVs and generally only on smaller vehicles.
Today’s studies recognize that many PHEVs will be fairly large SUV-like vehicles. Recently, attention has been shifting to BEVs, since they appear to be viable for commuting and may represent a majority of electric vehicles twenty years from now; several manufacturers believe this to be the case and utilities should realize they know more about the automotive market than anyone in the power industry. While the electrical characteristics of their chargers look quite similar, PHEV and BEVs must be treated as separate and different types of loads – they differ greatly in a number of key characteristics.

A detailed load curve basis looking at daily and annual load curves of demand is needed, since electric vehicle charging demands and value vary greatly by time of day and coincidence with other uses is what really drives peak equipment loading impact.

Equipment lifetime analysis is needed at all levels of the system, since almost all EV scenarios greatly affect the expected lifetime of equipment. If EV loads are left uncontrolled, peak loads increase greatly and load factor degrades. Equipment sized by traditional standards to the new “with EV” peak has longer expected lifetimes than normal. By contrast, many types of DR and Smart Grid scenarios for EV service result in much higher local and system load factors than today’s, to the extent that equipment loaded to traditional standards in these scenarios has much shorter predicted lifetimes. Therefore, in EV studies, detailed assessment of loading cycles and expected equipment lifetime and its economics plays a much larger role in determining economic and reliability results than in almost all other types of T&D planning.

Spatial heterogeneity. For a variety of demographic-market-economic reasons, EV penetration into a utility’s customer base will not be uniform as a function of location. EV load will by very “lumpy” from a spatial standpoint. For example, when overall market penetration is only 10%, there will likely be some neighborhoods with 30-40% penetration and others with near 0%. This clustering or lumpiness of EV penetration changes the overall impact results quite a bit, greatly affecting which technology strategies a utility may choose to accommodate EVs, and how it will plan to deploy them.

In all EV studies that have been and are being done to date, this effect is studied using spatial electric load analysis methods pioneered by Quanta Technology’s Lee Willis. Quanta recently has developed a unique shortcut for accurately assessing this factor without undue work used in other study methodologies.

Customer needs and value raise two important issues. First, having the utility “fill up” the gas tank of a family or small business vehicle materially increases the value proposition (the benefits electric service is providing) as customers see it. But it also changes the customers’ reliability needs: power interruptions that means one cannot watch TV or cook dinner are annoying and inconvenient to utility customers, but power interruptions that mean one does not have a “full tank” to drive to work in the morning are another thing altogether. Furthermore, there is broad range of opportunity to mix EV loading and charging scheduling with more traditional DSM and DR resources and optimization. In many households and small businesses the EV will be considered a more important, less deferrable end use than more traditional electric end uses like washing clothes, heating and cooling, and even running some production machine. Peak reduction to accommodate EV charging may be most effectively done with DR applied to other loads in combination with EV charging loads. Regardless, this is a field with a lot of unknowns and many interesting pilots right now, and an area for substantial study and innovation in the future.
Quanta Technology’s Methodology

Quanta Technology typically applies a representative model approach to EVIS studies, a T&D impact planning method proven in over 25 years of load growth, new technology, DR, and DG T&D impact study. It has been updated to modern EV and Smart Grid planning needs.

In this approach, a statistical pattern study of the utility’s T&D system and customer based identifies a set of representative areas – usually six to fifteen small portions of the utility’s system, along with a set generalization rules and formula. Detailed impact studies are done on circuits and equipment in this set of representative areas, with impact results then extrapolated to the overall system using the generalization rule base. The advantage of this approach is that it provides both very detailed bottom up engineering and operations analysis of EV impacts on all levels of equipment and circuits, and dependable overall top-down estimates of the impact that the utility will see across and at all levels of its system, yet at a cost far less than that for studying the entire system. The number of representative areas needed for a detailed study depends on the diversity of the utility’s customer base and T&D system design, and the degree of confidence desired in the overall results inferred for the entire system.

Studies begin with an assessment of current customer usage and daily load curve shapes and annual usage patterns. Potential EV market penetration and loads are analyzed for the customer base and area geography and demographics by applying spatial electric load analysis methods and end-use load curve concepts. This develops a model of household and charging center loads for further study.

Using the representative set of study areas as a base, scenarios of future EV impact are studied in two stages. An initial “static” stage applies a traditional load flow-predictive reliability-thermal loading-operating costs approach to determine basic electrical, reliability, equipment lifetime, and operating cost impacts at peak and off peak periods and annually, in increments from 0 to 100%. Impacts along with capital and operating cost changes to handle completely uncontrolled and several levels of controlled EV charging loads are estimated in this stage.

Quanta studies the full range to 100% for two reasons. First, many EV impact versus market penetration curves are very non-linear, with multiple break-points, each driven by different causes, limits, or factors. In Quanta’s experience, it is best to identify all of these, even if some lie at market penetrations not expected anytime soon. Second, while a utility’s major interest will likely be on market penetration levels, which will first create situations that stress its system and require significant attention and spending, experience has shown that the eventual high market penetrations often define what works as a long term strategy. Basically, one needs to understand impacts at these levels in order to understand if proposed fixes at low market penetrations are anything more than short-term solutions, or if they have an evolutionary path to an efficient long-term policy.

The second stage of an EVIS study applies a detailed dynamic analysis of various control or customer or demand response programs, generally set up as strategies for which both electrical and business impacts can be assessed, looking at how circuits and equipment interact on a daily basis with EV charging loads, controllers, system economics, etc. . . . Typically, these look at various demand response, Smart-Grid, and rate-customer response programs. The goal here is to assure that proposed control or pricing studies have the flexibility to accommodate customer and utility system needs efficiently and fully. Scenarios of EV market penetration studied may be far fewer than in stage 1: usually only a few key market penetration scenarios need be studied. However, scenarios specific to other issues, including customer
mix and juxtapositions of others factors like residential versus city center or “charging garages” or stations, and other factors, may, need to be studied.

**Resources and Data Needed**

Quanta Technology’s EVIS studies start with a proven pre-foundation of information of EVs, chargers, etc., modular sub-models for various parts of the analysis, Quanta’s full set of analytical tools including all standard industry load flow, reliability and other electric engineering tools, and several unique tools Quanta has developed include spatial-temporal modeling for customer and EV loads. Quanta’s resource base for EV studies includes:

- Models/information based on electrical characteristics of chargers
- Customer-based spatial-temporal model of EV loads/cycles
- End use load cycle/coincidence models of other loads and EVs
- Lifetime models of major & commodity equipment by type
- Combined electrical & reliability model of energy delivery systems
- Dynamic automation models for DR and Smart Grid studies
- Representative system elements selection
- Proven methodology and study processes

To this is added specific data about the energy delivery utility’s system and business situation obtained from the utility for which the study is being done:

- Utility customer, diurnal, weekly, monthly, seasonal, and annual load data and end use data
- Data on state/local EV policy-regulatory issues unique to the utility
- Overview statistics on the utility’s energy delivery system & operation
- Specific detailed data on the selected representative area of the system
- Tables of cost and economic data for additions to T&D systems

**The Project Process**

EVIS studies are tailored to the specific utility’s situations and needs but generally track along Quanta’s standard methodology:

- Review of utility strategic questions and goals pertaining to EVs and scope project studies
- Statistical analysis of the customers and T&D
- Selection of number and specific representative study areas
- Build generalization rule sets. Verify model accuracy.
- Calculate required market penetration scenarios
- Stage 1 study of 0 – 100% market penetration scenarios for base assessment, most-flat, and in-between control scenarios.
- First results review, discussion of strategies and approaches.
- Identification of key behavior characteristics, dynamic study of demand, equipment loading and performance, circuit loading and performance, and system performance (both electrical and economic)
- Stage 2 analysis: dynamic modeling of selected scenarios and situations.
Assessment of results
Report and Workshop on final results.

Results

Deliverable products from a Quanta Technology EVIS studies are a report, database of study results, and workshop on study results, which provides an information base from which the utility can make decisions about how it wants to handle EV loads and combine its plans for those with other important strategic policies and priorities.

EVIS studies provide detailed information on the expected impacts to the utility’s T&D systems:

- Peak demand
- Energy served
- Controllability of loads
- Coincidence of peak loads at various levels of the system
- Voltage, voltage regulation, power factor, losses and the need to control and manage all of them
- Customer needs for reliable delivery of power
- Equipment lifetime
- Need for revision of loading and planning guidelines
- Technology needs for Smart Grid, ToU (Time of Use) and RTP (Real time Pricing) or other DR (Demand Response) approaches
- Evaluation of impacts over the full utility system from total system load through transmission, switching stations, and substations and substation transformers, three-phase primary feeders, single-phase laterals, service transformers, secondary circuits, service drops, and service equipment.
- Evaluation of a set of standard “scenarios” that provide a picture of the full range of possible impacts and policy issues that have to be considered.
- Do nothing (system as is – this typically overloads at low market penetrations)
- Capacity accommodation (utility’s T&D system is augmented as needed at higher penetrations with standard new guidelines)
- Capacity augmentation with loading adjusted to current expected lifetimes
- Flattest possible (assumes best possible peak reduction using load control or Smart Grid at each penetration level studied with adjusted lifetimes accounted for)
- Flattest with full charge by morning: the “flattest possible” scenario constrained by a requirement for 95% of EVs to be fully charged overnight (this is sometimes a constraint at interim penetrations and more)
- Two customized scenarios tailored to the utility’s specific interests.
- Expected changes in peak demand and peak day load curve shape off peak day load curve shapes, annual energy sales, annual energy duration curves at various levels of the system.
- Expected changes in demand response amounts and deferability of load at peak and off peak periods.
- Detailed assessment of changes in load coincidence behavior on the system and locationally (at various key points) within the system.
• Electrical/thermal loadings and lifetime impacts on the system equipment at all levels including all levels of transformers and cable and switched volt/VAR control equipment.
• Electrical performance impacts including changes in voltage profiles, voltage regulation, power factor, electric losses, reliability, harmonics, and operability.
• Estimated capital and operating costs for all scenarios and strategies that involve equipment.
• Reliability indices like SAEVF2C1 (System Average EV Failure to Charge Index) which measures the expected annual performance of the utility in “filling up” EV owners batteries, taking into account storm situations as well as non-storm issues.

**Deliverables and Results**

Deliverable products from a quick EV distribution impact study include:

• A written report describing what was done, the methodology applied, fully describing all work and all findings and conclusions.
• An EV impact benchmark report bundled with the utility report, showing the utility’s base case impacts as compared to those on other systems Quanta has studied and will explain differences and similarities.
• An on-site workshop (one day) to go over the study results, that provides an information base from which the utility can make decisions about how it wants to handle EV loads and combine its plans for those with other important strategic policies and priorities.

**Quanta Technology Experts in EVIS**

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**References and Resources**