The ABB Medium Scale Power Transmission Test Case

Mats Larsson
Corporate Research
ABB Schweiz AG
mailto:Mats.Larsson@ch.abb.com

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1 Introduction

This report describes a test case intended for control synthesis and analysis of hybrid systems. It is the third test case developed in the EU project in the Control and Computation project (IST-2001-33520). The first two test cases concentrated on the introduction and illustration of the basic driving dynamics and hybrid aspects of the emergency voltage control problem using small test systems. This has enabled various research groups to test their ideas and their applicability in this application domain. These cases exhibit continuous non-linear dynamics resulting from load recovery dynamics. The discrete dynamics result from tap changer controllers and generation capability limits as well as the switch characteristics of the the emergency control at our disposal. For a review of these phenomena, readers are recommended to review the two reports for the previous test cases Larsson (2002a,b).

However, in reality power systems are typically large and consists of many generators, lines and customer load centres. This test case takes a step toward power systems of more realistic size, by combining several components. Compared to the smaller test cases, the dynamics become much richer and it is possible to study also interactions between components in the different areas.

The computer implementation of the test system is available as Modelica code as well as SIMULINK SimStruc.

2 Modelling and Implementation

The basic power system contains three areas Figure 1. For simplicity, the three areas are identical with the exception of certain parameter values and that the generator in Area 1 has infinite capacity, whereas the two generators in Areas 2 and 3 are modelled with capacity limitations for the voltage controllers. The generator in Area 1 models a strong network to which the network portion under study is connected and the two other generators represent physical power plants. The three areas are connected with three double tie lines modelling a transmission. As the main disturbance we will model outages of these lines. In each area there is a meshed subtransmission system consisting of three lines feeding a distribution system consisting of a transformer with an automatic tap changer controller.

The models have been implemented in Modelica (Tiller, 2001). See the source code and its HTML documentation for a detailed information about the implementation of the various component models.

Figure 1 shows how the power system models has been modelled in Modelica and exported as Simulink DLL files:

`openloop.dll` is a file containing the continuous dynamics of the power system. It is a nonlinear system with three dynamic states.

`primarycontroller.dll` is a file containing the models of typical primary controllers for the transformers and the generators. It has only discrete dynamics. These control systems has been described in detail in Larsson (2002a).

`primarycontrolled.dll` is the combination of the two previous subsystems as shown in Figure 1. The main task of this benchmark problem to design a secondary controllers that can stabilize this system.

The Primary controlled system has the following inputs:

- CapStep–a 3x1 integer vector that can take the values [0,1] corresponding to off/on for the capacitors in areas 1, 2 and 3, respectively.
- LoadStep–a 3x1 integer vector that can take the values [0,1,2] corresponding to shedding of 0, 10 or 20 % of load in areas 1, 2 and 3, respectively.
- TapVref–a 3x1 continuous variable that can take values in the interval [0.9..1.1] corresponding to the setpoints of the voltage regulators of the tap changer controllers in area 1, 2 and 3, respectively.

In addition there is a disturbance input (which can be assumed measured):

- Faulted–3x1 integer vector that can take values [0,1,2] corresponding to outage of none, one or both of the lines connecting the areas. The first vector position is for the lines between areas 1 and 2, the second for the lines between areas 2 and 3 and the third entry is for the lines betweeen areas 1 and 3.

There are four output vectors assigned:

- V – a 8x1 vector consisting of the three load voltages, the two generator voltages and the three capacitor voltages.
- Efd – a 3x1 vector consisting of the field voltages of the generators in areas 2 and three, respectively.

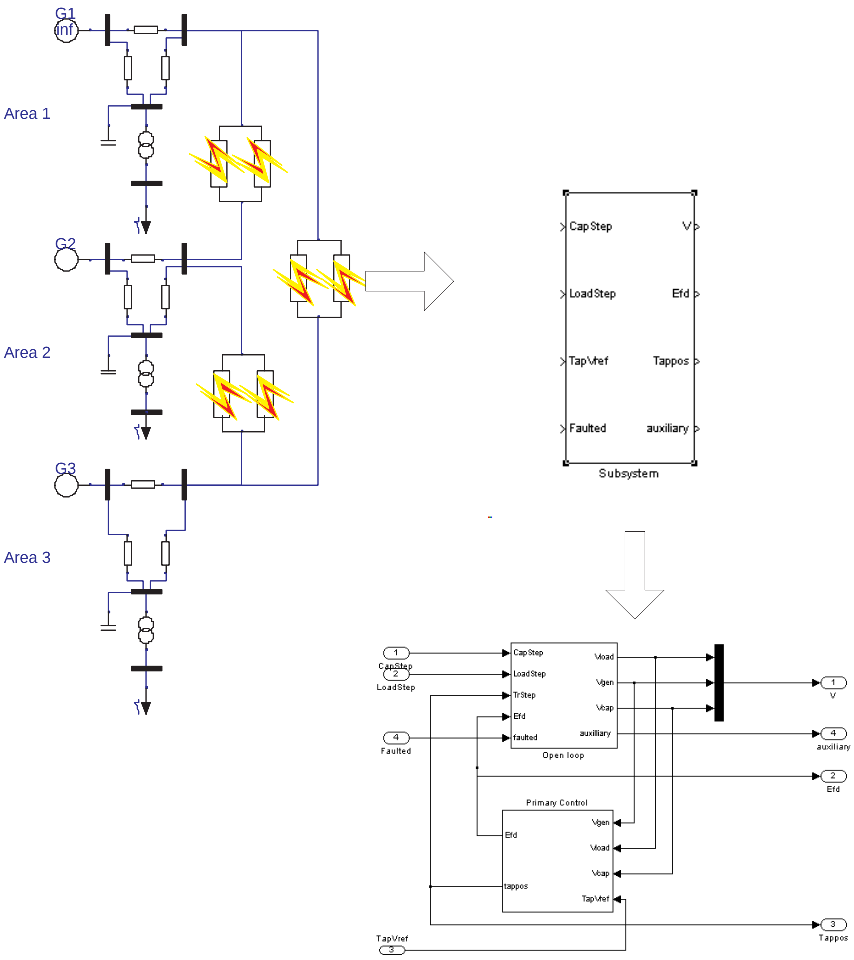

Figure 1: The physical power system and its hybrid system representation.

- tappos – a 3x1 vector consisting of the tap positions of the three tap changers.

3 Control Objectives

The aim of the emergency control is to keep all load voltages at values above 0.9 p.u at all times. The load voltages correspond to the first three elements of the output vector V.

A secondary aim is to minimize the amount of load shedding applied. The tertiary objective is to keep the load voltages at the load buses close to 1 p.u, and to minimize the amount of capacitor control required to do so. That is, load shedding can be used to fulfil the primary objective but not the the tertiary.

Computational delay times of up to 30 s are acceptable, however all controls are more effective when applied as soon as possible following a disturbance.

3.1 Example Simulations

This sections presents some example simulations and demonstrates the application of emergency controls. These controls have been generated by trial and error and do not demonstrate an optimal solution according to the control criteria.

These cases can be reproduced using models in the Modelica source code or the Matlab m-file `runcases.m` which are included with the distribution of the destcase.

3.2 Case 1. Double line outage

Figure 2 shows the system response to a double line outage of the tie-line between areas 1 and 3 at time 100 s. This severely weakens the transmission system and the supply to the remote areas becomes difficult. Directly following the disturbance the generator voltage controller in Area 2 saturates and the voltages there decline rapidly. The saturation of the controllers can be observed from the signal Efd, which saturates at its maximum of 1.78 p.u for both generators. As the tap changers attempt to restor load voltage also the generator voltage controller in Area 3 saturates and voltages start to decline also here. No emergency control actions are taken, and there is a complete voltage collapse in Areas 2 and 3. At around 980 s, the simulation stops because the network equations become unsolvable.

3.3 Case 2. Double line outage stabilized by tap changer reference change

Figure 3 shows how the voltages can be stabilized by means of tap changer reference change. In the previous case, we saw that the tap changes played a major role in the collapse. By lowering the reference voltages for the tap

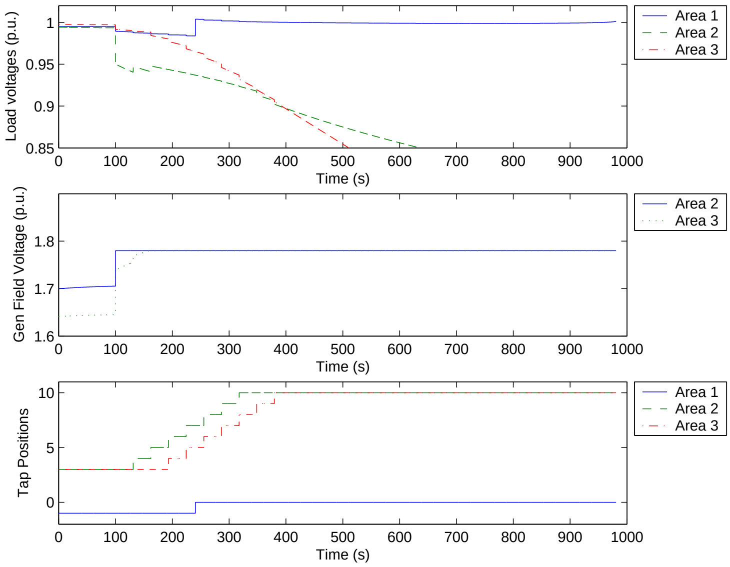

Figure 2: Voltage collapse due to double line outage. No emergency control applied.

changers, the load restoration dynamics can effectively be disabled and the system can remain stable. Here the voltage references are changed from 1 to 0.95 p.u. at time 150 s in both Areas 2 and 3. Due to this, the tap changer in Area 3 makes two downward tap steps at time 180 and 210 s, which takes the generator in Area 3 out of its saturation limit and control of voltage in Area 3 is regained. Although the controller once again saturates at time 390 s the voltages stabilize within the prescribed limits.

3.4 Case 3. Double line outage stabilized by capacitor bank switch

As shown in Figure 4, it is possible to stabilize the system also by switching the capacitor banks. Here, the capacitor in Area 2 is switched in at 150 s, which stabilizes the voltages close to the nominal value. Also here, the voltages stabilize after the generator in Area 3 is taken out of its capacity limitation by the connection of the capacitor.

3.5 Case 4. Triple line outage

Figure 5 shows the response where the initial double line trip is followed by a second trip of one of the lines between areas 2 and 3. At 150 s, both the the tap reference change and the capacitor bank switching that were applied in cases 2 and 3 are carried out, but these now fail to stabilize the system and the

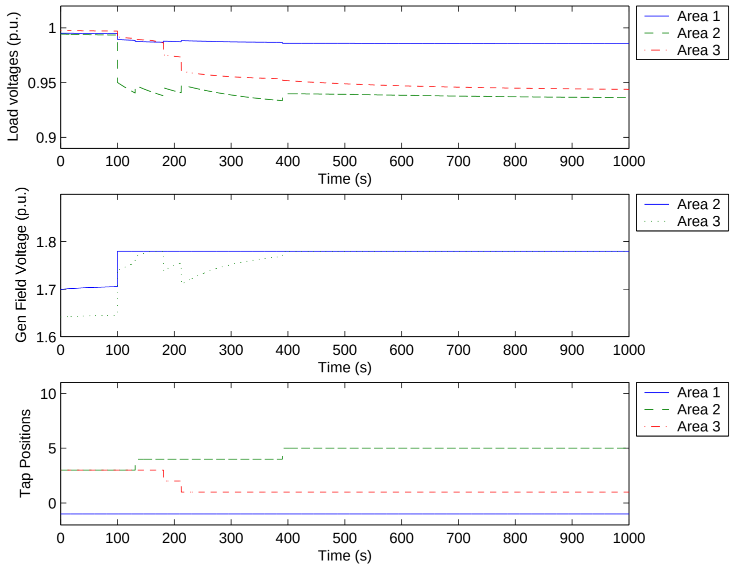

Figure 3: Double line outage with stabilization by tap voltage controller reference change at time 150 s.

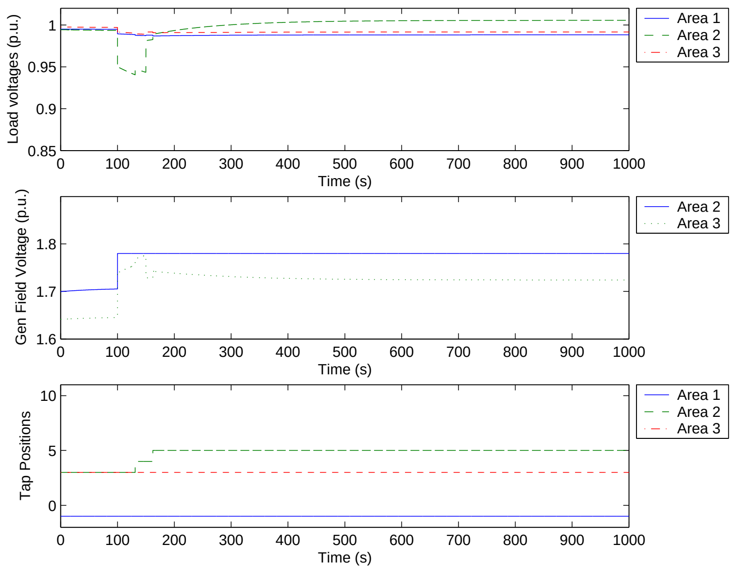

Figure 4: Double line outage with stabilization by tap voltage controller reference change at time 150 s.

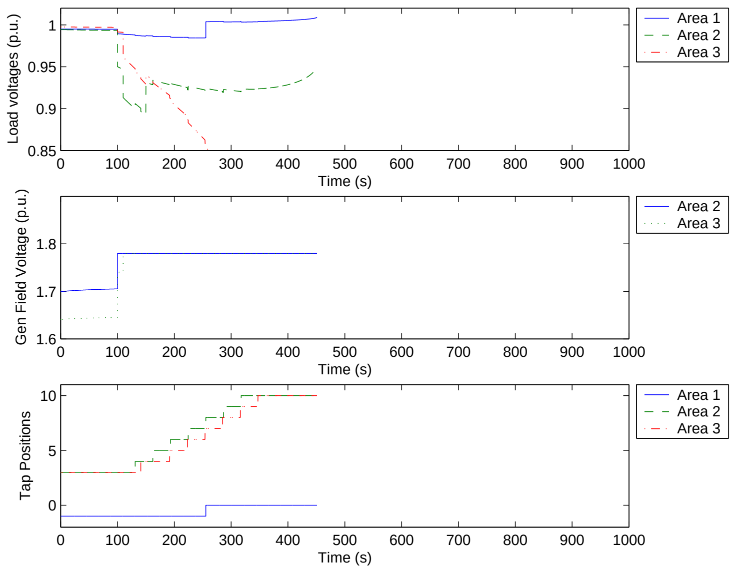

Figure 5: Triple line outage. Stabilization by tap voltage controller reference change and capacitor bank step at time 150 s is unsuccessful.

simulation stops due to unsolvability at around time 470 s.

3.6 Case 5. Triple line outage and stabilization by load shedding

Figure 6 shows the response to the triple line outage with one step of load shedding executed in each of Areas 2 and 3. As shown, the application of two load shedding steps successfully stabilizes the system

3.7 Case 6. Triple line outage and stabilization by load shedding, capacitor bank switching and tap voltage reference change

Figure 7 shows the response to the triple line outage with one step of load shedding executed in both Areas 2 as well as the tap reference change and the capacitor bank switching at time 150 s. By compining the load shedding in Area 2 with the other emergency controls, it is possible to avoid load shedding in Area 3.

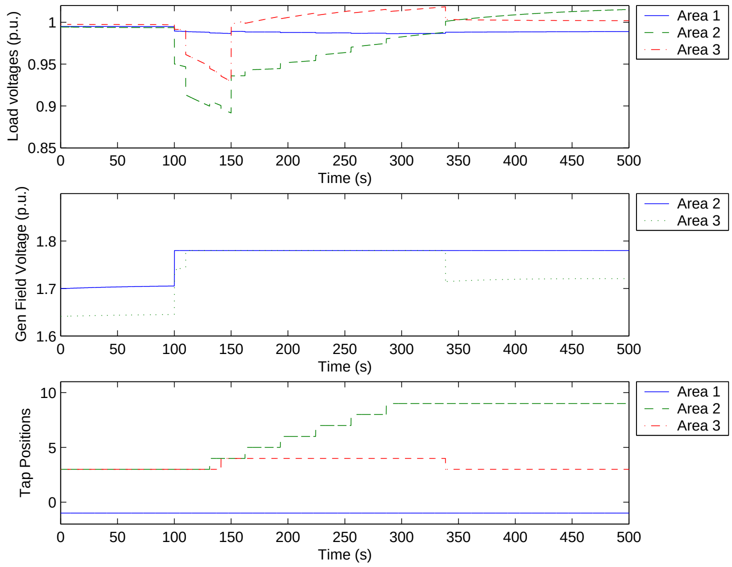

Figure 6: Triple line outage. Stabilization by load shedding at time 150 s is successful.

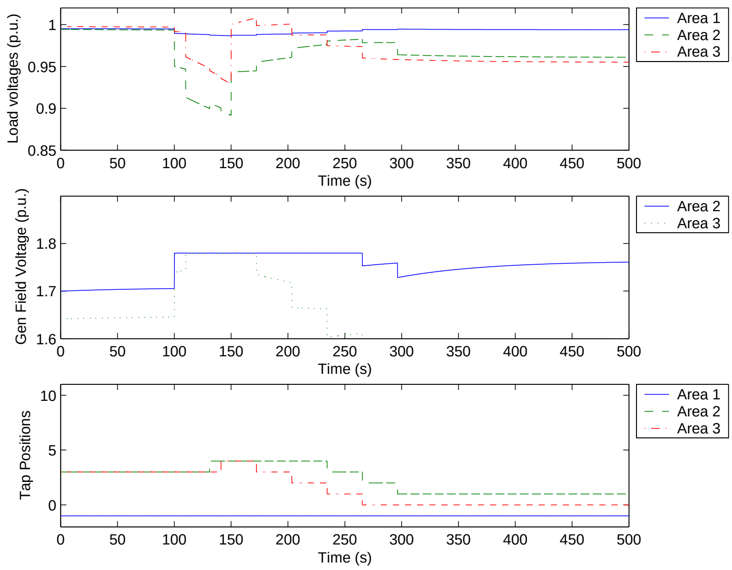

Figure 7: Triple line outage. Stabilization by load shedding at time 150 s is successful.

4 Conclusion

This report describes the third power transmission test case developed for the European project Control & Computation. It can be used to illustrate and test secondary controllers that detect and arrest voltage instability in power system. The testcase models internal (primary) controllers in tap changers and generators and includes inputs for secondary controls such as load shedding, capacitor switching and voltage reference change for tap changers.

The model is distributed as a runnable models for use with Simulink as well as the original Modelica code that can be compiled and Simulated with Dymola.

The models have been developed and tested with Dymola version 5.2a and Matlab/Simulink v6.5.1.

5 Acknowledgement

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