

THE IMPACT OF AUTOMATIC SHUNT SWITCHING ON VOLTAGE STABILITY

HOW DO DIFFERENT TIME SETTINGS IN AUTOMATIC SHUNT SWITCHING SCHEMES AFFECT VOLTAGE STABILITY?

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ABSTRACT

This article is a summary of the master thesis "Extremspänningsautomatikens inverkan på spänningsstabilitet". The thesis is a pilot study on what impact different strategies for automatic switching of reactive shunts have on voltage stability in an electric power system. A dynamic analysis has been performed through real-time simulations in ARISTO¹ on the NORDIC32-svedala system. This article covers three of the seven different switching strategies that were examined in two different but common scenarios typical for the Nordic power system.

It is shown that the time settings of individual automatics have an impact on overall system performance and that quick action is crucial in situations where voltage collapse is imminent. It is also shown that, by letting the automatics take voltages at adjacent buses into account, the collapse can be avoided completely.

INTRODUCTION

Power system stability is one of the main focus areas for system operators all around the world. Historically transient stability has been the main issue, but with increasing demands such as increased transfer capacity, energy efficiency and renewable production other problems have emerged. Due to these circumstances problems with voltage stability is usually the main reason behind the limiting of transfer capacity in the Swedish power grid.

The voltage in the Swedish transmission grid is monitored by the TSO² Svenska Kraftnät

from the national control center in Stockholm. The control of the voltage is mainly automatic through AVR's³ on synchronous generators and compensators and SVC's⁴ but also includes manual and automatic switching of reactive shunts.

The size of the shunts in the 400 kV transmission grid are typically between 100-200 Mvar, which corresponds to an ability to change the voltage 4-6 kV depending on operating conditions. The scheme of switching is set with fixed voltage thresholds and fixed time delays. In switchyards where there are more than one shunt installed the scheme is to connect shunts one at a time in a predetermined order. To do this the delays are differentiated by a second in-between each connection, see Figure 1.

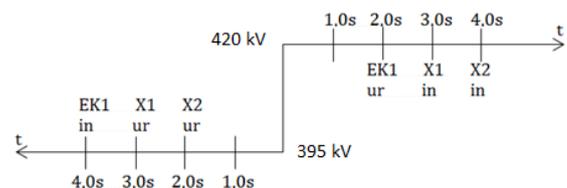


Figure 1. Connection scheme for a bus with three shunts, where the rated power of X1 is lower than that of X2.

OBJECTIVE

The main objective of this work is to determine whether there is incentive to change settings of the current switching scheme and what gains this would bring in terms of safety margins or transfer capacity.

METHOD

The literature study covered voltage stability and the use of reactive shunts.

¹ Advanced Real-time Interactive Simulator for Training and Operation.

² Transmission System Operator

³ Automatic Voltage Regulator

⁴ Static Var Compensator

Different strategies for automatic switching were proposed by SvK and through discussions and interviews with experienced engineers decisions about implementation were made. The different automatic schemes were then implemented in ARISTO where dynamic analysis was performed through real-time simulations in the NORDIC32-svedala system seen in Figure 2. Two different scenarios were simulated and the different strategies were evaluated.

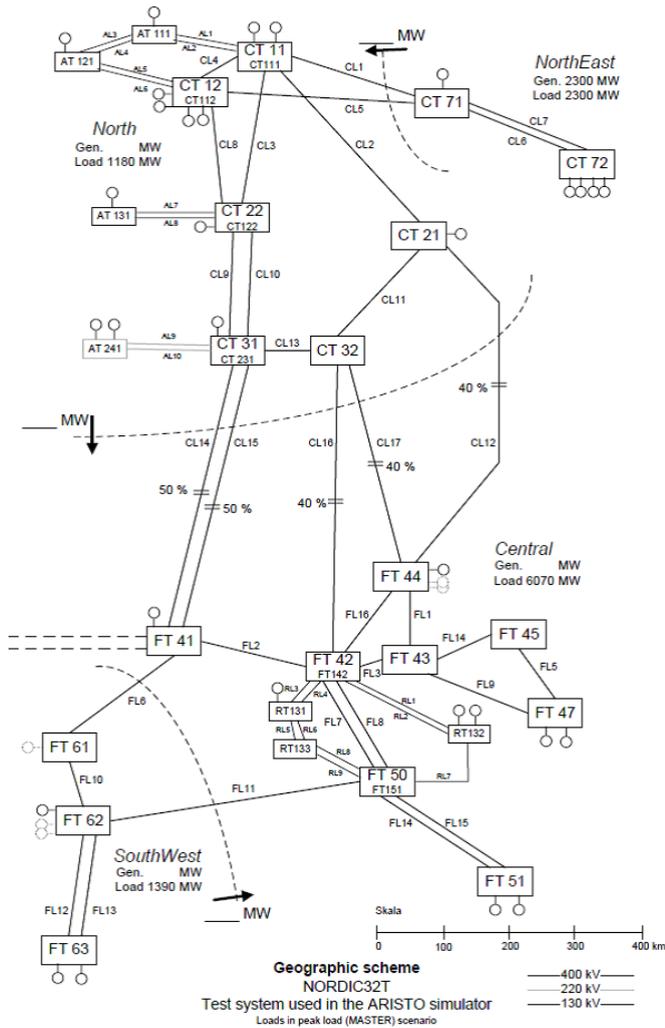


Figure 2. Net diagram for the NORDIC32-svedala system.

SCENARIOS

As previously noted two scenarios were defined. The first one concerns problems with voltage stability and illustrates the gains of a more aggressive switching strategy. In this scenario, referred to as winter, the system is heavily loaded with high transfers from north to central. The trip of a production unit in the central area sets the strained system on a path towards voltage collapse.

The second scenario concerns automatic line reclosing and shows that the gains from the aggressive strategy in the previous scenario now cause serious problems. In this scenario, referred to as summer, lots of production units in the central parts are taken out of service. This means that even though the system load is not heavy there is high transfer from north to central. The most heavily loaded line experiences a short circuit and the line is disconnected by the distance protection. The fault is temporary and the automatic line reconnection 500 ms after the disconnection is successful.

AUTOMATICS

The standard implementation of the automatics described above was used as a reference during simulations. This strategy, referred to as *A*, was also modified, as seen in Figure 3, to examine the advantage of shorter time delays.

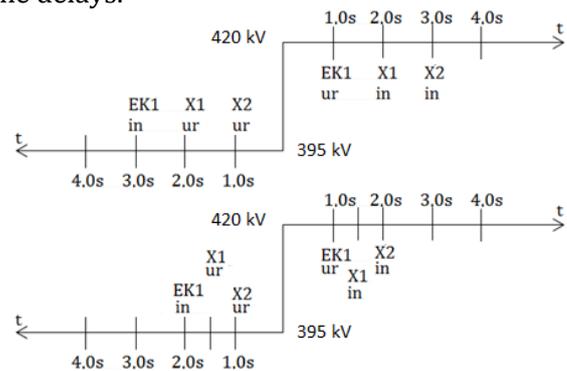


Figure 3. Variations of the standard automatics strategy.

Another strategy designed for fast action, referred to as *C*, was also implemented and tested. By using a fixed voltage threshold and a voltage-time area as limit fast action could be achieved. The area is calculated as a continuous sum of voltage snapshots. If the area, seen in Figure 4, exceeds the limit the first action will be taken.

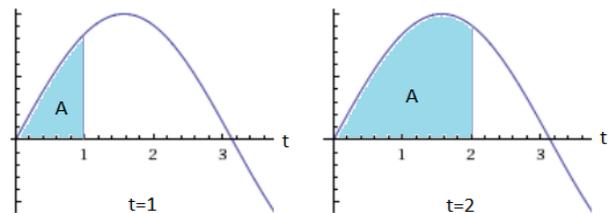


Figure 4. Example for voltage-time area limit.

As in the previous case the automatics was modified to examine the gain of a more

aggressive strategy. This corresponds to limits of five, four and three kVs before action. The last strategy presented, referred to as *F*, is an extension of strategy *A* where voltages at adjacent buses, see Figure 5, are taken into account. This means that the automatics cover a wider area and compensates for low voltages at buses without automatic switching.

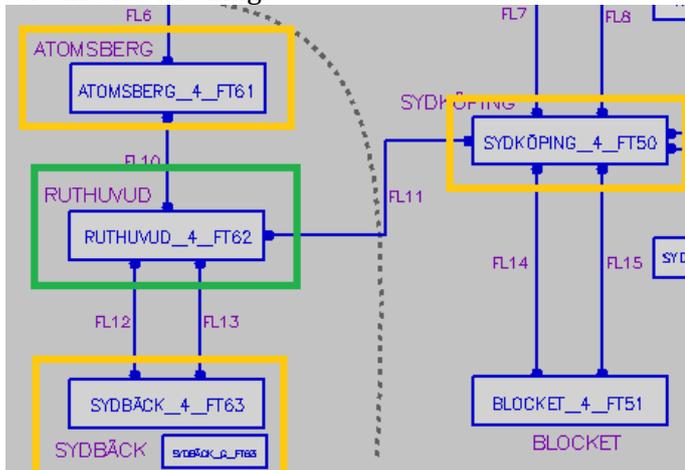


Figure 5. The automatics in Ruthuvud take the voltages at all adjacent buses into account for connection of the shunts.

To primarily use local resources for compensation (when both adjacent buses have automatic switching) the switching for adjacent bus is delayed by 750 ms, see Figure 6. Three variations of *F* were done in the same way as *A* to examine the advantage of shorter time delays.

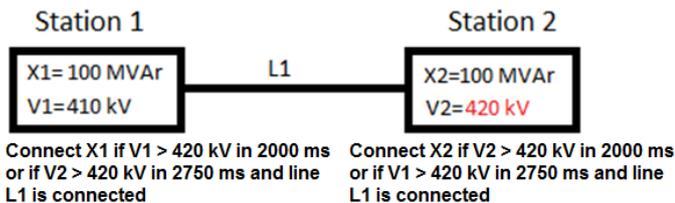


Figure 6. Automatics act if the voltage at an adjacent bus is unacceptable and the line is connected.

RESULTS

The result for simulations with automatic *A* during the winter scenario, seen in Figure 7, shows that decreasing the time delays has a positive impact on system endurance. The collapse is delayed by several minutes due to the quick action of the shunts.

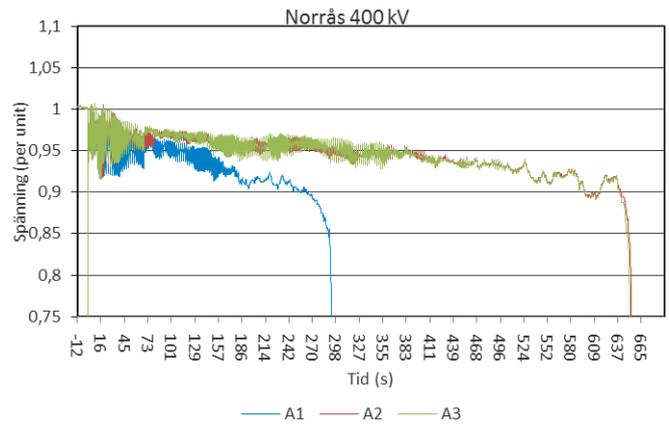


Figure 7. The 400 kV voltages in Norrås during the winter scenario with variations of *A*.

In the summer scenario the strategy takes no action, as seen in Figure 8. This is positive since a connection of shunts is unnecessary due to the temporary short circuit.

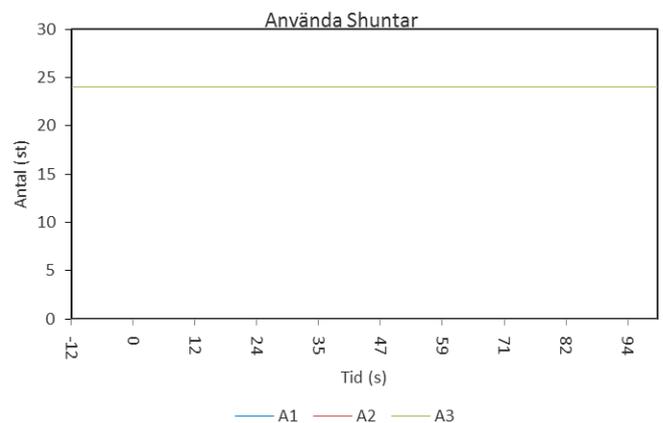


Figure 8. Number of actions for shunts in the system during the summer scenario with automatics *A*.

The results with automatics *C* in the winter scenario are even more promising. Since the initial fault is large there is a quick response from the automatics, as seen in Figure 9. For the limits of 5 and 4 kVs the collapse is delayed by a half minute. With the third limit (3 kVs) the endurance is drastically improved and the collapse is delayed by 35 minutes.

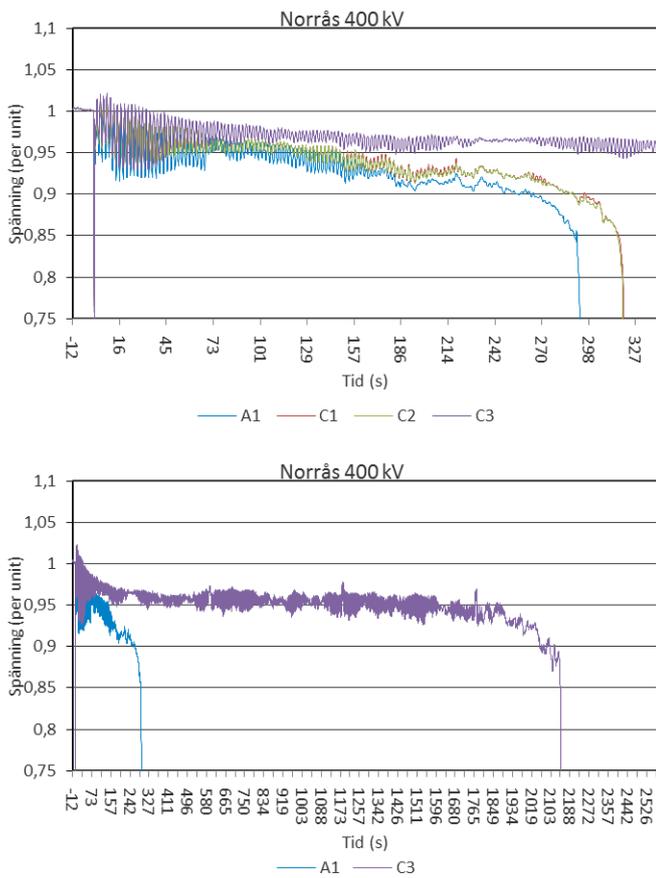


Figure 9. The 400 kV voltages in Norrås for the **C** automatics and reference **A**.

For the summer scenario the results are less promising. Due to the increased sensitivity the automatics initiate over 200 switching actions for the 5 and 4 kVs limits, as seen in Figure 10, all of which are unnecessary. For the 3 kVs limit the number of switches sums up to 273.

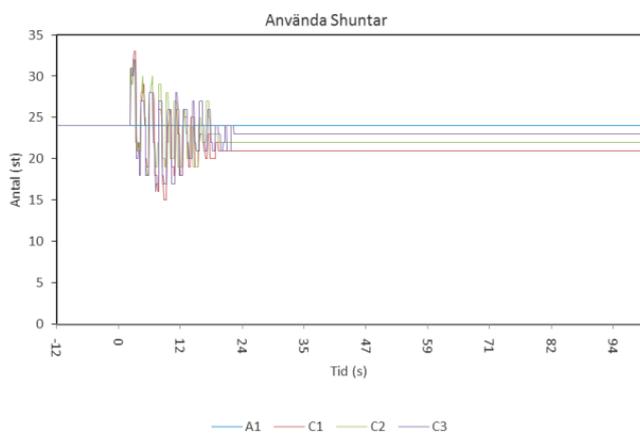


Figure 10. Number of actions for shunts in the system during the summer scenario.

During the winter scenario automatics **F** prevent the voltage collapse, see Figure 11. This is done through early switching (prior to fault)

caused by low voltages in adjacent buses. Due to the automatic actions the system have a larger, 300 Mvar, reserve of reactive power already in place when the fault is applied. This limits the need of tap changer actions and the voltage stabilizes at 0.97 pu.

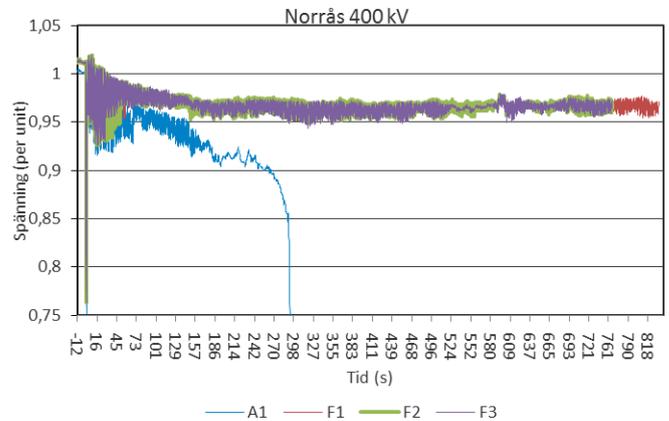


Figure 11. The 400 kV voltage in Norrås for automatics **F** and reference **A**.

For the summer scenario automatics **F** introduces some early actions as well. These connections cause tap changers to take action to decrease voltage and when the fault is applied these changes causes some extra switching's as seen in Figure 12.

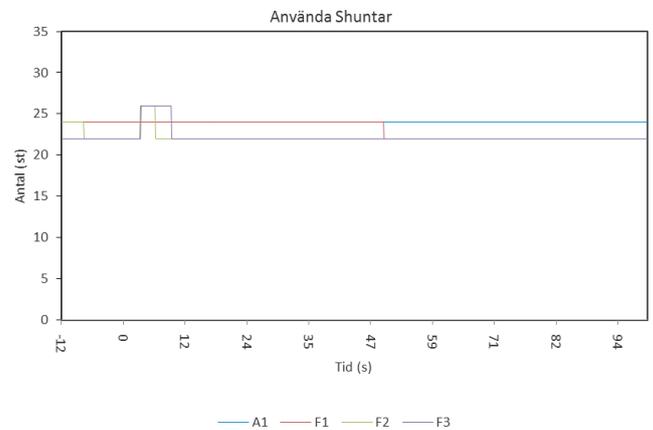


Figure 12. Number of switching actions for automatics **F** in scenario **S**.

CONCLUSIONS

As we can see from the results with **A** in the winter scenario a short time delay is positive for system endurance without any unwanted actions in the summer scenario.

By just decreasing the delay a little the probability for shunt connection is increased. This possibility of improvement is an easily understandable way of improving the efficiency without increasing complexity of the system.

This is also preferable since control center personnel needs to understand the reason behind switching to evade unnecessary outages.

From the results with automatics **C** we can see that an aggressive strategy is efficient in stressed situations. But at the same time interferes with other protection systems and due to this cause unwanted action. During a normal year the automatic shunt switching acts from 10 to 20 times in the Swedish transmission grid. From this we can conclude that 200 actions during a couple of seconds are definitely not good. The 200 actions are possible due to the equipment models in the simulator. In reality the energy in the breakers would last only for 2-3 consecutive before they need to be reenergized. This aside a control scheme introducing this kind of behavior is not desired.

From the results with automatics **F** we see that the system in the winter scenario can be saved. In this case through early action and an extended voltage control area. This shows the importance of high voltages throughout the system and the need of active use shunts for system stability. In the summer scenario automatics **F** introduces some extra switches but these are not directly linked to the fault itself and can probably be avoided by changing the delays.