Closure to Discussion on "A New Formulation of Distribution Network Reconfiguration for Reducing the Voltage Volatility Induced by Distributed Generation"

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The authors are grateful to Fahad S. Al-Ismail for his interest in our work [1] and his insightful discussion. The point-to-point responses to the discussion are presented below.

1) *About the type of of RES-DG (wind-based or solar-based) used in case study and the efficacy of the proposed methodology under time-varying scenarios.* The reconfiguration framework proposed in [1] is very general and applies to any type of RES-DG with high uncertainty. So we did not specify the type of RES-DG used in the numerical experiments. In addition, we agree with the discusser that the proposed methodology aims to obtain a steady-state voltage profile in a single operating scenario that has lower risk of voltage violation in case of DG output deviation caused by prediction error. However, the proposed methodology also works under time-varying scenarios due to the timescale separation between the system electromagnetic dynamics and scenario transition. Considering that the line R/X ratio in distribution networks is around 1.0, the time constant of line electromagnetic dynamics is around 3.1 milliseconds [2]. It implies that the distribution system will converge to the steady state of a new scenario in the order of ten milliseconds. By comparison, the scenario transition has a much greater timescale. For instance, the maximum change rate of solar power is around 3% of its capacity per minute [3]. Therefore, the steady-state analysis still applies to time-varying scenarios and the proposed methodology has a satisfactory performance.

2) *About the cost optimization of capacitor banks (CBs) of the proposed methodology.* The proposed methodology refers to the optimization of distribution network structure by tuning the line switches and CBs that are currently available in the system. We assume that the location and capacity of CBs are predefined. The installation and purchase costs of CBs should be considered in the planning stage (e.g., see [4–6] as mentioned by the discusser), which are not within the scope here. Nevertheless, the capability of network reconfiguration in mitigating voltage volatility, which has been revealed by [1], may bring new consideration to planning issues such as the optimal siting and sizing of CBs. It could be a future research direction to pursue.

3) *The purpose of setting tighter voltage bounds for some buses in the network reconfiguration model.* Note that the risk of voltage violation cannot be reduced by the voltage volatility constraint alone. A bus with low voltage volatility is still likely to have voltage violation if its voltage is very close to the upper or lower limit when the DG outputs are as predicted, e.g., a small DG output deviation will cause over-voltage or under-voltage of this bus. Therefore, it is the following two features that work together to lead to a low risk of voltage violation of a bus when the DG outputs deviate from the prediction:

- The bus has a low level of voltage volatility;
- The bus voltage is close to 1.0 p.u. when the DG outputs are as predicted.

The first feature is achieved by including the voltage volatility constraint, while the second feature is achieved by a tighter voltage bound. We now go back to the parameter setting for the reconfiguration model in the case study. Since buses 26, 27, 64, 65 have rather low voltage magnitudes and top voltage volatilities in the original network configuration (see Fig. 5 in [1]), we adopt tighter voltage bounds for them to regulate their risk of voltage violation in a more strict manner. As per the discusser's suggestion, we have tested the case when the normal bounds are adopted for these buses (i.e., $V_i^{\min} = 0.95$ and $V_i^{\max} = 1.05$). Fortunately it leads to the same reconfiguration and CB scheme as the case with tighter bounds. Nevertheless, we generally suggest that tighter voltage bounds should be considered for those buses with more strict requirement on the risk of voltage violation. The proper values of those tighter voltage bounds need to be determined by trial and error since the problem may become infeasible when the bounds are too tight.

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4) *The purpose of tighter voltage bounds in problem (20) in [1] and the quantification of the voltage profile and power loss achieved by this problem.* Problem (20) is used to evaluate the minimum amount of extra reactive power that is needed to obtain a satisfactory voltage profile in the traditional reconfiguration scheme, i.e., the voltage profile is similar to the one in proposed reconfiguration scheme. For the DG output scenario given by Table IV in [1], the black curve in Fig. 1 depicts the voltage profile achieved by the proposed reconfiguration scheme. On the other hand, if we apply an extra reactive support to the traditional reconfiguration scheme in the same DG output scenario, which is obtained by taking the normal voltage bounds in problem (20), then the resulting voltage profile is given by the red curve in Fig. 1. This voltage profile is significantly worse than the black curve, where some bus voltages are even slightly below 0.95 p.u. due to the approximation error introduced by the linear DistFlow equation. So in the case study we adopt the tight voltage bounds in problem (20) to achieve the voltage profile given by the blue curve in Fig. 1. By doing so we create an operating case in the traditional reconfiguration scheme that has a very similar control effect to the proposed reconfiguration scheme (the black curve). Hence the extra reactive power required by this case can fairly quantify the performance difference between the traditional reconfiguration scheme and proposed reconfiguration scheme. In addition, we supplement the power loss data in this DG output scenario upon the discusser's request:

- The traditional reconfiguration scheme: 0.0724 MW;
- The traditional reconfiguration scheme with extra reactive support by enforcing normal voltage bounds in problem (20): 0.0705 MW;
- The traditional reconfiguration scheme with extra reactive support by enforcing tight voltage bounds in problem (20): 0.0852 MW;
- The proposed reconfiguration scheme: 0.0394 MW.

It again highlights the merits of the proposed reconfiguration scheme, which achieves the least power loss even without extra reactive support.

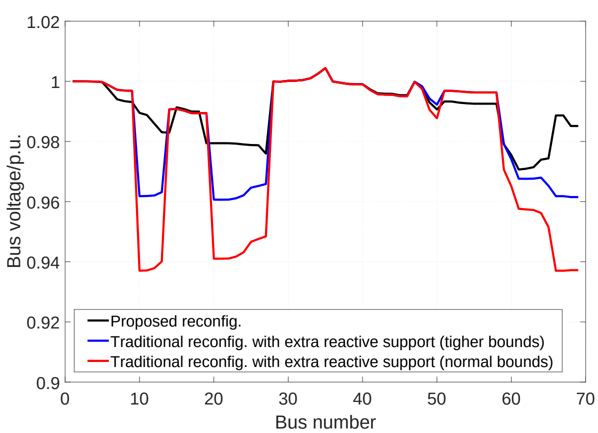

Figure 1. An example graph with negative weighted edges.

Moreover, we would like to note that the original intention of [1] is to reconsider the role of network reconfiguration in the voltage regulation of distribution systems with high renewable penetration. The traditional viewpoint of regulating voltage profile is to compensate the impact of renewable fluctuations by adjusting some control resources. From this viewpoint, network reconfiguration seems inadequate as its slow response may make it impossible to follow up with renewable generation. However, with the voltage volatility index derived using graph theory, we discover a new mechanism for handling renewable uncertainties by reconfiguration. It has been shown that network reconfiguration makes a distinctive contribution to voltage volatility reduction by optimizing the coupling pattern between the buses. We believe that putting more graph theory into the study is a promising way for providing new insights into the operation and planning issues in distribution systems.

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