# Study on Multiple-area Voltage Control Scheme and Tests on WECC System

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## Abstract

The proposed multi-area voltage control scheme is essentially "problem-oriented", which closely follows system operator's philosophy. It divides the network into separate control areas dynamically according to current system conditions. First, the SCADA voltage measurements are checked to decide whether there is any voltage outside a specified band around some "optimal" voltage profile. If any voltage violation exists, the violating buses are located and grouped into separate problematic control areas. In the following simulations, the local control areas are constructed such that the buses within 6 tiers of the control bus are included. The step-size for LTC tap changing is set to one tap at a time and the step-size for generator voltage adjusting is set to 0.01 p.u. The rules for calculating the costs of control actions are same as before, i.e. the cost for switching out a capacitor or reactor bank is zero, the cost for switching in a capacitor or reactor bank is 100.0, the cost for LTC tap changing is 200.0, and cost for generator voltage adjusting is set to 300.0. For any type of device, the cost of next action will increase by 10.0, and decrease by 1.0 at each time step. The control objective is to maintain all bus voltages within 2% band around the pre-defined voltage profile, and the maximum allowed voltage deviation is 5% away from the optimal value. The voltage penalty coefficient $\lambda$ is set to 1.0 and the maximum voltage penalty $P0$ is set to 7.5 for test purpose. The first simulation scenario is that both system experience line outages and/or load variations, thus voltage problems occurs simultaneously in both areas, and then the lines go back to service with load back 75 to normal.

**Key words:** problem-oriented, measurements, simulations, voltage penalty coefficient.

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## Introduction

In general, power system loads are a composite of a variety of electrical devices, For resistive loads, such as lighting and heating loads, the electrical power is independent of frequency. In case of motor loads, such as fans and pumps, the electrical power changes with frequency due to changes in motor speed. The overall frequency-dependent characteristics of a composite load may be expressed as fΔPL is the non-frequency-sensitive load change, Δwhere is the frequency-sensitive load change, and D is expressed as percent change in load divided by percent change in frequency. Substituting the above equation to the previous model (generator model), we get the following block diagram Using transfer function of closed loop can be G(s)/1 + G(s) H(s), the above model can be further simplified as follows [taking G(s) = 1/2Hs and H(s) = D] In the previous sections models for turbine-generator, power system and speed governing systems are obtained. In practice, rarely a single generator feeds a large area. Several generators connected in parallel, located also, at different places will supply the power needs of a geographical area. Quite normally, all these generators have the same response characteristics in load demand. Such a coherent area is called a control area in which the frequency is assumed to be the same throughout in static as well as dynamic conditions.

In such a case, it is possible to define a control area, grouping all the generators in the area together and treating them as a single equivalent generator, i.e for purpose of developing a suitable control strategy, a control area can be reduced to a single speed governor, turbo-generator and load system. Putting together, the carious models derived so far a single control area can be conceived as shown below. The basic requirements to be fulfilled for successful operation of the system are the generation must be adequate to meet all the load demand. The system frequency must be maintained with narrow and rigid limits. The system voltage profile must be maintained within reasonable limits In case of interconnected operation, the tie line power flows must be maintained at the specified values. Should the generation be not adequate to balance the load demand, it is imperative that on e of the following alternatives be considered for keeping the system in operating condition: Starting fast peaking units Load shedding for unimportant loads, and Generation rescheduling The block diagram of single area system, where the gain and time constant in each block are as described in the individual section before, is as shown below.

## Review of Literature

The voltages before any control actions, *VPF* are the voltages after control actions obtained from power flow, *VLVE* are the estimated voltages after control actions given by local voltage estimator, and *VERR* are normalized estimation errors. The total error shown is the summation of the absolute estimation errors on the local buses excluding the boundary buses (tier 3 buses) J. S. Rao, S. S. Nagaraju and P. S. Raju,2007.

From above tables, it can be seen that the estimation errors for most local buses are quite small, especially for those buses in the first tier. The maximum errors usually occur on the boundary buses (tier 3 buses), which may caused by our approximation using a constant α for all boundary buses. The errors could be further reduced by using different parameters for each boundary buses. Also it is observed that the total error increases as 33 the switching capacity increases, which is reasonable due to the linearization model. The results could be improved by extending the computations to say four or five tier local subsystems instead of the three tier networks used in the study Z. Prakash, S. K. Sinha, A. S. Pandey and B. Singh,2009. Estimation of Capacitor/Reactor Switching Effects Under normal operating conditions, capacitor/reactor switching could be treated as nearly constant reactive power injection change which will be distributed along the transmission lines connected to the shunt switching bus and cause the voltage changes on the buses in surrounding area Z. Yukita et al.,2013. Assume that the changes of reactive flow of transmission lines are related only to terminal voltage magnitude changes under normal conditions, the following linearized reactive power line flow equation can be derived, M. P. I. Ahamed, P. S. N. Rao and P. S. Sastry,2013. only transmission line parameters, measurements of reactive power line flow and measurements of bus voltage magnitudes are needed to +calculate those derivatives, thus given the voltage changes at two terminal buses, the change of reactive power line flow could be estimated without running power flow, S. Sijak, O. Kuljaca, L. Kuljaca and S. Tesnjak,2001. Now assume that a small local control area has been formed around the switching capacitor/reactor, let us investigate how reactive power injection change at certain bus is distributed along all the lines connected to the bus.

## Material and Method

The proposed multi-area voltage control scheme is essentially “problem-oriented”, which closely follows system operator’s philosophy. It divides the network into separate control areas dynamically according to current system conditions. The basic control framework is same as the one presented in Section 3.1. The computation procedure of the control scheme is shown in Figure 3.1. First, the SCADA voltage measurements are checked to decide whether there is any voltage outside a specified band around some “optimal” voltage profile. If any voltage violation exists, the violating buses are located and grouped into separate problematic control areas. The grouping is actually achieved by finding the worst violation bus and forming a problematic area that includes several tiers of buses around the bus, then expanding the area diameter 3 times to preventing control interference of neighboring areas. After excluding all busses inside the expanded area, the voltages on remaining buses are checked. If any violation buses exist, a new problematic area is formed around the worst violation bus, and the process is repeated until there is no violation bus. For each problematic area, the best control actions are found by using some optimization algorithms. If there is no control device available, an alarm will be sent to the operator. After issuing switching commands, the voltages after the switching will be compared with their expected voltages. Significant mismatches between expected and actual voltage levels will be reported to the operator via alarms.

Since the standard IEEE 30 bus system is too small to be divided to several control areas, the tests are performed on the WECC system only. Again, the WECC 2017-2018 Winter (case ID 213SNK) planning case is used and modified for test purpose. Except the candidate control devices available in west Oregon area listed in Table, additional devices in area are chosen as candidate control devices and these control devices and their initial settings are listed in Table 1 and Table 2.

| Device Type | Range Setting | Status |
|---|---|---|
| ADDY 230 | 49.1~49.1 | OFF |
| BELL MI 230 | 64.5~64.5 | OFF |
| BONNERS 115 | 11.9~11.9 | OFF |
| COLVE BPA 115 | 13.5 ~ 13.5 | OFGF |
| CUSICK230 | 15.0~15.0 | OFF |
| DEER PRK115 | 15~15 | OFF |
| SAND CRK 115 | 11.9~11.9 | OFF |
| **Capacitor** | | |
| TRENWOD 115 | 25.4 ~25.4 | OFF |
| BOUNDARY230 | 1.009~1.079 | OFF |
| **Generator** | | |
| LIT GOOS 500 | 1.040~1.110 | OFF |

**Table 1** Additional control devices available in Spokane area.

## Conclusion

This control scheme is in general an expansion of the voltage control presented in chapter 3 to handle multiple voltage problems simultaneously. The scheme itself is quite open, in the sense that any voltage control algorithm can be integrated into it for a particular area. For example, if the state estimator has a partial solution, then the model-based controller could be used with minor modification in the areas with valid state estimation solutions, while the alternate controller could be applied to those areas without valid state estimation solutions. Moreover, for those problematic areas with large amount of generators inside, the hybrid multi-phase automatic voltage controller that will be presented could also be integrated into the scheme easily.



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