Optimizing Control of a Power System during an Emergency

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Abstract

Demografi, infrastructure and economy puts pressure and demand on existing power supplies. When this demand is not met, it leads to strains on the electric power system which in turn causes instabilities such as voltage instabilities. This ongoing challenge needs a sustainable solution. By modelling a small power system in a programming language called Matlab, the maximum power demand that this virtual system can handle is computed.

1. Introduction

The Swedish power system is an example of an electric power system. Most of the power is produced in Northern Sweden while the demand is highest in South. The long distance which the power is transfered, is likely to increase the sensitivity to contingencies in the system and impede recoveries after faults. A memorable power system failure in the Swedish network, was the terrible blackout in Southern Sweden which took place the 23rd of September, 2003. Approximately, 1.5 million people were without any electricity for up to 5 hours [2014]. The two main triggers of this horrible event, were an internal fault in the nuclear power plant at Oskarshamn and a switchyard failure at Horred close to Varberg.

Two ways of preventing blackouts are by; 1) reinforcing the system by building new lines, 2) control actions which is regarded as less expensive and used in this study.

The aim of the study is to find the maximum possible pre-contingency load (the load before a contingency i.e. before a fault) for a power system subjected to a fault. While searching for the maximum power consumption before a fault occurs, certain limitations and system behaviors are implemented to have a more realistic event.

2. Methods

All computations are conducted on a system called the *Seven-Node System*, see Figure 1 taken from [Karystianos et al., 2007]. The system has seven connecting points, also known as nodes, three generators $P_{g,1}$, $P_{g,2}$ and $P_{g,3}$ at node 1, 2 and 3. A load and a capacitor (B) are connected to node 4. The connections between the nodes are called lines. The system components were approximated to increase the possibility of finding the maximum pre-contingency load by using Matlab.

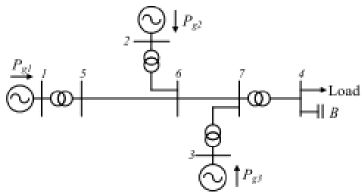

Figure 1: *An example of a power system from [Karystianos et al., 2007]. The power system consists of three generators P_{g1},P_{g2} and P_{g3} that are connected to the network via transformer. The transformers are positioned between busbars 1-5, 2-6, 3-7 and 4-7. The load and the capacitor (B) are in parallel and connected to busbar 4.*

The following models are used[1]:

- A line model without active power losses.
- A dynamic generator model with automatic voltage regulator (AVR)[2]. The AVR has a saturation point.
- The load recovery is either a time dependent linear load recovery model or a time dependent exponential load recovery model.

An important link, is the coupling between the reactive power and the voltage level at a node. A lack of reactive power at a node will result in a low voltage, forcing the load to be low and the power demand unsatisfied. This will lead to voltage instabilities which might eventually cause a blackout. So when searching for the maximum load the system has to remain voltage stable. A way of examining the voltage stability of a system is via the *Nose Curve* which can be read in the full report.

The Seven-Node System is subjected to a fault in line 5-6. Immediately, the load power and the load voltage decrease and the system will try to recover the load to meet the intitial power demand. This is illustrated in Figure 2.

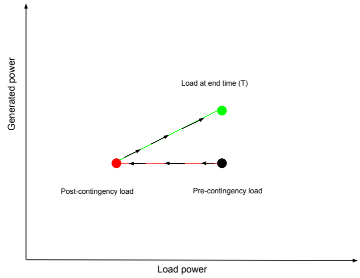

Figure 2: *Events in a power system subjected to a fault and the recovery path. The load power is on the horizontal line and the generated power is on the vertical line. There are three dots, a black dot representing the load before the fault, a red dot for the load right after the fault and a green dot representing the fully recovered load power. The load recovery is linear in this figure but can also be exponential.*

By setting up an optimization problem[3], the maximum possible pre-contingency load can be found, where the system is subjected to a fault. The system has to maintain stability during and after recovery. The optimization is done for different values of the generators $P_{g,2}$ and $P_{g,3}$.

[1] More details about the simplifications are found in the complete report.
[2] An automatic voltage regulator (AVR) is a device which automatically maintains a constant voltage level at a node.
[3] An optimization problem is a mathematical problem where one wants to find the maximum or minimum values of a variable while including constraints.

3. Results

The maximum pre-contingency load with a linear load recover model, can be studied in Figure 3, while the maximum pre-contingency load with an exponential load recover model is seen in Figure 4. The two horizontal axis are of the generated power from generator 2 and 3, and the load power is represented on the vertical axis.

The maximum possible pre-contingency load is found in most cases with both load recovery models (linear and exponential load recovery models). The optimization results are highest when the generated power from both the generators are approximately 1.5 p.u. each, i.e. in the middle of Figure 3 and 4.

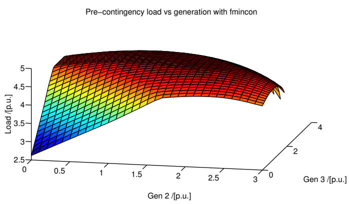

***Figure 3**: Pre-contingency load with linear load recovery model.*

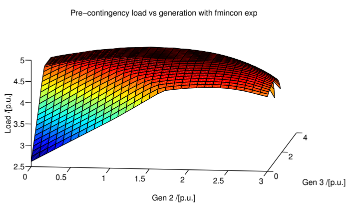

***Figure 4**: Pre-contingency load with exponential load recovery model.*

4. Conclusions

As observed, the pre-contingency load is highest when the generated power from generator 2 and 3 are approximately 1.5 p.u. each. The high results might be due the equilibriums found at those power values which allow high pre-contingency loads.

An important detail during optimization, is the initial values. The initial values will affect the results of the optimization and may even determine whether a solution is feasible or not.

Finally, the most important conclusion is that a maximum pre-contingency load can be found by using Matlab, simplified models of system components and time dependent load recovery models.

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