WHITE PAPER / **TRANSPORTATION ELECTRIFICATION**

# Evaluating the impacts of electric vehicles on utility distribution systems

**BY Carter Boyle**

Consumers and transportation companies are embracing the electric vehicle transformation, but electric utilities across the U.S. will need to prepare for increased demand. To avoid costly upgrades and mitigate the downstream effects of increased energy consumption, utilities should implement thoughtful standards and business practices.

## The advent of the electric vehicle (EV)

Between 2020 and 2025, electric vehicle (EV) sales in the U.S. will quintuple, increasing from 1.4 million to 6.9 million, according to S&P Global, a financial analytics firm. In 2022, Ford will manufacture and sell an electric version of the Ford F-150 — the Ford F-150 Lightning. Trucks in Ford's F-Series are often ranked among the most popular vehicles in the U.S. General Motors (GM) has rebranded for an all-electric future, adding plug imagery to the new logo and announcing plans to have 32 electric models by 2025. America's off-roading icon, the Jeep Wrangler, is now available as an electric hybrid, in addition to the 4x4. The Cadillac Lyriq's commercial was the third most-watched during the 2021 Super Bowl, and the vehicle launches in 2022. Car manufacturers aren't the only players making big moves in the EV space. Siemens, Schneider Electric and Southern Company founded the ZETA coalition in 2020 to lobby for 100% EV sales by 2030.

The advent of American EVs is here. While EVs have many benefits, including the potential to reduce carbon emissions, further analysis shows that the burgeoning consumer appetite for EVs will impact electrical distribution systems across the country.

## Impacts

The influx of EVs will exacerbate existing issues and create new burdens for utilities of all sizes across the country. EVs heavily impact circuit efficiency and maintenance due to heavy phase unbalance and immense coincident load. The longevity of grid equipment will be compromised and outage consequences will worsen as electrification accelerates. On the other hand, increased grid equipment capacity, enhanced demand response and revitalized standards could mitigate the majority of these risks.

## Phase unbalance background

Current phase unbalance measures asymmetry in a three-phase system. It originates from asymmetric system loading, which is heavily driven by single-phase laterals and worsens when load balancing techniques are not prioritized in distribution planning. Current phase unbalance is coupled with voltage unbalance. Current unbalance tends to be about five times higher than voltage unbalance.

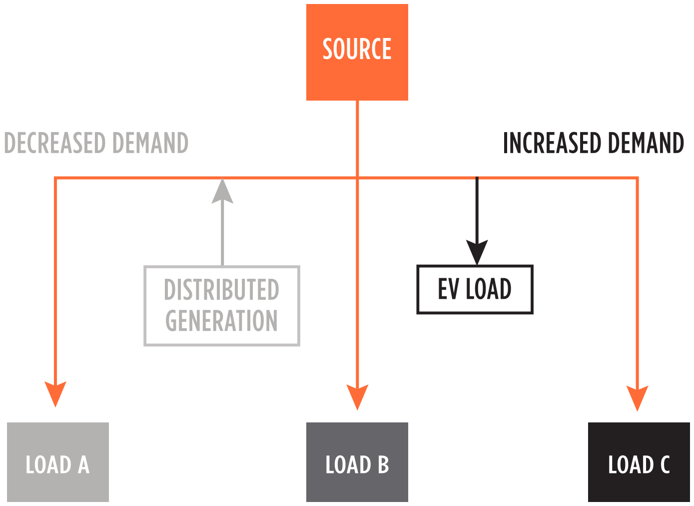

**Figure 1:** *A simplified distribution circuit is shown above with a source feeding three single-phase laterals A, B and C. The current unbalance is exacerbated by the combination of new load and generation.*

## Current phase unbalance

EV charging loads on the end-of-the-line single-phase laterals can lead to extreme phase unbalances in the absence of proper planning for these loads.

In Figure 1, the system is perfectly balanced in the base case, with the same load on A, B and C. Phase A receives distributed generation, decreasing current demand. Enough generation can cause reverse power flow on this phase. Phase C receives EV load, increasing current demand. As a result, the current unbalance is exacerbated by the combination of new load and generation rather than either alone.

In cases of extreme phase unbalance, we encounter two issues:

- Protection coordination strategies generally assume voltage unbalance of less than 3%. Unbalanced phases lead to fuse preloading, which results in miscoordination of fuses with other protection devices. Additionally, line-to-line single phase loads do not generate the ground fault current necessary to trip the ground relay.
- Three-phase motors and variable speed drives are designed to operate most efficiently on a balanced three-phase system. As the system becomes unbalanced, motor operation and efficiency suffer. A voltage unbalance of 5% causes temperature increases in excess of 25%.

An analysis of data from a mid-sized investor-owned utility in the United States shows poorly balanced circuits in a sample area have 12% phase unbalance at the service transformer on a summer night without EV charging. As EV load increases on these circuits, phase unbalance can increase to above 250%. When measured at the meter under no-load conditions, a circuit should maintain a voltage unbalance of less than 3% (current unbalance of about 15%), according to American National Standards Institute (ANSI) 84.1-2020.

## Coincident peak load

Across the U.S., EV adoption as of 2021 stood at less than 1%, with market share hovering around 2%. Conservative estimates project that the market share should increase to 12% and 29% by 2025 and 2030, respectively. These levels of market share translate to adoption levels of approximately 2.4% in 2025 and 7.5% in 2030. Honda plans to stop selling gasoline-powered vehicles entirely by 2040. At adoption levels as low as 5%, the peak demand on a circuit can increase 20%. At 20% EV adoption, the peak demand on a distribution circuit can easily double, as typical charging times align with peak summer air conditioning usage and increased electric heating during the winter.

### Coincident peak demand

Peak demand is the 15-minute period when energy consumption is highest for a customer. Coincident peak demand is the customer demand when the system consumes the most energy during a 15-minute period.

Evening charging is not the only concern. EVs can charge at any time of day. These vehicles can charge in business parking lots, parking garages and at work during the daytime, leading to very clustered intermittent demand. At night, passenger vehicles charge at residential homes on single-phase lateral lines. Similarly, parking garages and transport depots will have multiple chargers in a concentrated area. To reach 1 MW of load, a parking garage would only need 70 Level 2 AC chargers.

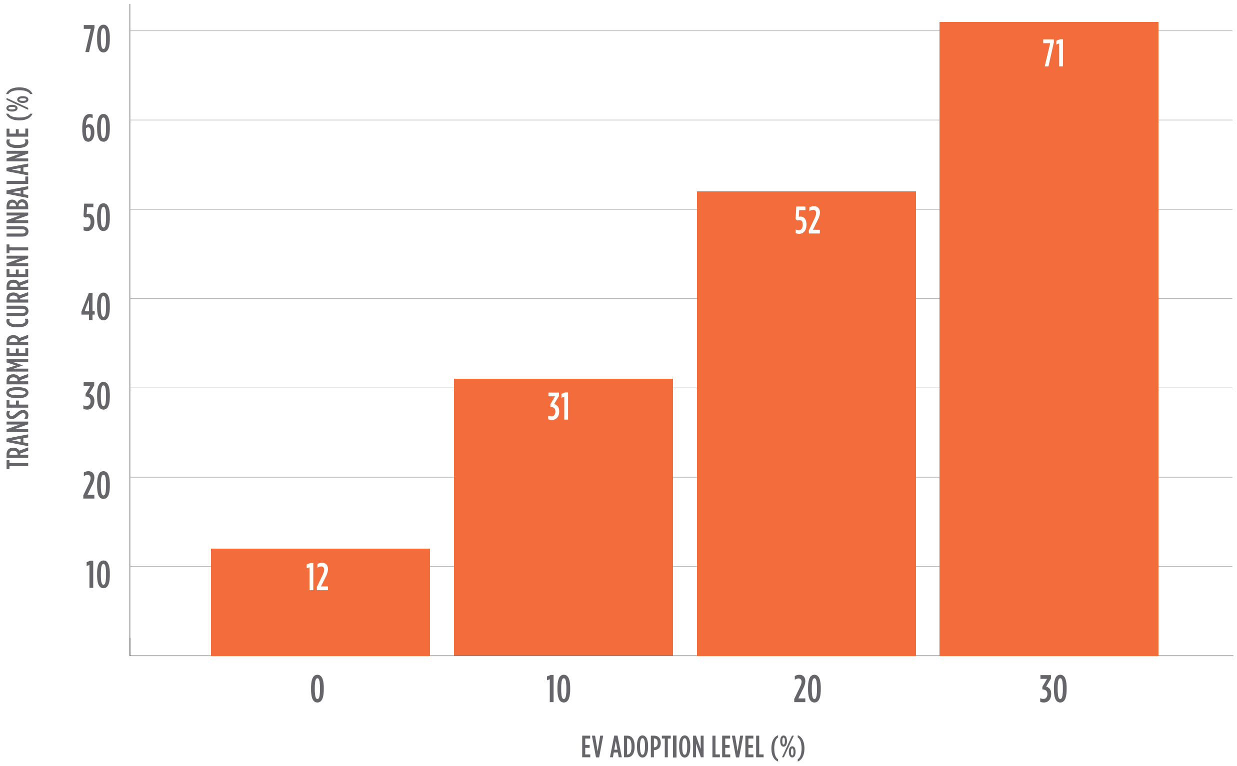

**Figure 2:** *Current unbalance at different levels of EV adoption for a circuit dominated by residential and commercial customers in the Midwest. Even at 10% adoption, current imbalance exceeds ANSI-recommended levels.*

**Figure 3:** *Load density map accompanied by color-coded abnormal conditions. A dense EV load cluster is at the top of the diagram, located at the end of the circuit and far from the substation. When large loads come online far downstream, especially in 5-kV legacy voltage areas, they cause greater overloading and undervoltage. This increases the likelihood of outages related to equipment and power quality. Characteristics of the circuit and the community show 30% EV adoption on a summer night in a mixed-use neighborhood, with commercial and residential customers. When this circuit reaches 30% EV adoption, approximately 85% of the transformers and 6,000 feet of distribution line will be overloaded.*

EV charger ratings are increasing every year. At first, AC Level 1 charging had approximately 1.5 kW of demand. However, the 2020 Tesla Gen 3 Wall Connector is now capable of 11.5 kW. In addition, Ford and GM have announced production of electrified SUVs by 2024, and the home charger could be upgraded to 19.2 kW.

Overloading a typical suburban residential transformer is a highly plausible scenario. In this case, four residences with two-car garages are assumed to have 7 kVA of average baseload served by a 50 kVA transformer. Just three electric sport utility vehicles (SUVs) could place an extra 60 kVA on the transformer already carrying 28 kVA baseload, bringing the transformer to 88 kVA (176% loading). In a worst-case scenario, each home purchases two electric SUVs, resulting in an overloading of approximately 376%. When field crews replace this transformer, it won't be long before they need to return. On the example circuit in Figure 3, at 30% EV adoption, 85% of transformers were loaded to 120% or greater (71 overhead transformers and 35 pad-mounted transformers). Based on pricing from Figure 4, replacing the overloaded transformers on this circuit would be expected to cost between $2.4 million and $3.2 million. That's just the price tag at 30% EV adoption.

The 25 kVA transformer is the most common in the U.S. Since a single transformer feeds multiple homes, more than six electric vehicles could charge on a transformer. Considering transformer problems arise with two vehicles to a transformer, and even one per transformer causes issues at a distribution level, several measures will be required to prepare for EVs.

## How to prepare for it?

EVs represent significant challenges and opportunities. 1898 & Co. uses a strategic methodology combining demographic and business data, geographic information systems and circuit models to study potential impacts and create a tailored plan to minimize the cost of adoption and decrease operations and maintenance costs.

| | NONUNION | UNION |
|---|---|---|
| **Pole-mount** | **$24,500** | **$32,000** |
| **Pad-mount** | **$20,000** | **$26,500** |

**Figure 4:** *Union and nonunion pricing assumptions for a 14.4-/24.94Y-kV / 120/240 V — 25-kVA transformer in the continental U.S.*

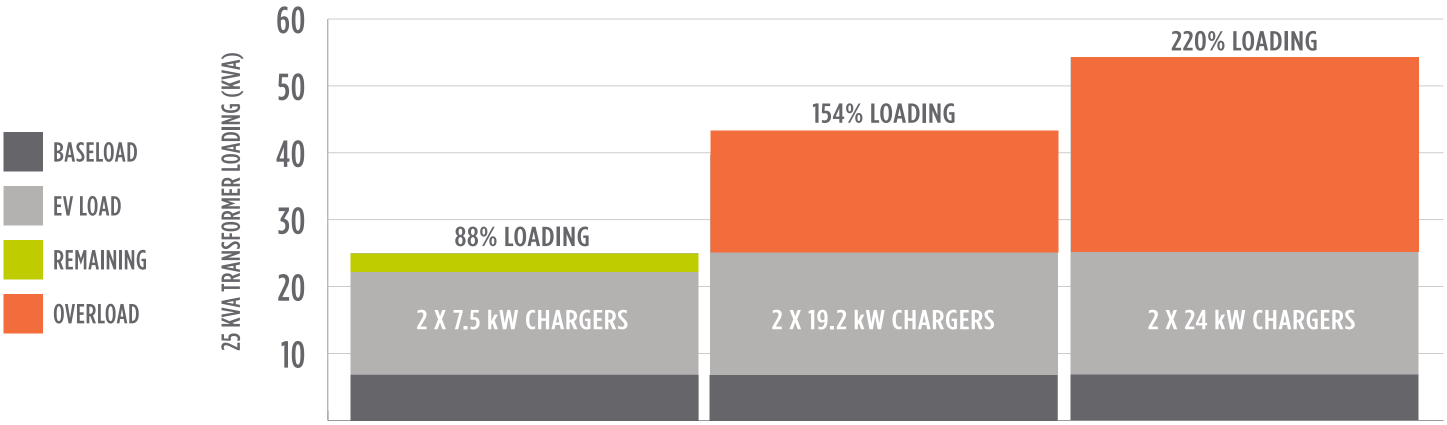

**Figure 5:** *How many chargers to a residential transformer overload? Scenarios for residential EV charging and its effects on the capacity of a distribution transformer.*

### Understanding customers and increasing engagement

Such planning includes utilizing communications to gain insights, boost efficiency and develop forecasts:

- Establish meter analytics to identify unregistered EVs and increase customer engagement to forecast EV adoption throughout your service territory.
- Equip customers with easy-to-use info on how to charge during off-peak hours and reduce their energy bill.
- Develop two-way communication between charging infrastructure and utility control centers. Two-way communication enables a world of demand response and forecasting options.

### Planning and engineering solutions

Making the most of existing assets and looking ahead to upcoming needs is a foundation. Also key is implementing updates that can make a difference now and in the future:

- Raise circuit voltages to decrease current unbalance and to serve the added EV load.
- Assess engineering standards for low-cost improvements that will avoid future maintenance or reinstallation and reduce upgrade costs. For instance, building a single-phase 15-kV lateral line with spacing for 35-kV and poles designed to handle three phases only adds about 10% to the project's cost. These measures also reduce the need to replace poles and conductor spacing in the future.
- Align utility-installed distributed generation with coincident load to determine when it can help with demand response.
- Standardize EV risk assessment studies to create custom risk portfolios by circuit.
- Develop resiliency frameworks to assess high-value resiliency improvement projects. EV risk mitigation happens through this process, which also benefits the overall health of the distribution system.

Due to the very long life cycle of distribution and substation assets (40–80 years), thoughtful standards and business practices are required to prepare for and mitigate the effects of EVs and avoid costly reactive system upgrades.

## Biography

**Carter Boyle** is a technical advisory analyst for the energy and utility industries at 1898 & Co., part of Burns & McDonnell. Carter has executed distribution planning studies, including reliability assessments, legacy voltage conversions, electrification studies and systemwide hosting capacity analysis. He has diverse experience in fields ranging from automotive to radio-frequency engineering and is currently focused on building a stronger, smarter grid. He earned a Bachelor of Science in electrical engineering from the University of Alabama.

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