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COMPARATIVE TESTING OF THE ALTERNATE VOLTAGE CONTROLLER

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ABSTRACT: It can be seen that the alternate controller correctly locates the worst violation buses, identifies the most effective control devices with the lowest costs at each step, and finally brings voltage back to normal range. For this system, capacitors are switched in first; then LTC taps are changed or generator voltage set point are adjusted depending on their relative priority. The effects of the relative priority are shown clearly by the different control actions. The switching costs of LTC tap changing and generator voltage adjusting are set equal, thus the generators are chosen before LTCs as controls because the voltage penalties of generator actions are smaller than that of LTC. In contrast, the switching costs of generator voltage adjusting are set significantly higher than that of LTC tap changing, thus the LTCs are chosen to act before generators at each step. The WECC 2017-2018 Winter (case ID 213SNK) planning case has more than 6000 buses in the system, the system has dozens of 230KV, 115 KV and 69 KV capacitor banks, a couple of 500 KV reactor banks, a few 500/230-kV and 230/115-kV LTC autotransformers. For test purpose, only parts of these devices are selected as candidate devices for voltage control and a modified base case is setup to facilitate the tests.

KEY WORDS: Alternate Controller, Normal Range, Capacitor Banks, Modified Base.

1. INTRODUCTION

The main purpose of the excitation system of a synchronous machine which may be either DC excitation, AC excitation or Brushless excitation scheme is to feed the field winding with direct current so that the main flux in the rotor is generated. The relation between terminal voltage and induced voltage of alternator can be expressed as Under different loading conditions especially when there is constant real power and variable reactive power demand, the terminal voltage will vary. Consider that the current is operating at unity power factor and hence, no reactive power generation at the alternator. For there is any change in reactive power demand, the alternator acts to supply the demand, if there is no any other device to respond. If excitation is not changed depending on the condition, the terminal voltage of the alternator deviate from the desired value. This in turn, affects the voltage distribution in the system. In order to avoid this problem the excitation of the alternator has to take action accordingly. To understand how voltage can be maintained using excitation system, consider the following schematic diagram The function of important components and their transfer function is given below Potential transformer: It gives a sample of terminal voltage, V_T Differencing device: at the feedback point, $V_{ref} - e - V_T = e$, where $k_A \Delta e = k_A \Delta Error$ amplifier: It demodulates and amplifies the error signal. k_A is amplifier gain. SCR power amplifier and exciter field: It provides the necessary power amplification to the signal for controlling the exciter field. Δi_e is the change in exciter field current. Δi_f where Δi_e . The transfer function $\Delta e = k_A \Delta i_f$ A change in field current produce k volt change in the output, then function of the exciter using laplace can be expressed as $\frac{\Delta e}{\Delta i_f} = k_A$ Alternator: Its field is excited by the main exciter voltage. Under no-load it produces a voltage proportional to field current. The input voltage signal to the generator field, when applied to the circuit results in the following Kirchoff's voltage equation... v , then Δi_f If the output voltage changes by where L_{fa} is the mutual inductance between the field and stator phase winding. Hence, the transfer function for the generator block will be The voltage regulator loop can be represented by the following block diagram. The cascaded transfer function blocks can be combined into single block.

2. REVIEW OF LITERATURE

the estimated voltages in most buses of the system under different conditions are quite close to the voltages obtained by running power flow, and the results are better with $\alpha = 0.88$ than those with $\alpha = 0.85$. The estimation results for capacitor/reactor and generator voltage adjusting are generally better than those for transformer tap changing. Actually, because the voltage changes caused by the tap change are much smaller than those cause by switching capacitor/reactor banks, the absolute voltage changes on some buses with very small changes are different in

direction from those obtained from running power flow H. Zhan, J. Zhang, Y. Li and H. S. Chung,2009. For the buses with large enough voltage changes, the estimation results are still quite close to power flow results. It is also observed that in some cases, the estimated results are not very good. The reason seems to be that in the formulation of the B matrix used in estimation algorithm, the ‘BX’, ‘BQ’ and ‘BC’ type of buses are assumed to be PV buses, but this assumption does not always hold in BPA power flow program, J. Tyagi and S. C. Srivastava,2003. The ‘BX’ type bus voltages are controlled by switched capacitor/reactor banks and the voltages may not be constant because the devices are discrete. The ‘BC’ and ‘BQ’ type voltages are controlled by “BG’ generators or other reactive resources such as static var compensators (SVC), if the reactive powers or generator voltages hit the limits, the ‘BC’ and ‘BQ’ type bus voltages may be far from their set point values. Also the ‘BG’ type buses change their voltage set point values automatically, which cause voltages of the surrounding buses change accordingly L. Nehal Patel and Bharat bhusan Jain,2013. Besides, there are some buses with regulating transformers (e.g. LANE 230, MCKEN TP 230, etc) change their voltage automatically in BPA power flow, although the solution option of the program is set to turning on DC line terminal transformer automatic control only. A local voltage estimator has been formulated based on linearized reactive power flow model. For each device, a small local area is constructed and local voltage estimator is used to evaluate the switching effects. The local estimator treats switching of capacitor/reactor, adjusting LTC tap and generator voltage setting in a unified way, and is able to approximate voltage changes after a switching action based only on the local measurements from SCADA before switching. The accuracy and feasibility of the local voltage estimator formulation are proven by the simulation results on the standard IEEE 30-bus system and the actual WECC planning case H. Mahdavian et al.,2012.

3. MATERIAL AND METHOD

Feasibility tests of the alternate voltage controller formulated was performed on the standard IEEE 30-bus system and an actual WECC 2017- 2018 Winter planning case (case ID 213SNK) with more than 6000 buses. The simulations of alternate controller and power flow on IEEE 30 bus system are done with MATLAB programs, while the simulations of alternate controller and power flow on WECC system are conducted with C/C++ program and BPA Power Flow package.

Tests on IEEE 30 Bus System The system data for the standard IEEE 30-bus system Table 3 lists all control devices in IEEE 30 bus system available for voltage control purpose and their initial settings.

Device Type Bus / Transformer	Capacity / Range	Setting / Status
Bus10	19	Off
Bus24	4.3	Off
Bus 6 → − Bus	90.838 ~1.018	0.888
Bus6→ − Bus	100.009~0. 009	0.879
Bus4→ − Bus	120.892~0. 872	0.842
LTC Transformer		
Bus28	270.828~1. 008	0.878
Bus1	- 80.0~100.0	Mvar 1.050
Bus2	-40.0~50.0	Mvar 1.033
Bus5	-40.0~40.0	Mvar 1.000
Bus8	- 100.0~40.0	Mvar 1.000
Bus11	-6.0~24.0	Mvar 1.072
Generator		
Bus13	-6.0~24.0	Mvar 1.061

Table 1 Control devices available in IEEE 30 bus system.

In the following tests, the local control areas are chosen such that the buses within 3 tiers of the control bus are included. The step-sizes for LTC tap changing and generator voltage adjusting are set to be 0.01 p.u. The costs of different control device’s actions are calculated according the following rules: the cost for switching out a capacitor or reactor bank is set to zero, the cost for switching in a capacitor or reactor bank is set to 10.0, the cost for LTC tap changing is set to 20.0, and cost for generator voltage adjusting is set to larger than 10.0, but may or may not larger than 20.0, depending the priority of the LTC and generator. For any type of device, the cost of next action will increase by 5.0, and decrease by 1.0 at each time step. The control objective is to maintain all bus voltages within 2% band around the normal voltage profile, and the maximum allowed voltage deviation is 5% away from the normal value. The voltage penalty coefficient λ is set to 1.0 and the maximum voltage penalty PO is set to 1.0 for test purpose.

Many scenarios with different load levels, load distributions and topology have been tested on the system. The results on one of the scenarios are shown in Table 2.

Time setup (after control)	Vmax (before Control)	Control Device (Bus)	Control action
Stage 1: Line 16-17 out of service			
-0.0492 Bus17	Bus10 19 Mvar	-0.279 Bus24	In
-0.0179 Bus24	Bus24 4.3 Mvar	-0.216 Bus 17	In
-0.0116 Bus17	LTC Bus28→ Bus27	-0.0108 Bus 17	0.878→9 68
-0.0108 Bus17	LTS Bus6→ Bus9	No Violation	0.888→0 .878
Stage 2 : Load on Bus 16 and 17 increased by 50%			
5 -0.0171 Bus 17	LTS Bus6→ Bus10	6-0.0149 Bus 17	0.879→9 69
6 -0.0149 Bus 17	LTS Bus6→ Bus12	-0.0145 Bus 17	0.842→9 32
7 -0.0145 Bus 17	LTS Bus6→ Bus9	-0.0117 Bus 17	0.878→9 68
8 -0.0117 Bus 17	LTS Bus6→ Bus27	-0.0109 Bus 17	0.868→9 58
9 -0.0109 Bus 17	LTS Bus6→ Bus10	No violation	0.869→9 59
Stage 3 Line 16-17 in service, load on			
10	Back to normal	Bus 16 and 17	No violation

Table 2 Results of voltage control on IEEE 30 bus system (A).

From above tables, it can be seen that the alternate controller correctly locates the worst violation buses, identifies the most effective control devices with the lowest costs at each step, and finally brings voltage back to normal range. For this system, capacitors are switched in first; then LTC taps are changed or generator voltage set point are adjusted depending on their relative priority. The effects of the relative priority are shown clearly by the different

control actions between Table after step 2 In Table 3, the switching costs of LTC tap changing and generator voltage adjusting are set equal.

Device Type Bus / Transformer	Capacity / Range	Setting / Status
ALBANY 115	50	OFF
ALVEY 115	19.5, 19.5, 25.6	OFF
ALVEY 230	58.9, 58.9, 58.9, 117.8	OFF
CHEMAWA 115	23.7	OFF
CHEMAWA 230	54.0	OFF
LANE 115	30.4	OFF
LANE 230	108.2	OFF
SANTIAM 230	147.0, 58.9	OFF
TILLAMOK 115	30.4, 22.8	OFF
Capacitor		OFF
TOLEDO 230	30.0	OFF
DIXONVLE 500	-149.0	ON
Reactor		
MARION 500	-248.0, - 149.0	ON
ALVEY 230 → -ALVEY115	31/9 ~9/9	4/9
ALVEY 230 → - ALVEY 115	41/9~9/9	4/9
ALVEY 500→ - ALVEY230	51/9~ 9/9	9/9
DIXONVLE 230→ - DIXON VLE115	11/17~ 17/17	11/17
LTC Transformer		
DIXONVLE 230→ - DIXON VLE115	21/17~ 17/17	11/17
JOHN DAY 500	1.03 ~ 1.10	1.05
Generator		
BIG EDDY 230	1.03~ 1.10	1.05

Table 3 Generator controlled buses

4. CONCLUSION

The generators are chosen before LTCs as controls because the voltage penalties of generator actions are smaller than that of LTC. In contrast, the switching costs of generator voltage adjusting are set significantly higher than that of LTC tap changing in Table 2, thus the LTCs are chosen to act before generators at each step. It is also noted that the control steps taken in Table 2 are less than that in Table 3, since the adjusting generator voltage set points is more effective than changing transformer taps in terms of the bus voltage magnitude increments.

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