Dear Editor and Reviewers,

We thank for your the opportunity to improve our manuscript, titled “Optimal Voltage Phasor Regulation for Switching Actions in Unbalanced Distribution Systems”. We have carefully considered all the editors and reviewers comments, and believe that all concerns have been addressed in the latest revision. We appreciate your time and effort in reviewing our submission.

Response to the Editor:

We understand the Editor’s concern on the lack of emphasis on the OPF. In Section 4C, we added a second experiment on a larger network with multiple switching actions to demonstrate the advantages of the OPF formulation, such as application to meshed networks. In Section 4D we also discuss the advantages of the linearized model and its incorporation into an OPF, and outline disadvantages and possible ways to overcome them.

We agree with the Editor that it is important to consider the interaction of devices performing voltage regulation and our proposed controller. As such, in Section 4B, we have incorporated DER performing Volt-VAr control that is not managed by our OPF. This was accomplished by incorporating the VVC algorithm as a constraint in the OPF. Our results show that the algorithm is able to minimize voltage phasor differences in the presence of voltage regulators which we do not control.

In this work, we did not consider controlling DER to enable switching in an economically motivated environment (from the perspective of the DER owner). In the optimization considered in these experiments, we assume that DER dispatch for economic purposes is suspended in order to devote said resources to reconfiguration efforts. We fee, that in the future it is feasible re-purpose privately owned or operated assets to protect critical infrastructure in an extreme weather event, cyber attack, or component failure. After the system has been reconfigured, it is expected that DER would return to economically motivated operation.

Response to Reviewer 1:

We apologize for lack of clarity in explaining the details of the assumptions and the Monte Carlo simulation. In this revision, we have attempted to clarify the nature of the approximations by adding additional discussion in the last three paragraphs of Section 2C, as well as substantial changes in Section 3. In this revision, we repeatedly provide the reader with a reference detailing many of the assumptions utilized in our paper. Specifically, in Section 2C (third to last paragraph), we note that by approximating the nonlinear terms in (18)-(19), we do not imply that the ratio of voltages between different phases in the resulting linearized model are constant (i.e. the linearized model captures unbalanced voltages). In Section 3, we have expanded the discussion regarding how the Monte Carlo simulation was structured and parameterized. In Section 3, we have been careful to emphasize that our proposed linearized model does capture network imbalances in system voltages and power flows.

Response to Reviewer 2:

In Section 4D, we emphasize that the algorithm presented in this manuscript is centralized and discuss requirements for the scalability of the approach to handle more networks. In order for the approach to be scalable, we require the availability of a network model of the distribution systems to be controlled as well as a communications infrastructure to relay sensing and actuation signals. Though this may preclude an on-line implementation (as the problem is presently formulated), we discuss in the last paragraph of the conclusions our previous experience adapting centralized OPF approaches for on-line use via the adoption of model-free and low-communications optimization techniques. We believe the work detailed in the present manuscript can be extended using these approaches to optimally regulate voltage phasor differences. We intend to explore this in the future.

In Section 4C, we perform a simulation on a network with two sequential switching actions. In this experiment, the OPF is solved for each specific switching action.

In Section 4D, we discuss of the limitations of the power flow model, in the context of the results of Section 3. We point out to the reader that the linearization error increases with substation loading. However, we note that even under very high loading conditions the resulting error is relatively small. We also briefly discuss how to overcome the effect of these errors via an iterative technique akin to sequential quadratic programming, and plan to investigate methods in future work.

Response to Reviewer 3:

The reviewer raises an intriguing concept with this comment. Yes, we believe it is possible to develop a methodology that determines an optimal switching sequence when more than one reconfiguration action is desired. Although this is a topic deserving lengthy thought and discussion, initially, one could imaging solving the OPF outlined herein with different switching sequences to minimize the voltage phasor difference across a particular switch. Although one could enumerate these possibilities, this approach would quickly breakdown when considering multiple switching actions over multiple networks. We have briefly discussed this in Section 4D and plan to consider an extension to the OPF proposed in this manuscript in future works.

In Section 4A, we discuss our previous efforts in formulating semidefinite relaxation OPFs, that incorporated the unapproximated angle equation of (25), with similar objectives as the proposed OPF in our work. Initial simulations were conducted on simple balanced radial networks with 6 nodes. We found that some of our simulations successfully returned a rank-one solution. However, this success was not repeatable under small changes of simulation parameters, on larger balanced, or any size unbalanced networks.

We added a discussion on expanding the power flow model for nodes with a transformer between them, using the analysis in ``Distribution System Modeling and Analysis'' by Kersting. We note that voltage phasor equations of unbalanced transformer models are often linear in voltage and current, and often take a similar form to KVL, with both the voltage and current vectors multiplied by constant matrices representing transformer properties. Thus we feel that the derivations of magnitude and angle equations in Section 2 can be lightly modified and applied to transformers.

Although the power flow solver used in this work was custom built, it has been verified against several off the shelf tools including GridLAB-D and OpenDSS. We are confident that the errors of the linearization would be equally reflected using a different power flow solver.

In Section 4, we clarify several important aspects of our simulations. First, in Section 4B and 4C, we provide discussion of our choice of the OPF objective function weightings. Values of 1000 for weights associated with voltage magnitude and phase angle terms were done so to offset scaling that occurs due to the fact that, in the linearized model, voltage magnitudes and phase angles are linear combinations of power injections that have been scaled by network impedances. As some of the impedance values are on the order of 0.001 Ohms p.u., a value of 1000 was a suitable choice.

In Section 4A and 4B, we clarify the reason for considering four-quadrant DER operation. In this paper, we wanted a DER model general enough to consider present and potential future DER functionality, such as vehicle-to-grid, or distributed battery charging/discharging. These devices can both source and sink both real and reactive power, thus warranting a 4 quadrant DER model.

Finally, In Section 4A, we clarify that the OPF we propose is not economically motivated. Rather we assume that economic activity would be suspended in favor of grid reconfiguration operations. We feel it is logical, that in the future it is feasible re-purpose privately owned or operated assets to protect critical infrastructure in an extreme weather event, cyber attack, or component failure. After the system has been reconfigured, it is expected that DER would return to economically motivated operation.

We thank you again for the ability to resubmit the manuscript. We are available to field and questions or comments you may have.

Sincerely,
The Authors