NSF Center for GRid-connected Advanced Power Electronic Systems (GRAPES)

GR-17-08

Coordinated Optimal Voltage Regulation for the Next-Generation Distribution Grids with High Penetration of PV Generation

Yue Zhao
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Project Overview

- **Project Start Date:** January 1, 2017
- **Expected Completion Date:** December 31, 2018
- **PI Name:** Y. Zhao
- **Overall Project Budget:** $40,000 (Y1)
Technical Slides

• Where does this fit into the strategic plan?
• Why is this relevant to our IAB?
• Where are the power electronics?
• Expected deliverables including students, publications, patents, copyrights, technology transfer
Challenges & Needs

Background

- Electric power grid is currently undergoing a paradigm shift from a centralized network to a more distributed one, with ever increasing numbers of DERs scattered throughout the grid.

Benefits

- Energy savings, reduced system losses, deferred or avoided network investments, improved resilience and power quality.

Challenges

- Voltage violations, aggravated variability and load forecast errors, two-way power flows, and inadvertent system dynamics from interactions among DERs and between DERs and the distribution system.
Voltage Violations

- current voltage regulation schemes are designed to manage one-way power flow and cannot easily accommodate the fast changing dynamics in the distribution grids. – Controllability

Lack of Visibility

- Traditional utility data acquisition and monitoring systems are ill-equipped to gain real-time visibility of DERs, since these systems typically do not extend beyond substations and are not able to acquire measurements on DER performances. – Observability
Challenges & Needs

- DE-FOA-0001495: ENabling Extreme Real-Time Grid Integration of Solar Energy (ENERGISE) 05/02/2016
- DSM1.2 Development of SMART INVERTER technology complementing work by DOE
- Reactive power support: unity power factor; oversized inverters; possible decrease of the profits of the PV owners
- GR-17-08: Coordinated Optimal Voltage Regulation for the Next-Generation Distribution Grids with High Penetration of PV Generation
An illustration of a small network with three clusters of nodes identified by using (a) divisive methods and (b) agglomerative clustering methods, which are typically good at discovering the strongly linked cores of communities.
Active Node Cluster Identification

An illustration of the proposed active node cluster identification
An illustration of the proposed coordinated voltage regulation framework
Coordinated Voltage Regulation

A 36-node network partitioned using the proposed method

Voltage profiles of the node 24
An illustration of the proposed coordinated voltage regulation framework
The interaction topology of a cluster can be represented by a graph $G_K = (V_K, E_K)$ with the set of nodes $V_K$ and edge set $E_k \subset V_k \times V_k$.

Neighbors of agent $i$ are denoted by $N_i = \{j \in V_k : (i, j) \in E_k\}$.

Each node measures its local voltage magnitude and calculates the local deviation ($\Delta u$) from nominal voltage ($u^*$) transmits its state to its neighbors, receives their neighbors’ $\Delta u$ states and updates its state at the next iteration.

$$\Delta u_i[k + 1] = a_{ii} \Delta u_i[k] + \sum_{j \in N_i} a_{ij} \Delta u_j[k]$$

$$a_{ij} = \begin{cases} 
\frac{1}{1 + |N_i|} & \text{if } j \in N_i \\
0 & \text{otherwise}
\end{cases}$$

$Q$ needs to be injected by the agent $i$ is

$$\Delta Q_i[k] = \Delta u_i[k] / S_{ii}^{VQ}$$
Model Predictive Control (MPC)

- Model predictive control (MPC) will be utilized for reactive power control of DERs at device control layer.

- The proposed MPC will include a sensorless current mode control through none phase-locked-loop (PLL) based grid synchronization that supports decoupled power control and seamless mode transition from grid-synchronized to grid-isolated operation.

- The advantages of the proposed approach includes improved performance and the capability of multi-objective optimization, e.g., the cost function can be design to minimize switching frequency subject to meeting the reactive power requirement.
COVoR Summary

Coordinated Optimal Voltage Regulation

- Active node cluster identification algorithm
- Multi-agent system (MAS) based reactive power sharing among smart inverters
- Model predictive control (MPC) for PV inverters
- M1.3: Coordination schemes amongst various devices on a microgrid
- D1.1: Algorithms for determining the state of the system and how best to dispatch
Milestones for Mid-Project (Y1)

- Successful development of MPC for smart inverter, implementation the proposed MPC in Matlab Simulink and validation of its effectiveness;

- Successful implementation of MPC in the solar inverter prototype in PI’s lab and validation of its effectiveness;

- Successful development of distribution grid partition method, implementation the proposed method and validation of its effectiveness. (123/8500)
Milestones for Mid-Project (Y2)

- Successful development a VR zone prototype with at least three PV inverters;
- Successful implementation of MAS in the solar inverters and validation of its effectiveness.
Anticipated Outcomes

- A multipoint self-sensing and real-time monitoring system for the distribution grid with high PV penetration;
- A smart PV inverters controller with enhanced reactive power support capability using MPC;
- A coordinated optimal VR software package, which will be compatible with the commercial solar inverters.
- Students, publications, patents, copyrights …
Thank you!

Comments & Questions?

Yue Zhao, Ph.D.
Assistant Professor
Department of Electrical Engineering
University of Arkansas
yuezhao@uark.edu