AUTOMATIC REACTOR HUNTING AVOIDANCE DURING POWER SYSTEM RESTORATION

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Introduction

Nowadays, Electric power systems are one of the basic parts on which actual society and economy are based. Our society extremely depends on the secure and consistent electricity supplies, being the main support of current industrial, economical and social activities. Furthermore, this dependence is becoming stricter as the society progresses.

However, power systems are very complex systems, which are vulnerable to faults of different nature due to high number of variables. The frequent danger that threats the complete availability of power are the large scale blackouts, occurred in case of lightning, natural disasters, operator's errors, technical faults and so on. A large scale blackout has a critical impact on society, since electrical energy is inaccessible in the electric power grid and thus the economy is forced to stop.

As far as the Swedish power system is concerned, it is characterized by long high voltage transmission lines connecting North of Sweden, which has the large percentage of the power generation in the country, to central and southern parts of Sweden where the power consumption is concentrated. In consequence, due to this system topology, the risk of voltage collapse at the central or southern parts of the country is an inherent feature of the Swedish system.

The ideal situation for a reliable power supply would be to prevent the system from any blackout. However, blackouts may occur and it is impossible to predict when. Hence, power system restoration must be considered as a critical issue for Transmission System Operators (TSO). One of the main objectives of TSOs is to perform a power system restoration as fast and safely as possible, in order to minimize the duration of the blackout.

During the restoration after the blackout in Sweden and Denmark on 23 September 2003, a particular problem appeared and increased the restoration time, known as reactor hunting. This project is focused on studying this phenomenon: its causes and its effect, and also ways of avoiding it in order to reduce the restoration process.

Reactor Hunting

The restoration strategy after a blackout starts with long transmission lines being energized. This leads to high voltage at the end of transmission lines due to the Ferranti effect.

In order to reduce the voltage, shunt reactors are connected to the system. Shunt reactors are devices that are used to control the voltage in transmission lines and are controlled by what is called Extreme Voltage Automatics (EVAs).

The EVAs have a tolerance band which defines the behaviour of the shunt reactor. The tolerance band has an upper and lower voltage limits and the objective is to maintain the voltage level within these limits.

If the voltage is above the upper limit of the tolerance band, the EVAs connect the reactor shunt; and on the other hand disconnect it if the voltage level is below the lower limit.

It is important to note that, during restoration, the power system is weak. Thus, connecting the reactors will probably produce critical low voltage (below the lower limit), then the EVAs will turn off the reactor again, returning the voltage to the high level. The reactor will therefore cyclically connect and again disconnect.

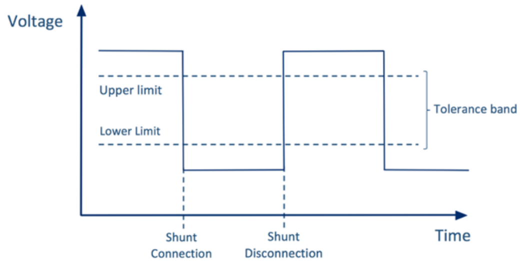

Figure 1. Reactor Hunting phenomenon.

This phenomenon is called reactor hunting (figure 1), which produces large voltage fluctuations between high and low voltages outside the tolerance band. Thus it has a negative effect on the power system and needs to be handled as quickly as possible in order to prevent these fluctuations and possible damages.

Adaptive Tolerance Band Method

The conventional procedure for TSOs to avoid reactor hunting is to deactivate the automatics during restoration time. This leaves the shunts in manual operation, which leads to a longer restoration process.

It is almost straightforward to imagine that an automatic method for reactor hunting avoidance will be faster than manual operation and the restoration time will suffer an important decrease, which will be beneficial in blackout restoration.

This project presents a proposal for real time automatic reactor hunting avoidance founded on the "Adaptive tolerance band" concept, which adapts the EVAs behaviour based on the network strength. This new control scheme uses short circuit capacity to predict the voltage drop after shunt reactor connection and then adjusts the lower limit of the tolerance band in order to maintain the voltage within the limits and prevent reactor hunting from happening (figure 2).

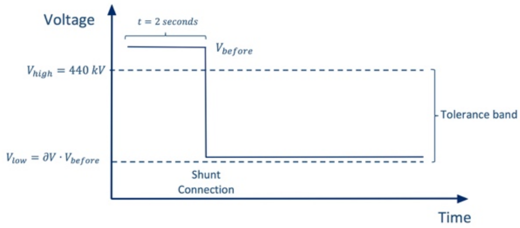

Figure 2. Adaptive tolerance band method

The important thing of this methodology is that it predicts the decrease in voltage after shunt connection. If the prediction is accurate, the lower limit will be adjusted precisely so any other external alteration of the voltage still can be detected by the automatics.

In addition, the voltage drop prediction allows to detect if an extreme low voltage will be encountered after shunt reactor connection, so it can be decided either to carry on with the restoration or take other paths, or take additional measures to control the voltage.

Methodology

The core of the project was to implement this technique in a program which is able to perform a restoration process from an initial blackout scenario avoiding reactor hunting in real time with the automatic adaptive tolerance band method. The program allows the user to select any restoration path possible.

Since the adaptive tolerance band is based on the network strength, the program is designed to calculate the Short circuit power from the Thévenin impedance of the specific point of the network for each restoration stage. This Thévenin impedance is calculated from the bus impedance matrix.

The bus impedance matrix represents the actual strength of every point of the system for any particular time, so it is useful for the purposes of this project and also for other applications, such as short circuit faults, protection device design, etc.

In order to test the viability of the idea presented, this project was done in a computer and simulation environment. The NORDIC32 system, which is a simplified model of the Nordic electric power system was used for this project

ARISTO was used for power system simulation. The real-time Reactor Hunting avoidance was developed in the MATLAB programming environment and the communication between both was done by AMCX communication tool.

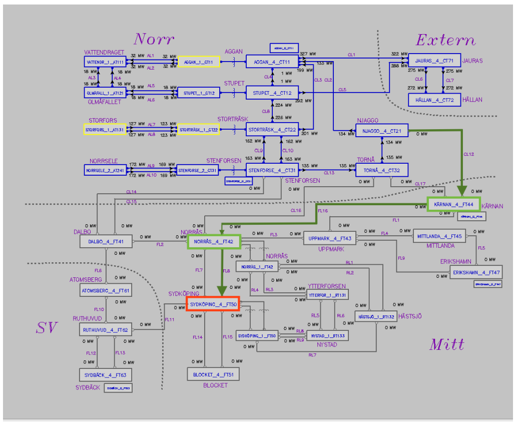

Figure 3. NORDIC32 test system in ARISTO simulator. Restoration path 1.

Simulations with two different restoration paths (one of them is presented in figure 3), starting at the same initial southern blackout scenario, will prove the effectiveness of the method proposed in the project for reactor hunting avoidance and will show the reactor hunting phenomenon before and after avoidance.

Results

Two different restoration paths are simulated with the program developed. Both paths encounter Reactor hunting at the last stage of the restoration process, which is the same bus.

Restoration path 1

The upper graph of figure 4 shows the voltage profile (black colour), without applying Adaptive tolerance band, of the connection of the last bus in the restoration process. The lower graph applies the Adaptive tolerance band method. The upper and lower limit of the tolerance band are represented in blue and red colours.

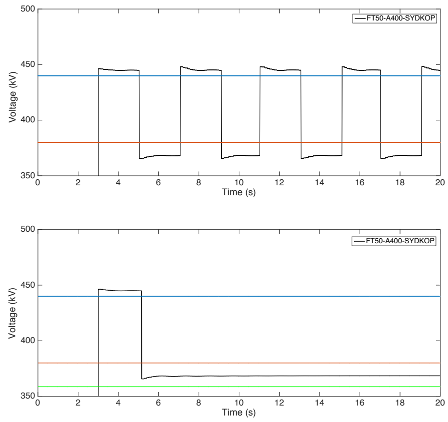

Figure 4. Restoration path 1. Reactor Hunting (upper) and Adaptive tolerance band implementation (lower).

As it can be seen, Reactor Hunting appears in the first situation. The bus is weak, and the voltage drops below the tolerance band after the shunt reactor connection. On the other hand, by adjusting the lower limit of the tolerance band (green colour), the voltage stays within the new limits and there is no reactor hunting.

Restoration path 2

Figure 5 represents the same simulation as figure 4, but for restoration path 2.

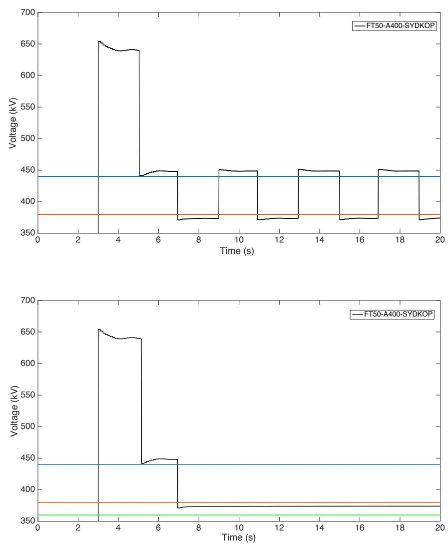

Figure 5. Restoration path 2. Reactor Hunting (upper) and Adaptive tolerance band implementation (lower).

As it can be seen, the voltage rise after the bus connection is higher than the previous case. The first shut reactor connection is not enough to decrease the voltage to levels within the tolerance band limits. In consequence, a second reactor shunt must be connected. This reactor shunt is smaller, but the bus is weak so the voltage drop is large enough for reactor hunting to happen (upper graph). Adaptive tolerance band method avoids reactor hunting again (lower graph) by adjusting the lower limit of the tolerance band.

Conclusions

As a result of the project, it is stated that the adaptive tolerance band method for reactor hunting avoidance is useful, and the program developed proves this idea after the simulations with the NORDIC32 test system.

The program accurately implements "Automatic Adaptive Tolerance band method" for Reactor Hunting phenomenon in real time. The program allows the user to select any restoration path and the results are displayed on the screen.

The program is adjustable for any initial situation or electric power system model, so it is possible to simulate the reactor hunting avoidance in every possible scenario by configuring the database of the program.

In addition, although the program is designed specifically for the ARISTO simulator, the methodology is exportable and adjustable to any system and any simulator, being possible to export it to a real power system.