Data-Driven Integration of EVs into Distribution Grids:
State-of-the-art and Challenges

Yubo Wang, PhD
Siemens Corporation, Corporate Technology
CT RDA NEC EMB-US
yubo.wang@siemens.com
Motivations: rapidly growing charging power and EV penetrations

Household Charging
3-7 kW

Office Charging
22 kW

Public Charging
50-350 kW

Compare the number with 14 kW, a typical U.S household load without EV

From distribution grids perspective, how to perform effective monitor, prediction and control?
Outline

• EV Monitoring
  • Monitoring Granularity
  • Existing Communication Infrastructure and Standards
• EV Profile Prediction
  • A Comparison to Solar Generation
  • A Data-Driven Case Study
• EV Charging Control
  • Existing Models
  • Going Distributed
• Conclusions
Monitoring Granularity

Where shall DSO put meters?

- Existing meters for billing is on the EVSE side, however the accuracy may not be acceptable
- Non-intrusive meters are expensive
- Intrusive meters need extensive infrastructure work
- Small load are less interest to DSOs

What should be the data throughput?

IEEE 69-bus benchmark test system

Monitoring is coupled with prediction and control
On vehicle side, various communication standards exist. ISO 15118 offers most possibility in extracting EV information and charging schedule negotiation but it is not yet widely adopted.

On EVSE side, OCPP is not yet IEC 61850 compatible (important for utility) and there is no clear understanding of what the utility needs from EVSE.

WiFi based communication for overhead eBus charging systems using Directional Antennae (OppCharge)

Development of sensor based alignment systems

On-board communication controller integration for standard compliant DC charging methods (SAE J1772/J3068, DIN 72101)

OCPP 1.6 for connection to CPO

HomePlug GreenPHY based communication for plug-in charging systems (SAE J1772/J3068, DIN 72101, ISO 15118)

Communication Controller development for High Power DC Charger (Siemens ECC3200)
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A Comparison to Solar Generation

Predictions are important in transmission level
- Generators takes time to start up
- Start up cost
- Economic operation

EV profile prediction is crucial for
- Effective transmission level planning
- Distribution level EV charging control

IEEE 14-bus test system

For solar generation
Radiation
Cloud
History
Online parameters

For EVs
Less external features
Instead of power
? Arrival Time
? Leave Time
? Energy Demands
A Data-Driven Case Study

- Data collected for one calendar year
- Use Kernel Density Estimation for generating model-free distributions according to collected data
- Numerically approximate with Sample Average Approximation for a stochastic programming

Three typical EV owners on campus
Wang et al. 2017

How much data is needed for an accurate exaction?
Can we study an aggregated EV loads?

Average load mismatch, Wang et al. 2017
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Existing Model: EV Modeling

- **Power constraints**
  \[ p_{b}^{i,m}(t) + q_{b}^{i,m}(t) \leq s_{b}^{i,m}(t) \]

- **Energy constraints**
  \[ e_{L}^{i,m} = e_{SL}^{i,m} + \sum_{r} p_{r}^{i,m}(t) = e_{F}^{i,m} \]
  \[ e_{SL}^{i,m} + \sum_{b} p_{b}^{i,m}(t) = e_{F}^{i,m} \]

In many literatures, EV is treated as static load, see He et al 2012, Sortomme and El-Sharkawi 2012

If EV is modeled this way, how is it different from a stationary battery?

Maps to the stochastic modeling in the *Prediction* section

But are the parameters treated as known in the equations really accessible?

Maps to the monitoring issue in the *Monitor* section
Existing Model: Lumped vs. Distributed

Networked model outperforms the lumped counterpart in terms of voltage regulation and network loss

How to account for system scalability? And privacy concerns from EV owners?
Going Distributed

- First of all, convex relaxations.
  - See Javad and Low 2012 for SoC relaxation
  - See Javad et al. for SDP relaxation
- Tightness hold in most of the distribution case
- Convergence is guaranteed
- Distributed framework

1. Decision variables are randomly initialize
   *Could do warm start

2. SDSO optimize for bus level problem and propagate communicator to DSO

3. DSO optimize for grid level problem and update and propagate communicator to SDSO

4. Update iteratively until converge based on primal/dual residual

 ✓ Account for scalability
 ✓ Protects EV owner user privacy
**Going Distributed**

For a difficult case (most of the constraints are active), converges in <40 steps using over-relaxed ADMM

Problem size about 20k D.V

How to account for communication failures?

How to deal with numerical issues?
Conclusions

• Focused on EV integration to distribution grids from the grid operator’s perspective
• Reviewed techniques in monitor, prediction and control
• EV charging seems to be much harder than most of accessible literatures
• A lot of open questions to be solved, efforts needed from both academia and industry
• Connecting the gap between car manufacturers and utilities
Thank you!

Please send comments to

Yubo Wang

yubo.wang@siemens.com
Reference