European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out

TRANSNATIONAL ACCESS
USER PROJECT FACT SHEET

USER PROJECT	**H2020 ERIGrid research infrastructure project**
Acronym	**DD-CVC**
Title	**D**ecentralized and **D**istributed **C**oordinated **V**oltage **C**ontrol: coordinated control of DERs to enhance LV distribution network voltage profile
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TA Call No.	

HOST RESEARCH INFRASTRUCTURE			
Name	**University of Strathclyde**		
Country	**United Kingdom**		
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1. USER PROJECT SUMMARY (objectives, set-up, methodology, approach, motivation)

1.1 Introduction:

In power distribution networks with high penetration of photovoltaic (PV) generation, the reactive power capacity provided by the interfacing inverters has a large potential for voltage regulation.

The first objective of this project is design a voltage control method to solve the network voltage regulation problem. Therefore, a decentralized and distributed coordinated voltage control method based on reactive power of PV inverters is proposed in distribution networks. The proposed control approach comprises three level hierarchy: ramp-rate control (Level I), droop control (Level II), and distributed control (Level III). The proposed control method can smooth the voltage profiles, restrain the voltage rise/drop problem, and coordinate all PV inverters in real-time when there is no feasible local solution.

The second objective of this project is to test the proposed voltage control method through experiment. Therefore, a power hardware-in-the-loop (PHiL) experimental platform has been built based on real time digital simulator (RTDS). The controller of each PV inverter is implemented separately in RTDS with realistic communications among them. The proposed voltage control method will be tested under different scenarios to validate the effectiveness.

1.2 Methodology:

The proposed control approach comprises three level hierarchy: ramp-rate control (Level I), droop control (Level II), and distributed control (Level III). In Level I, a ramp-rate control is proposed to mitigate the network voltage fluctuations. While in Level II, a droop control is designed to mitigate the network voltage deviations. If the local compensation provided by Level I and II control is not enough to regulate the network voltage deviations within limits, the distributed control at Level III will respond and share the reactive power requirement to other inverters. The proposed distributed control will determine the reactive power requirements of all available inverters autonomously, so that the network voltages are controlled within the required limits.

The mathematical equations of the proposed voltage control method are represented as follows:

Level I: Ramp-rate Control

The utilization ratio of Level I control is represented as:

$$u_i^I(t) = K_i^I \left(V_i(t) - \frac{\sum_{j=t-\omega}^{t} V_i(j)}{T(t) - T(t-\omega)}\right) \tag{1}$$

where, ω is the length of the moving average window and K_i^I is the ramp-rate control gain.

Level II: Droop Control

The utilization ratio of Level II control is represented as:

$$u_i^{II}(t)=\begin{cases}K_i^{II}(V_i(t)-\overline{\tilde{V}}), & V_i(t)>\overline{\tilde{V}}\\ 0, & \underline{\tilde{V}}\le V_i(t)\le\overline{\tilde{V}}\\ K_i^{II}(V_i(t)-\underline{\tilde{V}}), & V_i(t)<\underline{\tilde{V}}\end{cases}\qquad(2)$$

K_i^{II} is the droop gain of i^{th} PV inverter. $[\underline{\tilde{V}},\ \overline{\tilde{V}}]$ represents the dead band for the droop control.

Level III: Distributed Control

The utilization ratio of Level III control is represented as:

$$e(t)=\begin{cases}K_i^{III}(V_i(t)-\overline{V}), & V_i>\overline{V}\\ 0, & \underline{V}\le V_i\le\overline{V}\\ K_i^{III}(V_i(t)-\underline{V}), & V_i<\underline{V}\end{cases}\qquad(3)$$

$$\dot{u}_i^{III}(t)=G_i^{III}[\sum_{i=1}^{N}a_{ij}(u_j^{III}(t-\tau(t))-u_i^{III}(t))]+e(t)\qquad(4)$$

where K_i^{III} and G_i^{III} are the distributed control gains. $\tau(t)$ is the time varying communication delay where $0\le\tau(t)\le\overline{\tau}$ with $\overline{\tau}$ being the tolerable communication delay upper bound.

1.3 PHiL Platform Set-up

In order to test the proposed control algorithm in a more realistic environment, PHIL experiment is conducted. A 7-bus distribution network has been implemented in RTDS. A 15kVA inverter and a 40kW resistive load bank with a 90kVA interfacing converter are replaced into the simulation model built in RTDS. The voltage and current signals between scaled up and down between the real-time simulation and the hardware equipment. The proposed control scheme has been developed for each PV inverter separately in RTDS, and the entire system is operated in real-time with a time step of 50us. Furthermore, all the communications required for the distributed control algorithm are implemented through real cable communications. Control signals are independently routed outside of the RTDS with GTNET cards, then into a communication emulator software and finally back into neighboring controllers in the RTDS. This allows for the evaluation of real dynamics introduced by the PV inverter and also analyzing the impact of realistic communication on the proposed control scheme.

2. MAIN ACHIEVEMENTS (results, conclusions, lessons learned)

2.1 PHiL Experimental Results

In this project, three test case has been designed to test the performance of the proposed control method. The effectiveness of each control level has been validated under PHiL experiment.

In Test Case 1, the ability of the proposed control approach to mitigate sudden voltage drops due to step changes in load is tested. Such a situation would normally occur in the evening in distribution grids, when load demand is high but there is a lack of PV generation. As there is no PV production, all capacity of PV inverters can be utilized to supply reactive power for network voltage regulation. The PHiL results prove the ability of the proposed control approach to: (i) mitigate voltage drop issues and (ii) work under step load changes.

In Test Case 2, the performance of the proposed control method with communication delays is investigated. The test system conditions remain same as in Test Case 1. Two types of communication delays are considered: (i) a constant time delay, and (ii) a variable time delay follows Gaussian distribution. The PHiL results prove that the proposed method can work properly under bounded communication delays.

In Test Case 3, the ability of the proposed control approach to mitigate voltage rise conditions arising from high PV penetration is tested. Such a situation usually occurs during the daytime within a distribution grid, when the load demand is minimal while PV generation is at its peak. Therefore, the PV capacity is slightly oversized to enable provision of reactive power output even under peak PV generation. The PHiL results reinforce the ability of the proposed control approach to: (i) mitigate voltage rise issues and (ii) work under real world PV data.

2.3 Conclusion

The performance of the proposed control approach has been validated through PHiL experiment, where one bus of the 7-bus distribution network was implemented by real hardware. The experiment results have demonstrated that the proposed method can deal with both the voltage fluctuations and voltage limits violation problems autonomously. Besides, it has been validated that the proposed control method functions normally under communication delays. The effectiveness of the proposed method has been validated with both inverter and communication dynamics in the PHiL experiment.

3 PLANNED DISSEMINATION OF RESULTS (journals, conferences, others)

Planned Journal Publication:

Y. Wang, M. H. Syed, E. Guillo-Sansano, Y. Xu, G. M. Burt, “Distributed Hierarchical Voltage Control: Design and Power Hardware-in-the-Loop Validation,” *to be submitted to Trans. Industrial Informatics.*