

**Comparison between
ARISTO
and
DigSILENT PowerFactory**



Blanca Hidalgo Hidalgo

Division of Industrial Electrical Engineering and Automation
Faculty of Engineering, Lund University

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June 2012, Lund Sweden

Abstract

Voltage stability is an important issue in electrical power system. As a result, several industrial-grade power system simulator tools are developed in order to estimate the behaviour of the electric power system under certain conditions.

Several tests have been developed to compare and to check different simulators and to prove their correct performance. Comparisons between commercial simulation tools as PSS/E, PowerFactory, SIMPOW, EUROSTAG have already been made but comparisons with ARISTO have not been found.

The aim of this thesis is to compare ARISTO with the more widespread simulator DlgSILENT PowerFactory. The tools employ different models, components, analytical and numerical algorithms; therefore, different result can be expected for the same benchmark system. One important reason for this is that ARISTO must prioritize real-time performance.

The project is carried out in two different parts. The first part describes the differences found between the simulators and the tests executed to find these. The second part checks how these differences affect the result in small and large systems to find out how significant they are in practice.

The different studies use smaller benchmark systems from Kundur book(1994) and the Swedish test system Nordic 32. Short term and long term dynamic simulations are run to test different aspects in the simulator.

It is concluded that in general, ARISTO performs well and simulation results are mostly close to those of PowerFactory. However, there are many issues that must be taken in account. Most important are modelling differences like damping factor and the lack of subtransient reactance definition. For general studies, the limited flexibility in defining component models in ARISTO must be considered. In this work the flexibility in modelling in PowerFactory has been used to build models like the fixed ones in ARISTO. In addition to this a few issues that seem like software bugs have been identified in release 4.4.1.

Acknowledgements

I would like to express my sincere thanks to Professor Olof Samuelsson for giving me the opportunity to work with that project and for his help and valuable advice. I also want to thank the continued help Lars Lindgren and Francesco Sulla have given me during the whole project.

I would like to thank my friends for their support over the whole year because without them this year would have been much harder. With special regard to my family and Andres, who I cannot thank enough their support these months.

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Chapter 1

1. Introduction

Stability of electric power system is an important issue. To have a complete knowledge about the system and to predict the behaviour under different situations is an important objective. As a result, several industrial-grade power system simulator tools are developed in order to estimate the behaviour of the electric power system under certain conditions.

1.1. Background

When a simulator tool is developed certain details choices regarding modelling and computations have been made in order to guarantee the specifications of the tools. Therefore, different result can be expected when the same benchmark electrical network is tested. To prove the correct performance in the commercial simulators tools, comparisons between them have been made.

The case present in [6] is an example about these comparisons. This paper is focus on the small-signal stability using the well-known two-area benchmark system from [1]. The analysis is an eigenvalues analysis and the result is compared with the following industrial-grade simulations tools: PSS/E, DlgSILENT PowerFactory, EUROSTAG and PST. The results from the different simulators are not exactly the same due to the different way to define the system.

A further example can be found in [7]. In the paper the performance of four common commercial simulator programs is compared, the tools are: PSCAD/EMTDC, SIMPOW, PowerFactory and PSS/E. The simulators are presented regarding their sustainability for simulations involving wind power within a short-term period of analysis. PowerFactory and SIMPOW show practically identical result but differences can be found with PSCAD and PSS/E. The differences could be due to the different solver algorithms in PSCAD and in PSS/E due to the different implementation in the model.

After several comparisons it is reflected that there are differences in the simulators but they work properly. The comparisons with the simulators describe above serve to check the simulator but comparisons with ARISTO have not been found, and therefore, the proper behaviour of this simulator has not been compared yet.

1.2. Motivation

The purpose of the thesis is to check the behaviour of the real-time simulator ARISTO. In order to guarantee real-time performance, ARISTO prioritize the time over the accuracy, while typically non real-time simulations do the opposite, therefore some choices regarding modelling have been made. It is interesting to compare this simulator to see if these details affect the simulation result.

The methodology followed in the thesis is compared ARISTO with a more widespread simulator such as DIgSILENT PowerFactory. Different models are built depending on the parameters and the situation is going to test. Simple models are used to check parameters and to find the different between both simulators. More complex models are used to check how these differences affect the simulations result.

1.3. Objectives

ARISTO and DIgSILENT PowerFactory are built for different tasks. ARISTO prioritize the time over the accuracy because it is used for training operators. On the other hand, the time is not a priority in PowerFactory, therefore the accuracy of the result is the important issue in this one. Moreover, it is needed to consider that different numerical methods are used in each simulator.

Due to these reasons, different result can be expected with the same electrical network. The fundamental goal of this work is not to verify if both programs bring exactly the same result but to check if similar results are obtained representing the same global behaviour.

Chapter 2

2. Description of the tools

This chapter describes briefly the two tools are compared in the thesis. This introduction about ARISTO and DIgSILENT PowerFactory and how to start using both simulators will be useful for future education situations.

2.1. ARISTO

After the blackout in Sweden in December 1983, the company Svenska Kraftnät together with ABB developed the real-time simulator ARISTO for operator training. ARISTO is an interactive real-time simulator which reproduces electromechanical dynamics and can be used as an electrical power system simulator running detailed models like is the case of the Nordic system with voltages levels from 400 KV to 70KV formed by 1500 generators, 3200 switchyards and 3000 loads.

Today ARISTO is a simulator used in Svenska Kraftnät for training operators, training for understanding systems behaviour, routine task control, operational planning, analyze disturbances, etc. Statnett, Vattenfall, E.ON and Fortum also use ARISTO for the same purposes. Technical universities in Stockholm (Royal Institute of Technology), Göteborg (Chalmers) and Lund also use ARISTO, but for education and research.

It is a tool for training and education analysis. It provides a detailed analysis with a high resolution power system model. It is able to run large systems with many components and automatics models. The simulations are fully interactive and include dynamics at real time speed with 20 ms time step.

The phenomena that can be managed are:

- Transient stability, short circuit and switching
- Long terms dynamic with frequency control
- Voltage collapse
- Automatic cascade tripping of Lines
- Island operation
- Restoration

ARISTO has a complete model library and for most studies it is not necessary to included more models in the system. The basic generator models are synchronous

machines with its corresponding excitation systems, PSS, rotor and stator current limiters and governors. Other components are lines, transformers, tap-changers for voltage control, SVC, dynamic and static loads models, relay protection and automatic equipment.

ARISTO is made for the Solaris operating system, and runs on X86 and Sparc processors. It is developed in C/C++ and it uses Data Views graphical library.

2.2. How to start using ARISTO

Before starting to use Aristo it is important to clearly understand the model structure it has. Every network component is defined as an object and it can be arranged in the hierarchical order. To understand easier this structure we can think about this hierarchical order like boxes inside others box which complete the whole model.

A graphical example can be seen in the next figure:

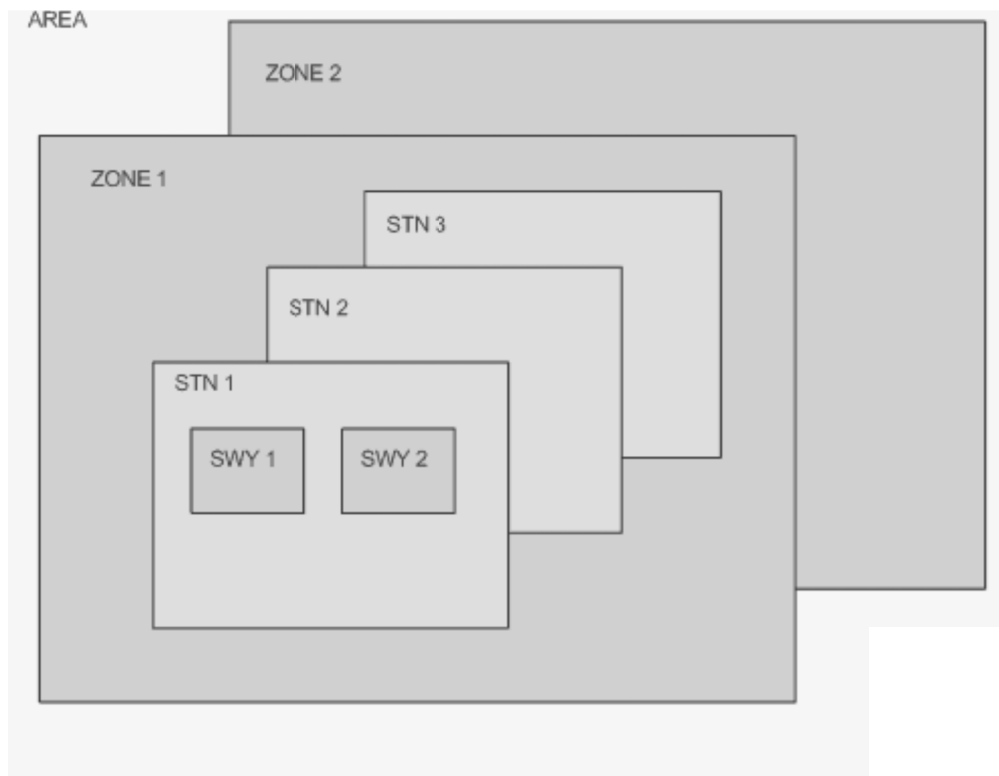


Figure 1. Hierarchical structure of a network model in ARISTO

First of all it is necessary to create the Switchyards (SWY) to include in them the different objects like generators, loads and shunts, which form the whole system, then connect those Switchyards together through lines or transformers. Each Switchyard is characterised by the corresponding voltage which cannot change inside it. Different Switchyards form one Station (STN) and a group of them develop a Zone. Several zones form an Area.

2.2.1. Create a new model

The steps necessary to follow when a new model is created are shown below:

- Open the Terminal and write “PSMcreate <name of the new project>”
- Select Terminal and write “ControlPanel” followed by Enter.
- In Control Panel click “File” and “Power System Model...”. Choose the new file which was created before, see Figure 2.

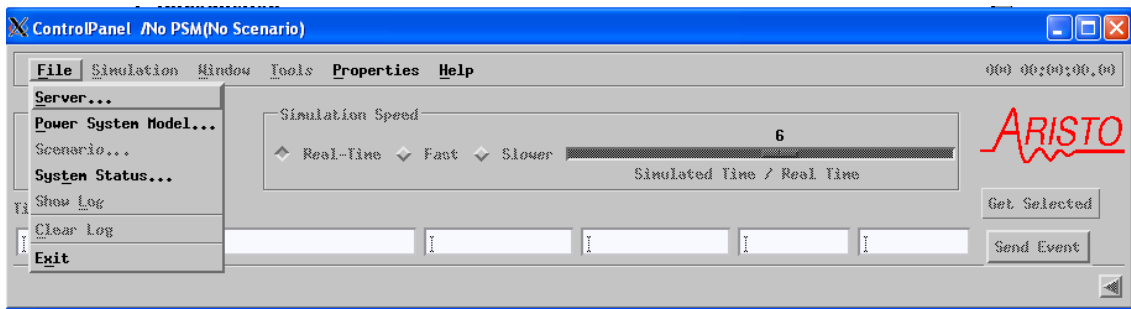


Figure 2. ControlPanel

To define the different components it is useful to find the default values as a reference described in [5] called “Model Descriptions”. The first step when building the model is to create the different Stations and Switchyards where the different components are placed.

The next step is to define the model:

- Open “Tools” in ControlPanel and then “Forms”. A list of components that can be defined will appear, see Figure 3.
- It is necessary to start creating a Station, after that create the different Switchyards which are placed inside that. The next step is to create the different object like

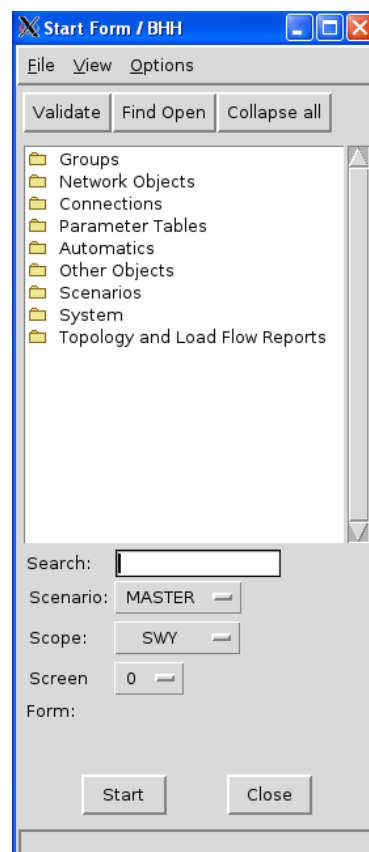


Figure 3. Start form

generators and lines inside the Switchyard and connect them with each other.

- To create a new object it is only necessary to go inside the file, press “Create Object”, name and define the data. To define the data it is only necessary to look in the top of the panel and select between the different windows to complete the information in all of it. Figure 4 shows an example of the switchyard panel.

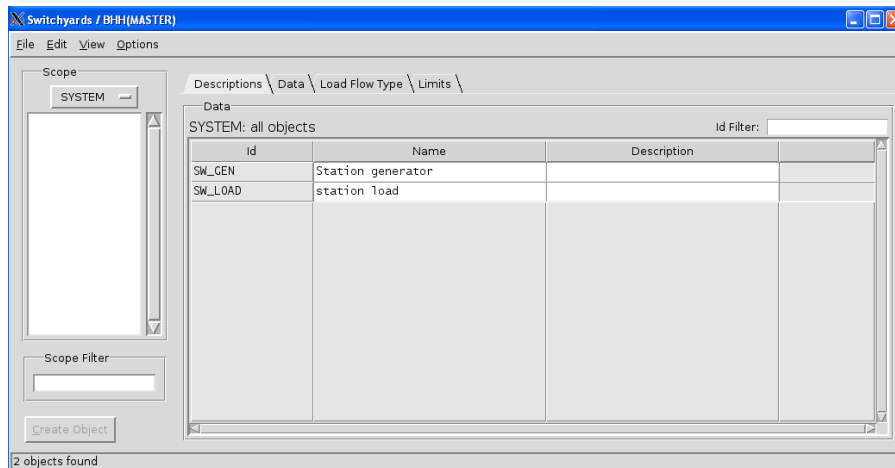


Figure 4. Switchyards panel

When the Switchyards have been created the objects in them are the next step:

- Select in the window “Network Object” the component which is to be defined. The way to create it is common for all: “Create Object”, define the characteristic in the windows in the top of the panel and so on.

The last step is to connect all the components in the model, by clicking in the window “Connections” that appears in Start form. To validate the model to check that it was defined in a correct way the option validate in the Start form panel can be selected.

2.2.2. Open a model

To open an old model it is necessary to follow the steps that were described in the previous part, see Figure 5.

- We need to open Terminal and write inside “ControlPanel” followed by Enter.
- In the Control Panel we need to click “file” and “Power System Model...” and choose what file you want to open.
- Then go to “Simulation” and “Enter...”, push the bottom “Start”. When the panel displays the message “Simulator Run-Time system started successfully” simulations can start. To start simulating it is only necessary to press the green key that simulates the signal start.

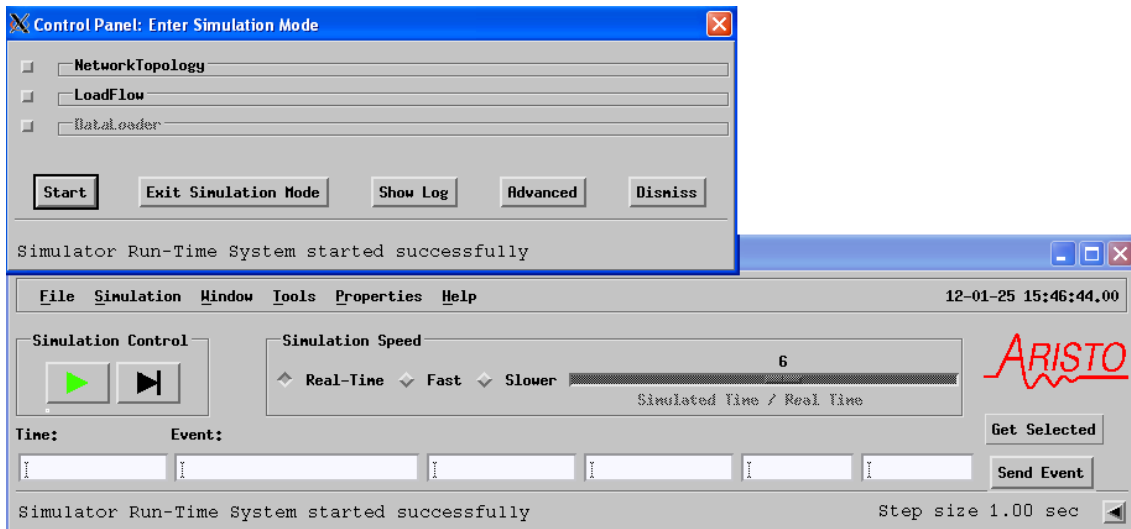


Figure 5. Start to simulate with ARISTO

The result and the behaviour of the system can be monitored in different ways.

- Through Netdiagram, which allows continuous information of the values in the system as in Figure 6. To use this option select “Window” and then “NetDiagram” in the main panel.

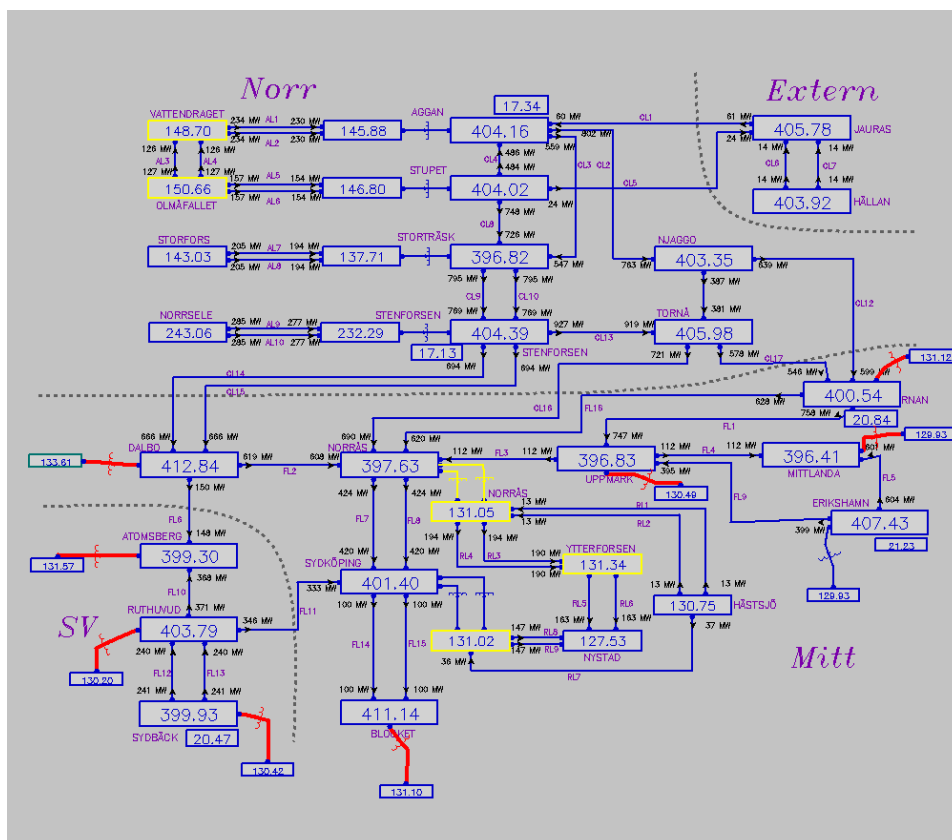


Figure 6. Netdiagram from ARISTO example

- Through TrendRecording, which shows plots of signals from the system during the whole simulation. This option will be obtained by selecting “Window” and “CurveDiagram”.

2.2.3. Execute different events

When the model is open and it is running it possible to generate events to disturb the static situation and make different tests. To do this it is only necessary to do:

- Click “Window” and “EventPanel”
- When the Event Panel is open, click “Edit” and “Event Selection” and a list will appear with events that can be chosen, see Figure 7.

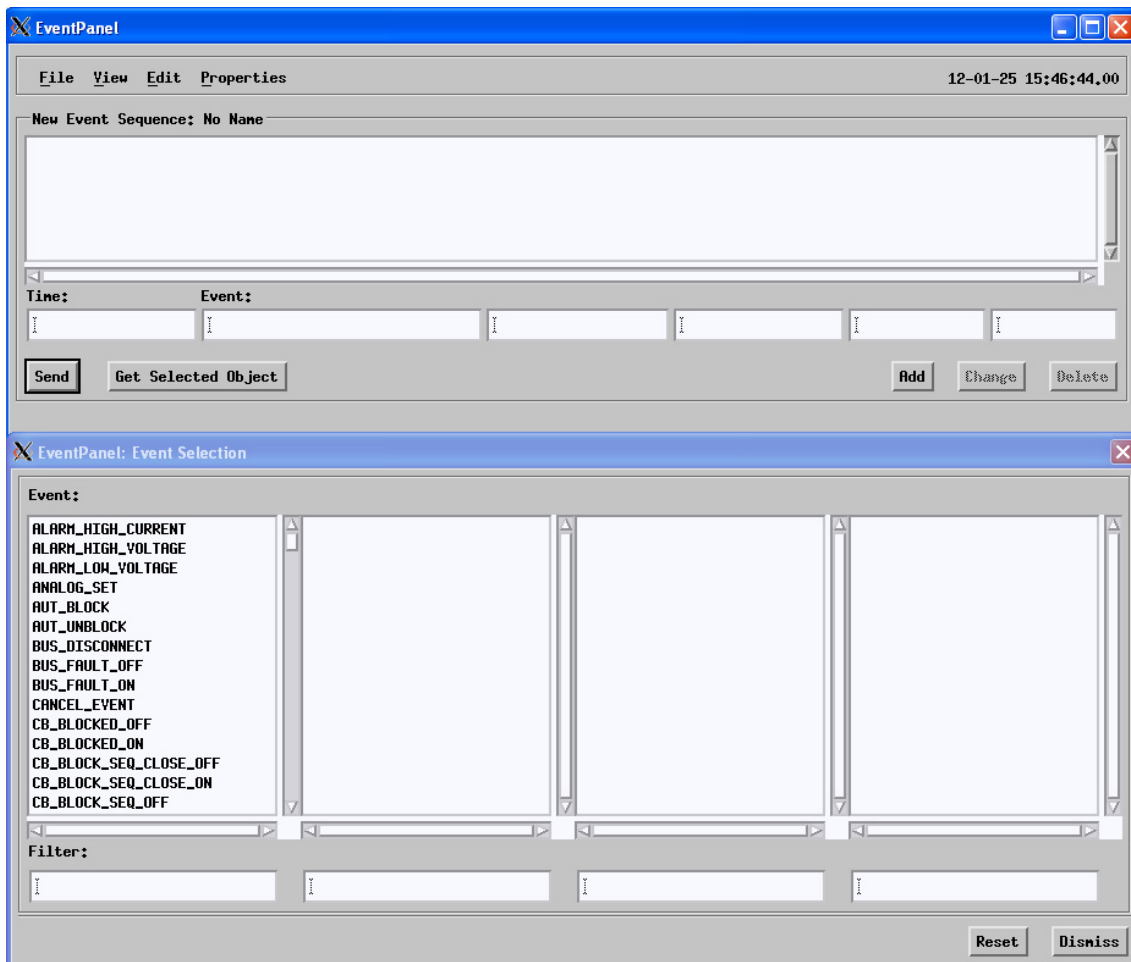


Figure 7. Event Panel

Following these steps a simple model can be executed and results can be plotted.

2.3. DlgSILENT PowerFactory

The DlgSILENT development started in 1976, using the talents of several expert engineers in electric power system and software. Since it was designed, the program has improved by incorporating some analysis characteristics that are required to plan, operate and demonstrate electric power systems.

DlgSILENT PowerFactory is a tool which combines reliability and flexibility. This simulator incorporates a list of workspaces and functions such as:

- Load Flow AC/DC
- Short-circuit analysis
- General faults
- Dynamic simulations
- Electromagnetic transient simulations
- Eigenvalues analysis
- Protection relays
- Harmonics analysis

The model library will be deeply explained in next chapter where an exhausted knowledge about the models description it is necessary.

The model library in this simulator is more flexible, the user can define and organize the libraries according to the model. In this case the change that could make in the simulator is not just the data in the different models, the function to describe it one can also be change as it is the case of the governors, controllers, etc. that can be exactly defined in a separate block diagram by the same transfer function as ARISTO case.

DlgSILENT has been developing with a new technology based on the object-oriented programming and C language. This program is compatible with every Windows and it offers a high level of flexibility and capability for analyze every aspect of an electrical system in an easy, correct and exact way. Today is a well known simulator due to the integration methods and its accuracy result.

2.4. How to start using DlgSILENT PowerFactory

One of the characteristic that makes PowerFactory an easy tool to use is the structure utilized to develop the different models. In this case the definition of the components is carried out directly in the component. The component is drawn on the screen and with only a click on the component a panel with the characteristic of the model opens.

2.4.4. Create a new model

To create a new model open the “File” menu in the main menu as is shown in the Figure 8. Then select “New” and “Project” , enter the name of the new project in the window that will appear and press OK.

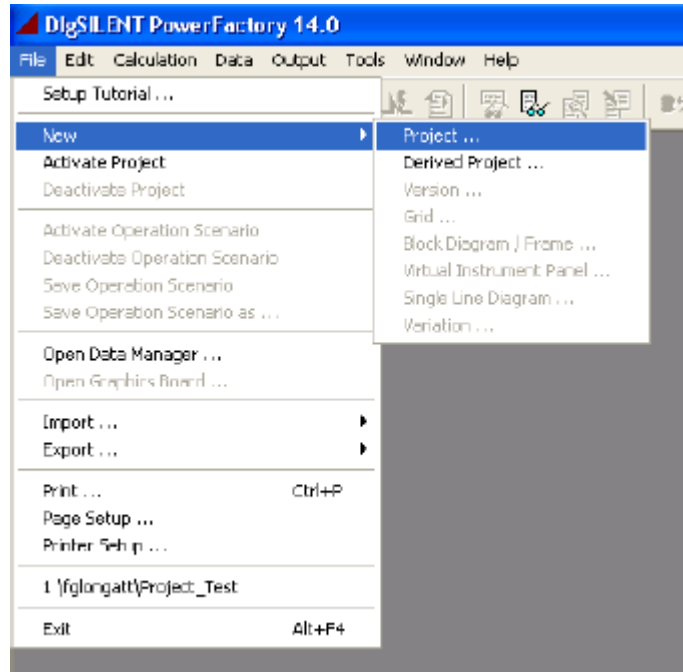


Figure 8. Create a new model in PowerFactory.

An empty screen will appear in the program, see Figure 9.

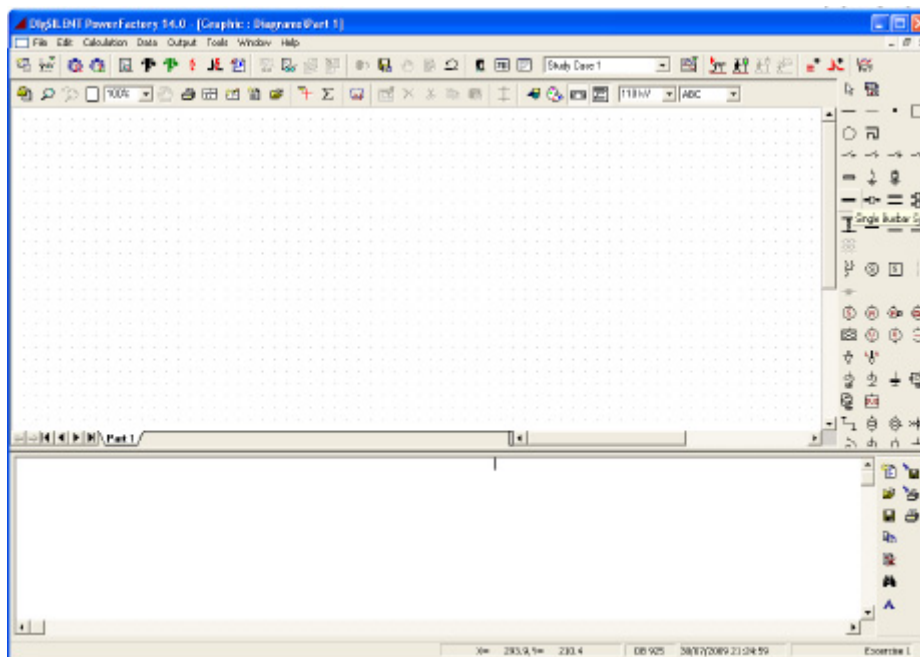


Figure 9. Empty screen shown in PowerFactory when a new model is being created.

At this stage the steps necessary to carry out are the following ones:

- Select the objects to add in the model. Those objects appear in the right side of the screen as is shown in the previous picture. To select just click on the object symbol and click again in the empty base in the position where it is required to appear.
- To define or edit the different components the easy way to do it is to double click above the element and complete the information required in each window tab named Load Flow, Basic Data, RMS and EMS simulation. In Figure 10 an example of a synchronous machine is shown.

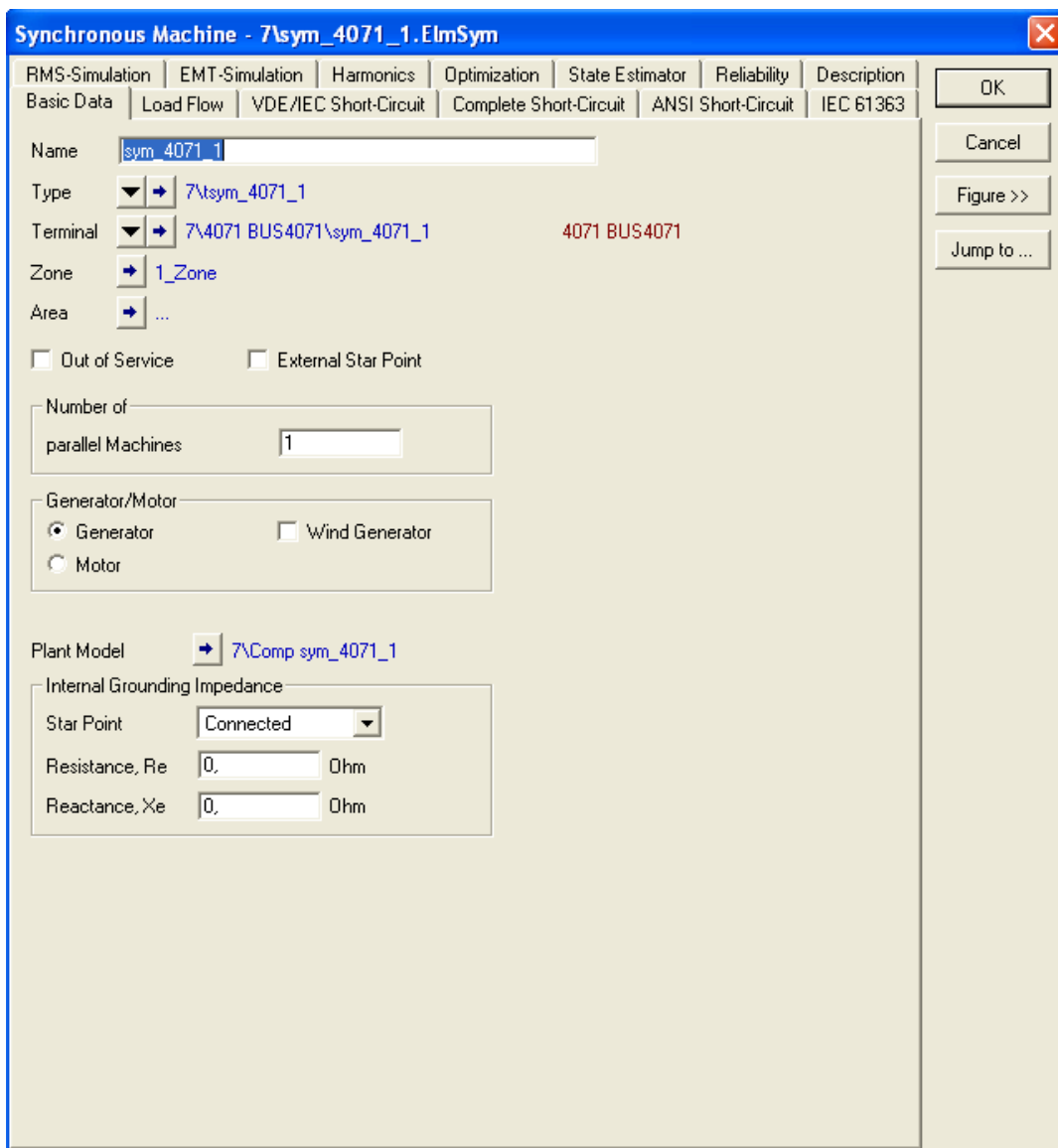


Figure 10. Example of a synchronous machine data window.

After completing all the necessary information the model is finished.

2.4.5. Open a model

To open a model, start the program and press the icon shown in Figure 11.



Figure 11. Open the list of models in PowerFactory

Then a list of models will appear. Then select the model to use. To open it just right click above the name of the model and select “Activate” as in Figure 12, then the schematic of the model will open directly.

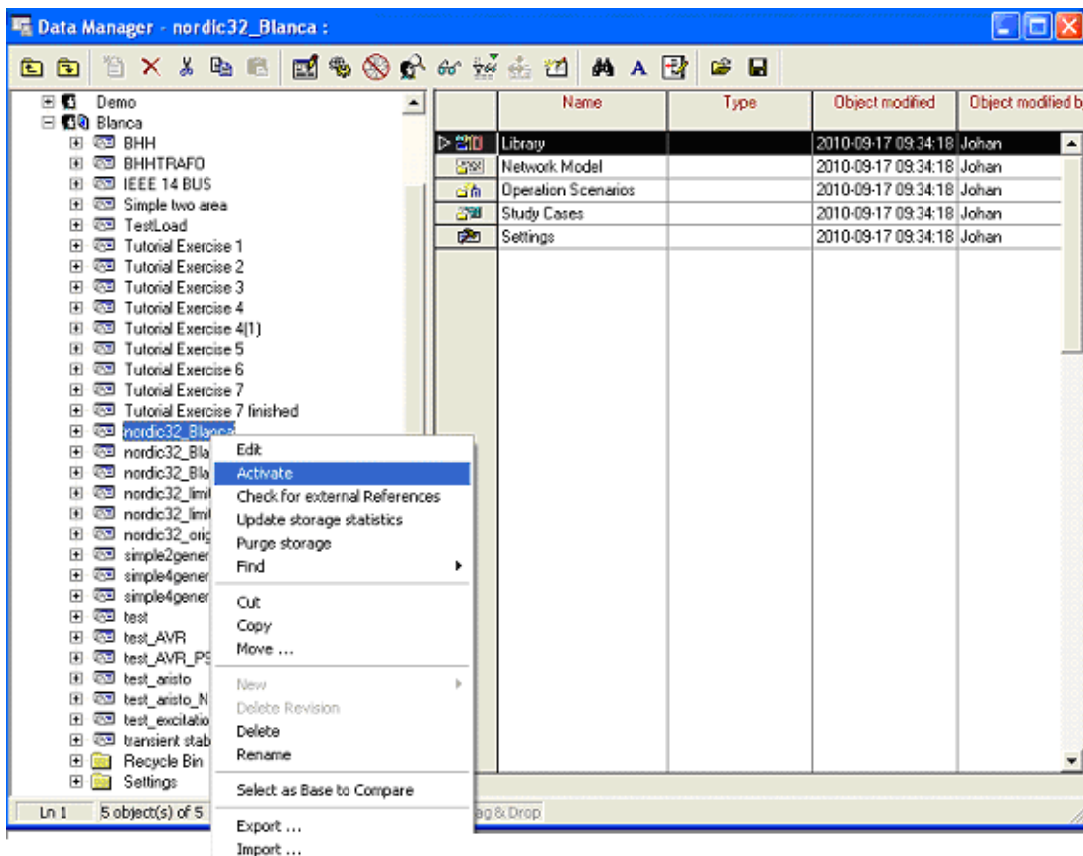


Figure 12. Activate a model in PowerFactory.

2.4.6. Execute different events

The first step is to calculate the Load flow: Just press the icon in Figure 13 to calculate the Load Flow and the program will do it and show the voltages, power, etc. together with each element.



Figure 1. Icons for Calculate the Load Flow

To run an event the next steps will be carried out.

- Define the event by right clicking as in Figure 14

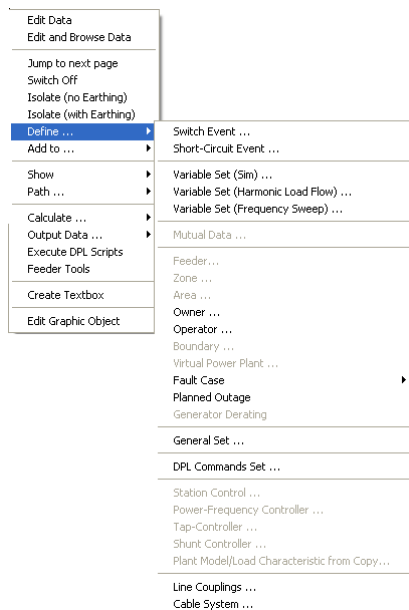


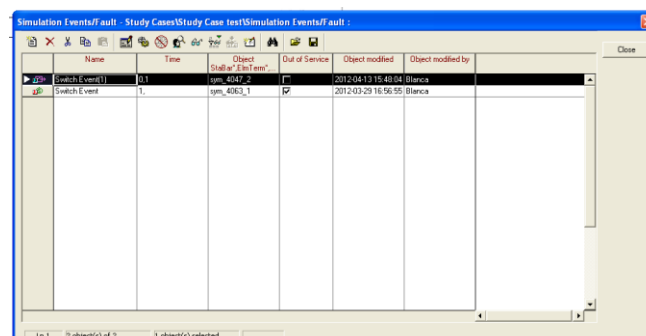
Figure 2. Define an event on an element in PowerFactory.

- The list of events is displayed by clicking on the icon indicated in Figure 15



Figure 3. Icon that show the list of event in PowerFactory

The list of events that will appear allows disabling an event by clicking “out of service” if it is not necessary to run this event at the moment.



- Before any event the program has to calculate the initial condition, and then run the simulation. To define the values that will be plotted it is just necessary to click the icon to define the plot and configured the elements and the variables are shown. These commands are selected by clicking the icons in Figure 16 and making the plot selections in Figure 17.

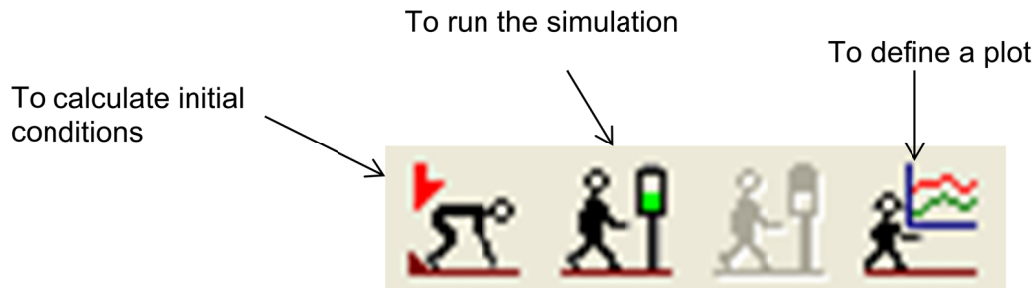


Figure 16. Icons from PowerFactory to calculate the initial conditions, run the simulation and define a plot.

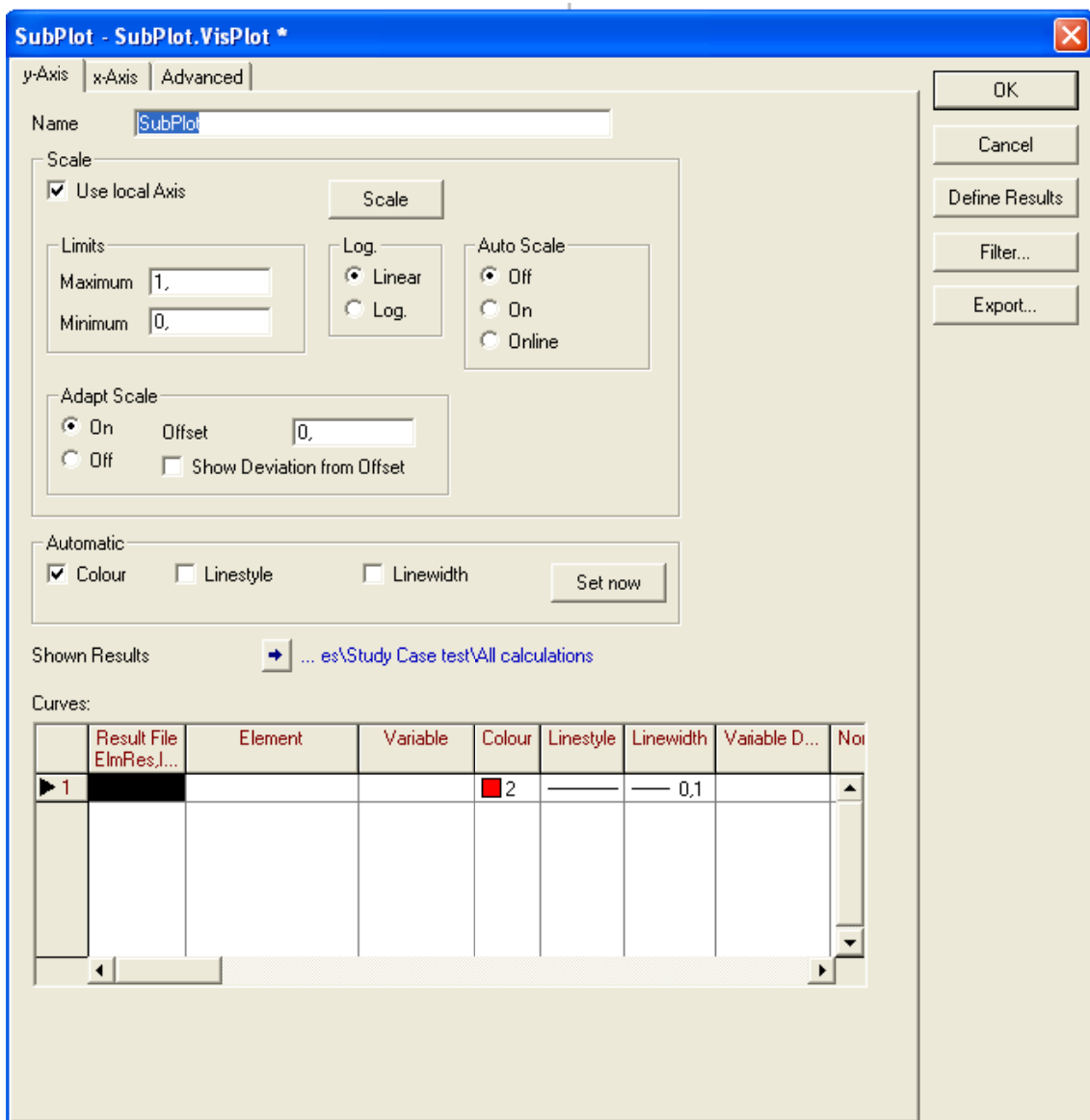


Figure 17. Define a plot in PowerFactory

2.5. Discussion about both simulators

Both simulators are able to managed phenomena as: Load Flow, Transient stability, short circuit analysis, dynamic simulations, etc. But they are able to perform also different phenomena. It is case of the restoration in ARISTO which is not able to perform in PowerFactory and the eigenvalues analysis which is able to manage in PowerFactory but not in ARISTO.

As it was explained above in the previous section, models are built in different way in both simulators. PowerFactory has a more intuitive modelling interface than ARISTO, therefore to build system in PowerFactory will be easier than in ARISTO.

Moreover the library in PowerFactory is more flexible. The user in PowerFactory can define and organize the library according to the model. However, in ARISTO the models are defined and the functions which define it one cannot be changed; only the data in the set model can be chosen. It is the case of the governors, controllers, etc. that can be exactly defined in PowerFactory in a separate block diagram by the same transfer function as ARISTO model.

Chapter 3

3. Comparison criteria

Several models are used in the thesis to check the different parameters and to find the differences between both simulators. This chapter describe the benchmark models used and the scenarios tested.

The criteria to select different models depend on the parameter which is necessary to check. In some cases small and simple system are necessary when a particular component is tested and the influenced of others elements must be ruled out. Complex models are also needed when a realist behaviour is studied and the influenced of others elements, working as a complete system, are required.

3.1. Two area system model

The two area system model is taken from [1] and consists of two similar areas connected by a weak tie for feeding two loads with different consumption. The schematic of the system is shown in the next figure. More information about the system can be found in [8].

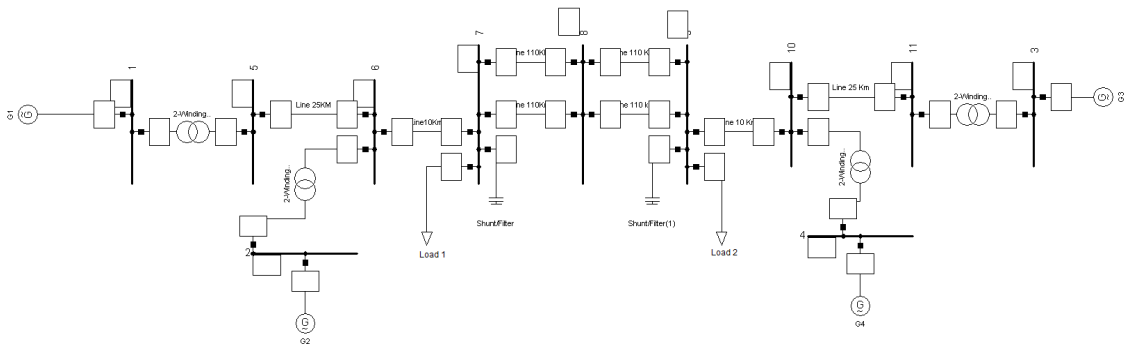


Figure 18. Schematic two area system

The two-area system is a benchmark model used to check the behaviour of different parameters under certain conditions. It is necessary to create different situations in different part of the system to compare the respond of the system according to the specific situation. For example, different faults in different places are necessary to be tested because the system respond in different way depends on the case. The system is large enough to create a lot of cases, but small enough to make effective discussions.

3.2. Simple model from a reference

Some parameters are necessary to be checked and compared with a reference because the results from both simulators are not the same. In the case that a simple system is needed and exactly the same model must be defined in a reference, a simple model take from [1] is used. The model is composed by one generator connected to an external grid by a transformer and two lines. The schematic of the model is shown below.

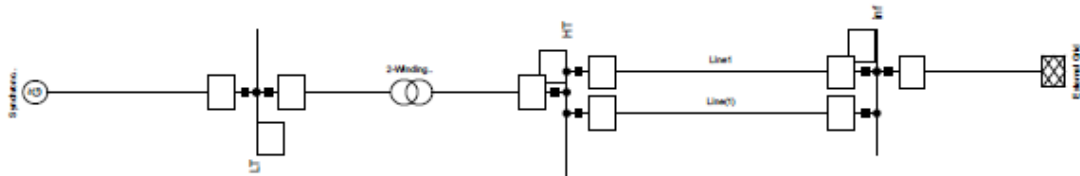


Figure 19. Model representation of Kundur book model.

Exactly the same model cannot be defined in ARISTO, therefore the model is built in PowerFactory and compared with the reference. When PowerFactory is tested and it is checked that this simulator is working properly, ARISTO and PowerFactory will be compared. The difference in both models, besides the controllers, is in Kundur model the generator is connected to an external grid, however, in ARISTO comparison the generator is connected to other generator which simulates an external grid.

More information can be found about the differences in the models can be found in [8].

3.3. Simple model

A simple model is needed to check the synchronous machine. A model without any influenced from others components is created. The schematic of the system is shown in the next figure.



Figure 20. Simple model schematic

The synchronous machine is connected to an external grid by a short line to be sure that the influences of this one is negligible. The model is simpler than the previous case because a comparison with a reference is not needed in that case.

3.4. Nordic 32

A complex system is necessary to be tested if ARISTO has a realistic behaviour. The Nordic 32 is the model used to run the Long term dynamic test with similar dynamics properties to Swedish and Nordic electrical power system. The model is described in [8] and it is taken from [3].

The system consists of four major parts: “North”, “Central”, “Southwest” and “External”. The network is rather long and the system is designed to have the main transmission in 400 KV but there are also some regions at 130kV and 220kV. In addition, some loads are connected to the bus with higher voltage through a transformer provides with tap-changers. Summarizing, the system is formed by 23 generators, 32 buses, 22 loads, and different transformers, shunts and lines.

The schematic is shown in the next figure where it represents each major part which are connected in the way that is plotted.

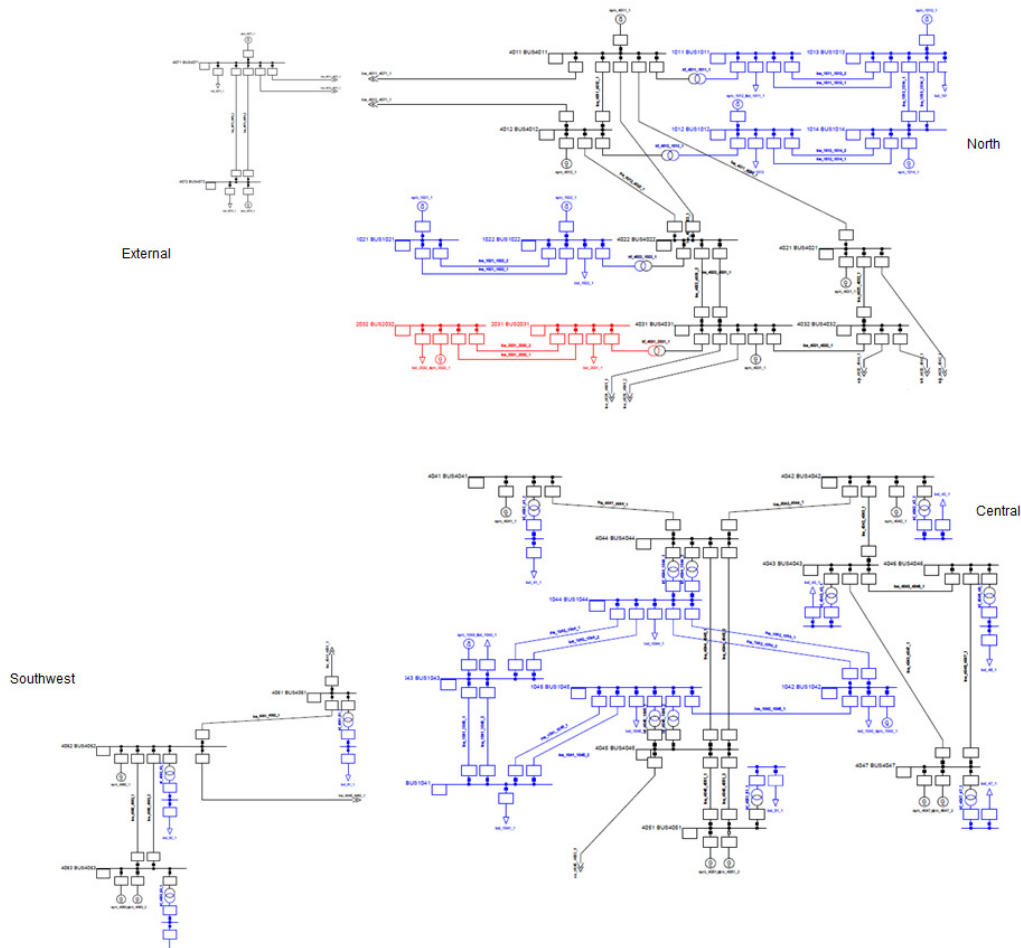


Figure 21. Overview of Nordic 32

3.5. Scenarios

Several scenarios are used in the comparison. The criteria to select the event depend on the parameter which is testing.

The events run are the following ones:

- **Increased and decreased the power of the loads:** When critical situation is not needed and compare the respond from both simulators under different conditions is the goal, the variation of the power is an appropriate way to develop because small and large variations can been made.
- **Faults:** When critical situations are needed faults in different parts of the system are performance. It is interesting to check the differences between the simulators when the faults are closed the generators and the cases where the faults distant from the generator.
- **Generator tripped:** When it wish to have a voltage collapse, tripping generators is an event which generate this one.

Chapter 4

4. Systematic comparison

This chapter systematically goes through a number of modelling issues of ARISTO and PowerFactory. The aim is to create simulation models in the two simulators with as similar performance as possible.

4.1. THE FREQUENCY

The frequency in ARISTO is defined based on the bus voltage phase angle. It seems that ARISTO behaves according to this equation:

$$f = f_0 + C \cdot \frac{\theta_1 - \theta_0}{\Delta t} \quad (4.1)$$

Where f_0 is the frequency in the previous step, θ_0 is the bus angle in the previous step, θ_1 is the bus angle in the next step and Δt is the step time.

To test the frequency the case chosen is the model from [1], the two area system described in the [8]. The disturbance executed in this case is a fault at 5 s close to one of the generators with an impedance of 0 Ohms and with a clearing time of 0.1 s. When the event has been running the result from the angle in ARISTO is as shown in Figure 22.

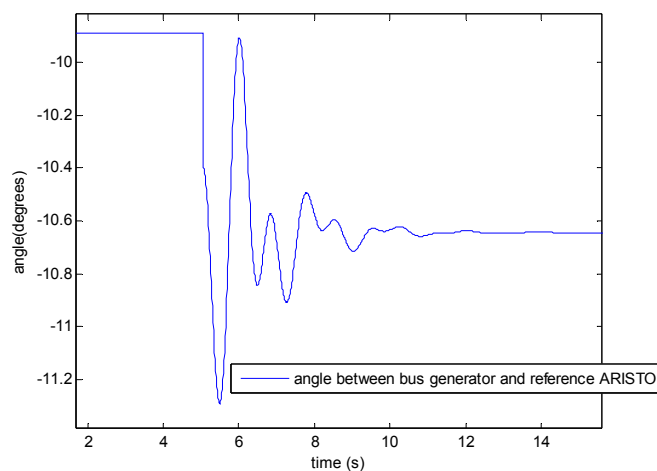


Figure 22. Angle between the bus generator and reference in ARISTO when a fault in the two area model is executed. Fault at 5 seconds and clearing time at 0.1 seconds.

The frequency response, in the same situation, is represented in the following plot.

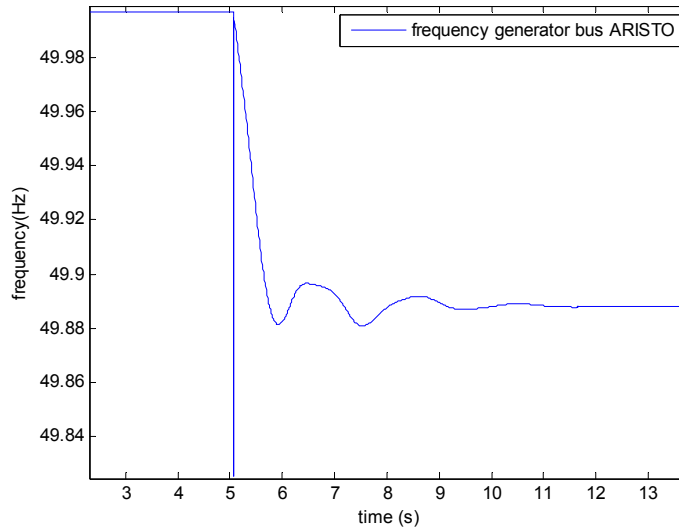


Figure 23.Frequency in ARISTO in the system when a fault in the two area model is executed. Fault at 5 seconds and clearing time at 0.1 seconds.

The peak in the frequency is related the phase angle jump as the fault occurs.

However, in PowerFactory the frequency does not have the same response. The angles at the same bus as in the previous case in PowerFactory and in ARISTO are shown in Figure 24.

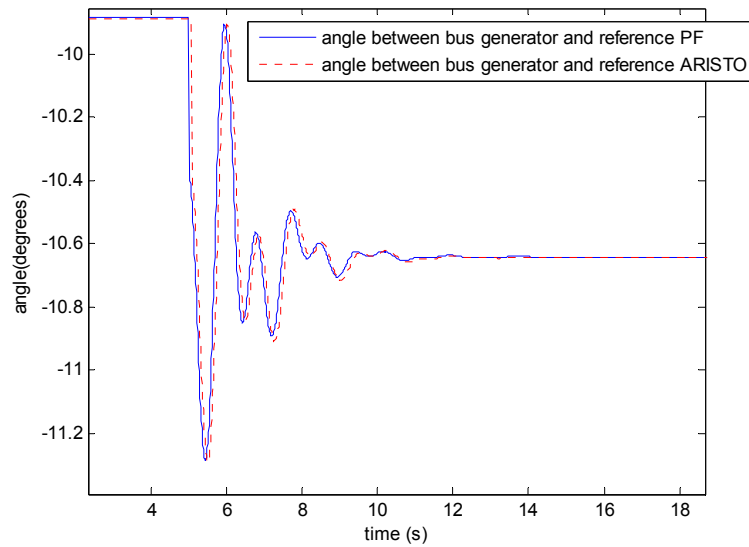


Figure 24.Comparison between ARISTO and PowerFactory in the Angle between the bus generator and reference when a fault in the two area model is executed. Fault at 5 seconds and clearing time at 0.1 seconds.

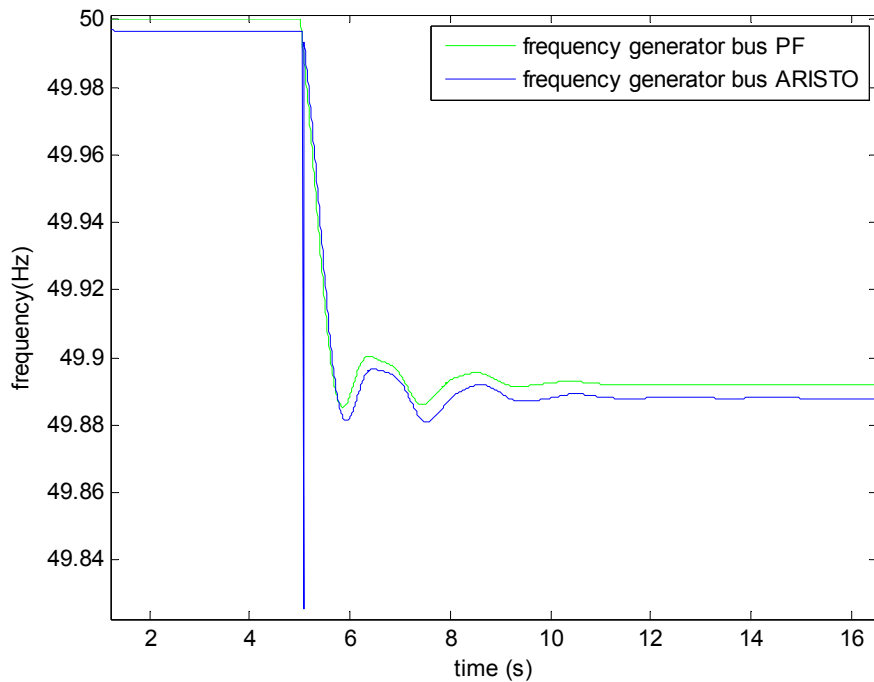


Figure 25.Frequency in ARISTO and in PowerFactory in the system when a fault in the two area model is executed. Fault at 5 seconds and clearing time at 0.1 seconds.

Although the angle in the bus is the same in both simulators, the frequency is not developing in the same way, even at the beginning. The peak produced in ARISTO, due to the sudden change in the angle, is not produce in PowerFactory because in PowerFactory the frequency is calculated using the admittances matrix and in this procedure this sudden change does not occur.

4.2. THE VOLTAGE REGULATOR

The models which describe the generator and the excitation system, including the related auxiliary controllers, are also different in PowerFactory and in ARISTO. The available models ARISTO include are defined in the table below.

| Type of model | Name | Description |
|--------------------------|------|---|
| Generator | SYM | Synchronous generator, round or salient poles |
| Excitation system | EXC | Voltage regulator and exciter |
| Mvar-regulator | MVR | Regulator for adjusting Mvar and voltage setpoints |
| Power system stabilizer | PSS | Additional regulator for damping of power oscillations |
| Rotor current limiter | RCL | Limiter for rotor(field) current affecting the excitation |
| Under excitation limiter | UEL | Limiter used to avoid instability due to under excitation |

Table 1. Models in ARISTO related to a synchronous generator

All these models influence together the machine behavior as described in Figure 26.

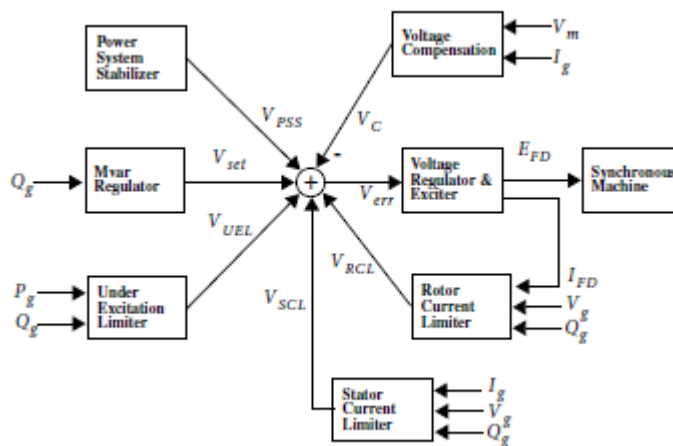


Figure 26. Schematic about generation units.

To compare both simulators the plant model will be defined in the simplest way, working just with the Synchronous machine, Voltage Regulator and Exciter. To define this performance in ARISTO it is just necessary to define in the exciter characteristic EXC to choose Excitation and Voltage regulator but not apply any other characteristic like PSS, etc.

PowerFactory has more flexibility to choose the model for the different tests. For this reason, the models will be chosen using ARISTO models and after that, the same model is going to be built in PowerFactory.

The excitation model consists basically of an exciter and a voltage regulator. Figure 27 describes this model.

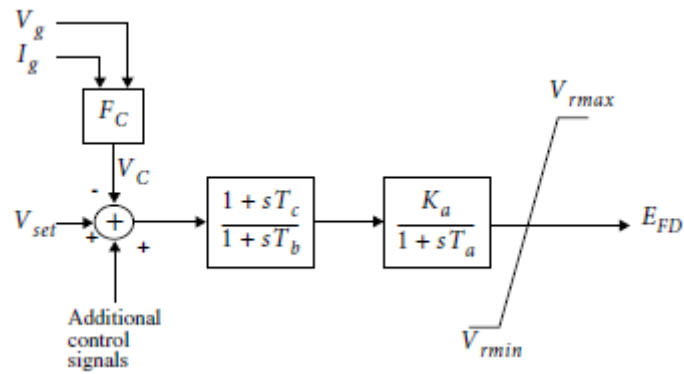


Figure 27. Schematic about the Voltage control in ARISTO

As the model is the simplest one, the additional control signals will be zero because it is working without any PSS, RCL and SCL, etc. Vset is the set value from internal Load Flow or by manual control. And VC will be equal to the generator voltage without any resistive or reactive compensation when Fc is defined in this model equal to zero. The remaining values are time and gain constant which can be defined in the same way in the PowerFactory model.

To build the same Voltage Regulator in PowerFactory it is only necessary to create a schematic and define it using the same parameters as in ARISTO. Figure 28 represents in PowerFactory the previous model defined in ARISTO.

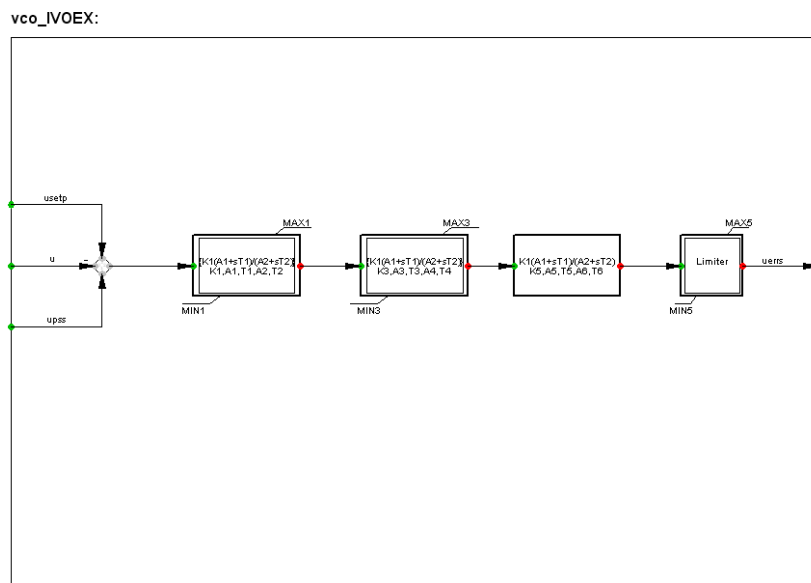


Figure 28. Schematic about The Voltage control in PowerFactory

The values from Aristo to correspond in PowerFactory are:

$U_{setp} = V_{set}$

$V_c = u$

$U_{pss} = \text{additional control signals} = 0$

The voltage regulator has to be developed in PowerFactory as described based on the ARISTO model. To be sure that this model is working properly and the problems do not come from this voltage regulator, a block diagram is built in Simulink to test it.

The schematic of this Simulink model is the next one present in the following figure.

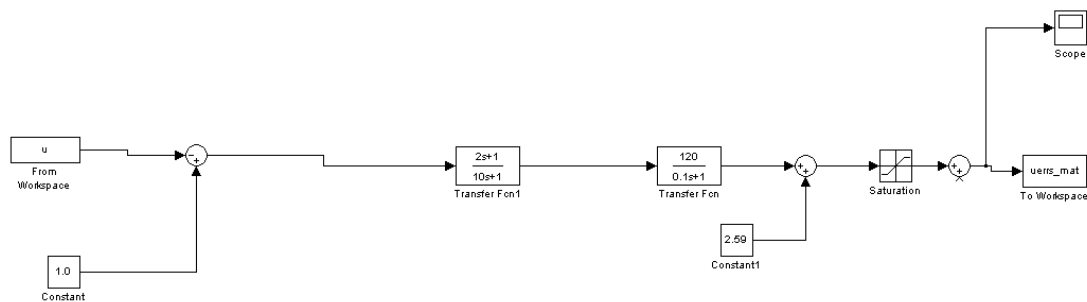


Figure 29. Simulink voltage control working in the same way as ARISTO

The output of this schematic is the Excitation Voltage which will be included to the synchronous machine. This excitation voltage is represented in the ARISTO model by E_{FD} and in Simulink model `uerrs_mat`. The input V_c in the ARISTO model is here represented here by `u` and V_{set} in the ARISTO model, is here directly replaced by 1 p.u., which is the voltage set point at this bus in the load flow.

In this schematic it is also necessary to add one more constant, which represents the initial Excitation Voltage on the generator to reach 1p.u voltage at the terminals. This constant is placed before the saturation curve that is automatically added in ARISTO and in PowerFactory. It comes from the Load Flow but, in this case, this external output should be added.

First, to check if the schematic is the same as in ARISTO a test with it is executed.

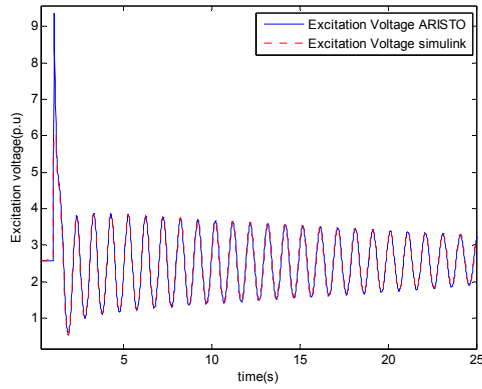


Figure 30. Excitation Voltage output comes from the test with Simulink. Comparison between Simulink and ARISTO

The graphic show that the response in the diagram built in Simulink is working the same as the voltage controller in ARISTO.

The schematic in PowerFactory case is the same as the previous one except the constant of the initial Excitation Voltage.

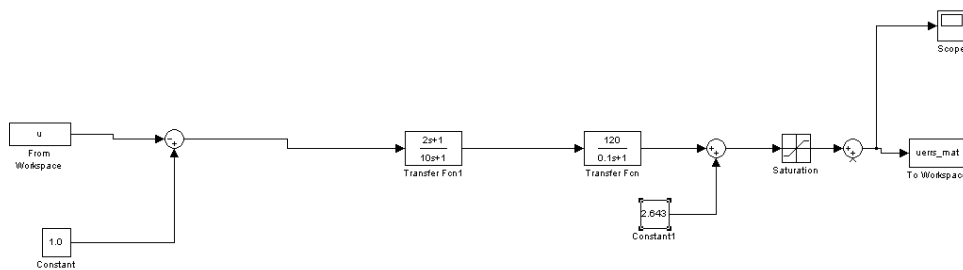


Figure 31. Simulink voltage control working in the same way as ARISTO

The result in this case is the following one.

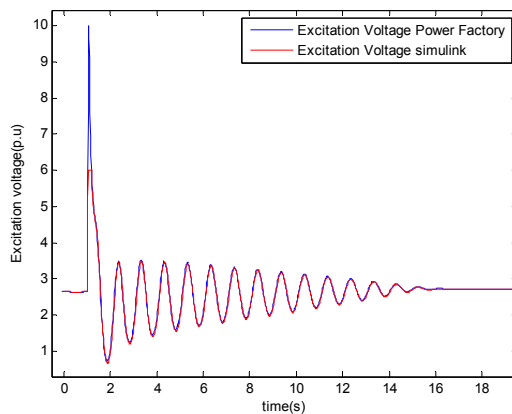


Figure 32. Excitation Voltage output comes from the test with Simulink. Comparison between Simulink and ARISTO

The result in PowerFactory demonstrated that in PowerFactory the Voltage Regulator is working correctly and in the same way as in ARISTO.

In conclusion, following these tests it is demonstrated that the voltage control is defined the same in both simulators.

4.3. THE EXCITATION CURVE

The saturation is modeled in the same way in PowerFactory as in ARISTO, and the saturation curve gives in both simulators the same result. The parameters that have to be defined are $S_{1.0}$ and $S_{1.2}$, which are obtained using the following function which define the model of the saturation curve in the generator:

$$S(E'_q) = \frac{B_s(E'_q - A_s)^2}{E'_q} \quad (4.2)$$

$$A_s = \frac{\sqrt{1.2 \frac{S_{1.2}}{S_{1.0}} - 1.2}}{\sqrt{1.2 \frac{S_{1.2}}{S_{1.0}} - 1.0}} \quad (4.3)$$

$$B_s = \frac{S_{1.0}}{(1 - A_s)^2} \quad (4.4)$$

The voltage control demonstrated in the previous point is also influenced by the saturation curve. Depending on this saturation curve the excitation voltage, which the generator needs to reach the specific set voltage, will be different.

This test is executed in a simple model formed by one simple generator and one infinite bus connected by a line with negligible impedance.

To develop this test it is necessary to fix the output excitation voltage of the voltage controller. This output will be limited fixing the output to a constant value. With this constant excitation the voltage on the terminal will be measured when the system is working in the steady state. The excitation voltage is varied between 0.2 p.u and 6 p.u and for each constant value the output voltage is read.

Therefore, the voltage output in this test is as shown below.

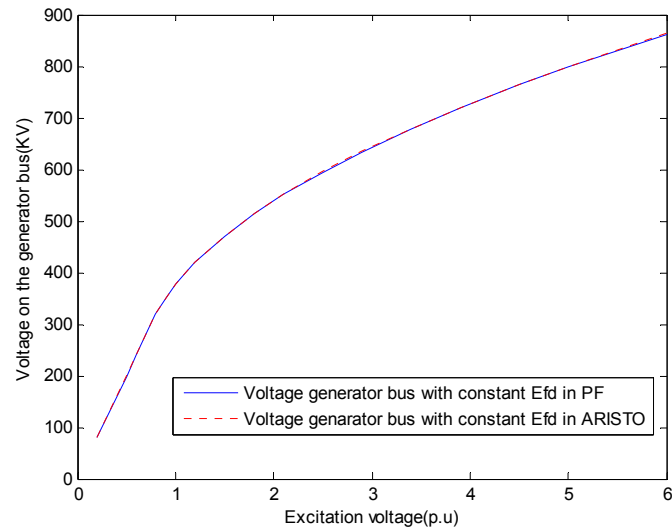


Figure 33. Excitation curve in ARISTO and in PowerFactory

After this test it can be demonstrated that the excitation curve in the generator in both simulator is the same.

4.4. THE GOVERNOR

To work with a constant and correct frequency it is necessary to add a turbine governor with a frequency controller. In the case of ARISTO this governor is defined when the characteristics of the synchronous machine are chosen. In any testing, the system will be working with the thermal plant generator model, therefore, the governor, which is going to be used, will be the thermal turbine governor.

As in the case of the voltage controller, the governor is going to be defined in ARISTO and the same model will be built in PowerFactory. The model used in ARISTO is shown in the following figure.

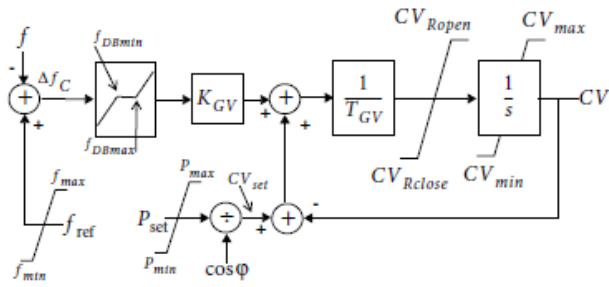


Figure 34. Schematic of The Governor in ARISTO

The limits of power and frequency are fixed when the system is defined: Pset is the Power defined in the Load flow and fref is the nominal frequency defined in the Load flow. The rest of the parameters are gains and time constants which will be defined in the same way as in PowerFactory.

The schematic in PowerFactory that defines the previous governor model is presented in the next graphic.

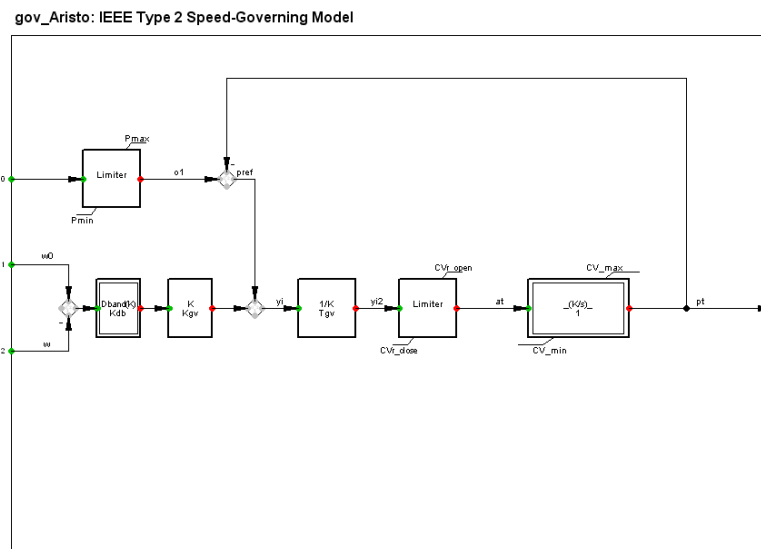


Figure 35. Schematic of the Governor in PowerFactory

The values in the schematic that correspond to the values from ARISTO:

$$f_{ref} = w_0$$

$$f = w$$

Comparing simulations show that the governor is working correctly and in the same way in both simulators.

4.5. THE DAMPING TERM

The damping factor represents in ARISTO and in PowerFactory different parameters. In ARISTO the damping term represents the damping windings in the synchronous machine using the letter D and it is defined based on Park's equation according to [5]:

$$E'_d = \frac{1}{T'_{q0}}(-E'_d + (x_q - x'_q)I_q) \quad (4.5)$$

$$E'_q = \frac{1}{T'_{q0}}(E_{FD} - (1 + S(E'_q))E'_q - (x_d - x'_d)I_d) \quad (4.6)$$

$$E'_d = V_d - x'_q I_q + r_a I_d \quad (4.7)$$

$$E'_q = V_q - x'_d I_d + r_a I_q \quad (4.8)$$

$$T_e = E'_d I_d + E'_q I_q \quad (4.9)$$

$$\dot{\omega} = \frac{1}{2H}(T_m - T_e - D\Delta T_e) \quad (4.10)$$

The damper winding is represented by the last term in (4.10) which adds a damping torque to reduce the changes in torque between two successive time steps. In order to avoid abnormal values of this additional torque in case of network transients, it is limited as shown in the next figure.

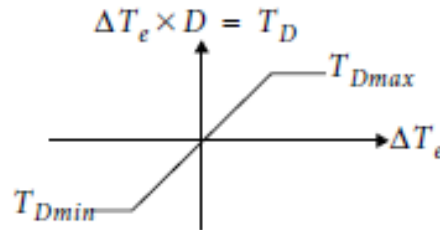


Figure 36. Behaviour for the damping factor in ARISTO

The input data is given in p.u. damping torque divided by p.u. change of electric power/seconds

However, in PowerFactory the damping factor represents a mechanical damping K_d defined by the following equation according to [1]:

$$\frac{2H}{\omega_0} \frac{\partial \delta^2}{\partial t^2} = T_m - T_e - \frac{K_d}{\omega_0} \frac{\partial \delta}{\partial t} \quad (4.11)$$

Where: H = the inertia constant.

W_0 = the rated angular velocity of the rotor in mechanical radians per second.

δ = the angular position of the rotor in electrical radian with respect to a synchronous rotating reference.

T_m = Mechanical torque in $N \cdot m$

T_e = Electromagnetic torque in $N \cdot m$

The comparison of damping performance is made using the simple two-area system from [1] described in [8]. This example is composed of four generators, two loads and four transformers. The biggest differences appear when a large disturbance affects the system. In this case, the event is running is an increment of a 60% in one of the loads in one step.

Without damping (damping parameters set to zero), the results from the system are presented in the followings plots.

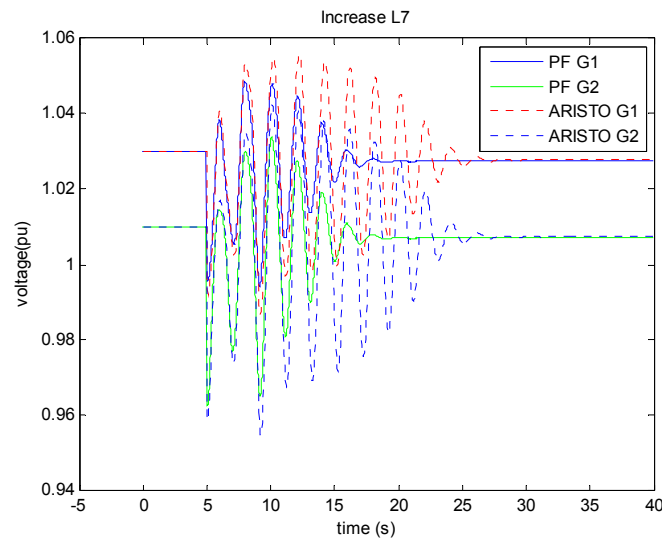


Figure 37. Voltage at generator bus 1 and 2 in ARISTO and in PowerFactory. The model used is the two-area system and the event is a step increase of one load by 60%. The damping factor is $D=0$.

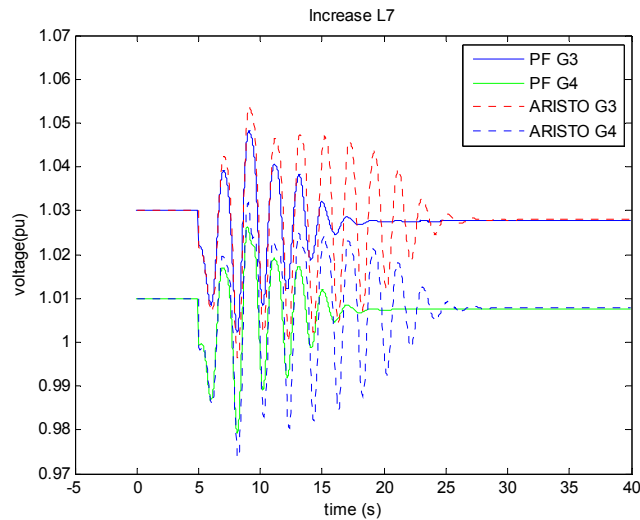


Figure 38. Voltage at generator bus 3 and 4 in ARISTO and in PowerFactory. The model used is the two-area system and the event is a step increase of one load by 60%. The damping factor is $D=0$.

The previous plots represent the voltage in each generator. It is shown that the oscillations are different in both simulators. PowerFactory has more damping than ARISTO. The following graphic shows the load power in both simulators.

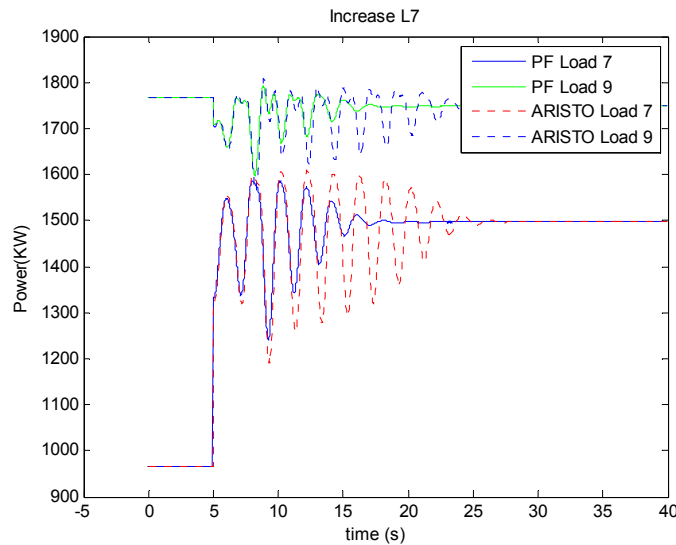


Figure 39. Active Power in the Loads in ARISTO and in PowerFactory. The model used is the two simple area system and the event increase the load to 60%. The damping factor is $D=0$.

In the next test the damping parameter in both simulators will take the maximum value that it can have in ARISTO. This value is: $D = 0.01$ and $T_{Dmax} = 0.01$. Both values D and T in ARISTO will take the same value as is suggested in [5]. As can be seen in figure 36, T_{Dmax} limits the values that can be reach when the damping term is multiply by ΔT_e in the schematic of the same figure.

When the damping parameters take this value in both simulators the result are as shown below.

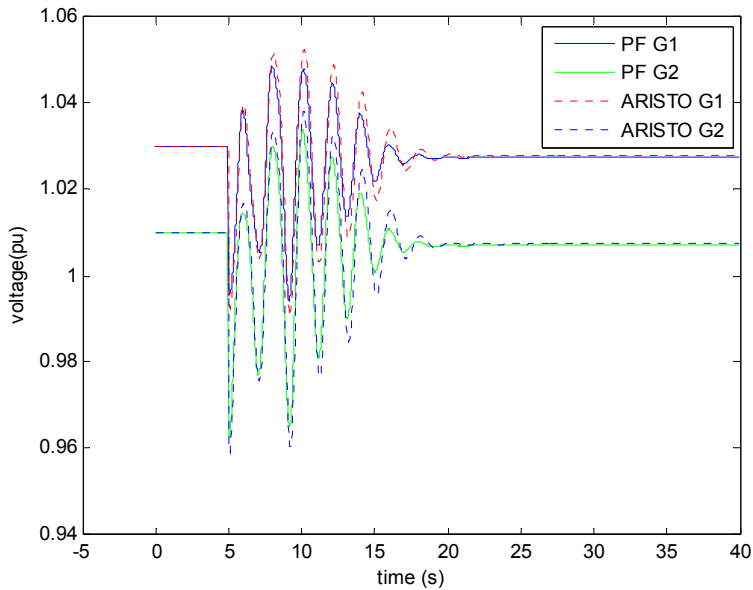


Figure 40. Voltage at generator bus 1 and 2 in ARISTO and in PowerFactory. The model used is the two simple area system and the event increase the load to 60%. The damping factor is $D=0.01$

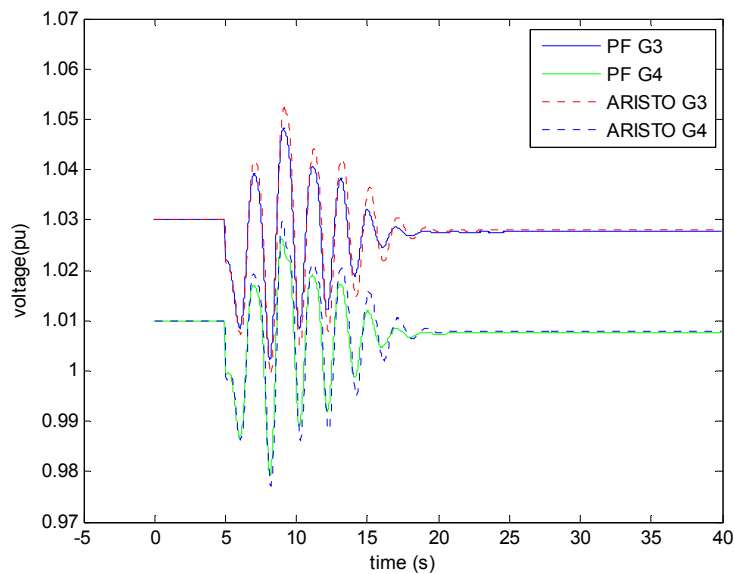


Figure 41. Voltage at generator bus 3 and 4 in ARISTO and in PowerFactory. The model used is the two simple area system and the event increase the load to 60%. The damping factor is $D=0.01$

With this result it is demonstrated that the damping parameter influences more in ARISTO than in PowerFactory. The change in the damping parameter in ARISTO makes the oscillations decrease faster than without damping ($D=0$). However, this behaviour is not seen in PowerFactory where the oscillation is practically unaffected.

It seems that the damping is defined in different ways but although the damping factor is not the same in both simulators its parameter could be proportional. To test this reasoning, the next test is carried out. It is then necessary to find a value in both simulators that in all situations work in the same way, possible with both simulators having different values.

In this case, the values when both simulators are working similarly is when $D=T_{Dmax} = 0.02$ in ARISTO and $D=0.002$ in PowerFactory. With these values the results are as shown below.

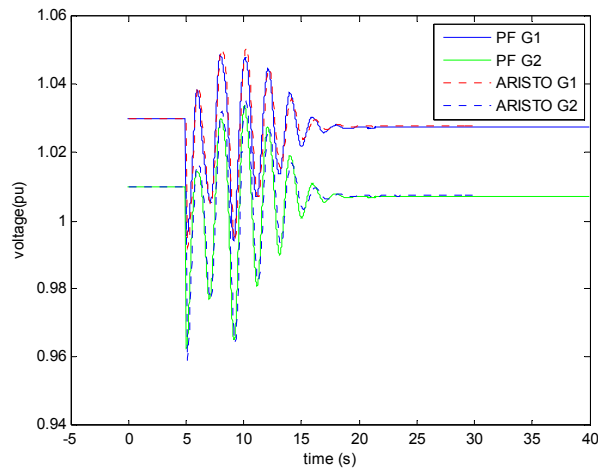


Figure 42. Voltage at generator bus 1 and 2 in ARISTO and in PowerFactory. The model used is the two simple area system and the event increase the load to 60%. The damping parameters are $D=0.02$ in ARISTO and $D=0.002$ in PowerFactory.

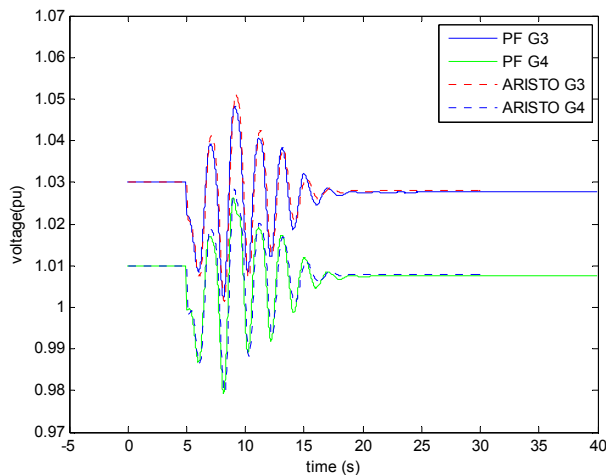


Figure 43. Voltage at generator bus 3 and 4 in ARISTO and in PowerFactory. The model used is the two simple area system and the event increase the load to 60%. The damping parameters are $D=0.02$ in ARISTO and $D=0.002$ in PowerFactory.

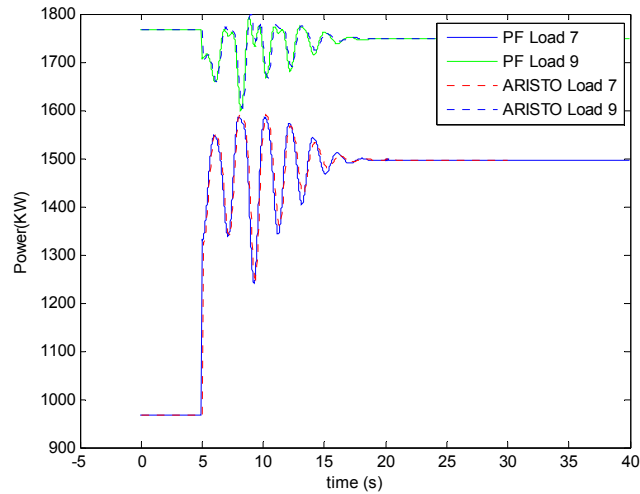


Figure 44. Active Power in the Loads in ARISTO and in PowerFactory. The model used is the two simple area system and the event increase the load to 60%. The damping parameters are $D=0.02$ in ARISTO and $D=0.002$ in PowerFactory.

The result in this case is now the same in both simulators. But when the disturbances which affects the system is changed from increase of load to a fault, the simulators again exhibit different results as shown below.

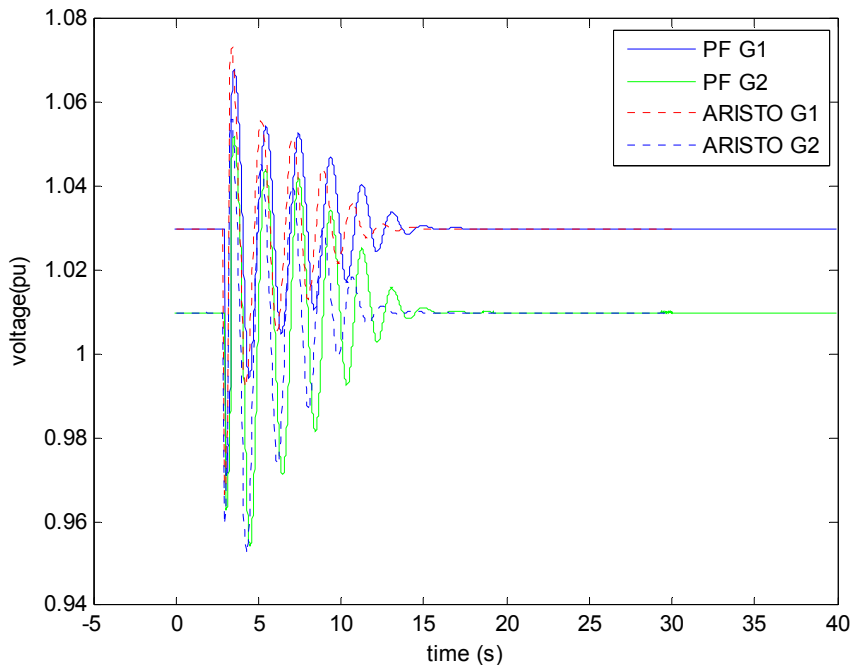


Figure 45. Voltage at generator bus 1 and 2 in ARISTO and in PowerFactory. The model used is the two simple area system and the event is a fault. The damping parameters are $D=0.02$ in ARISTO and $D=0.002$ in PowerFactory.

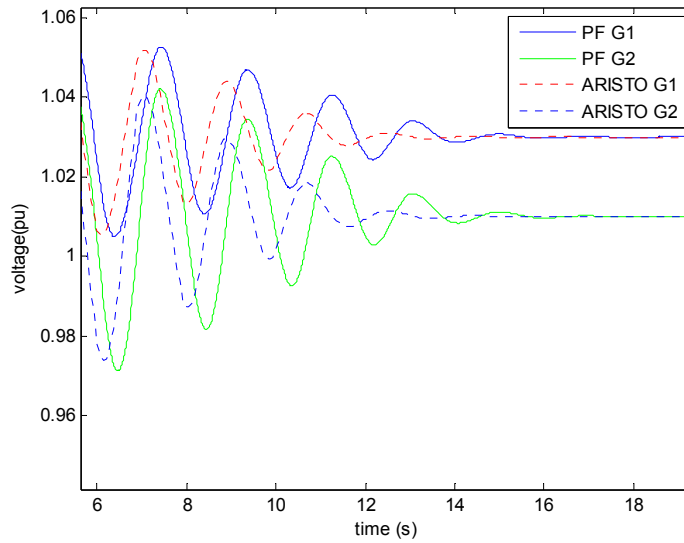


Figure 46. Voltage at generator bus 1 and 2 in ARISTO and in PowerFactory. The model used is the two simple area system and the event is a fault. The damping parameters are $D=0.02$ in ARISTO and $D=0.002$ in PowerFactory.

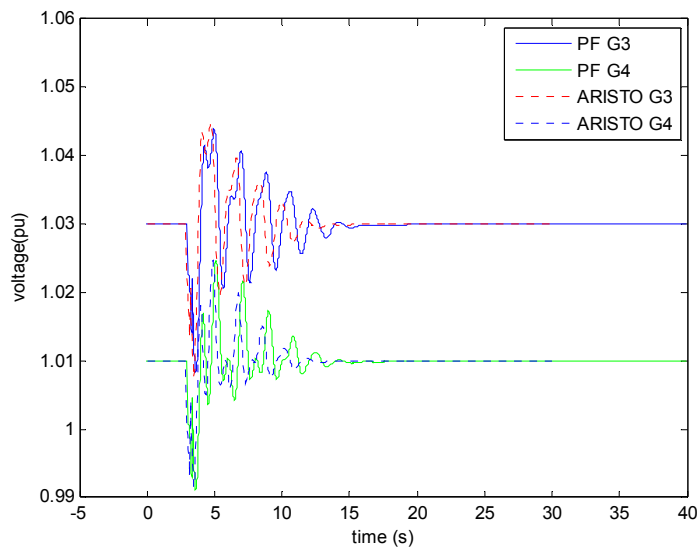


Figure 47. Voltage at generator bus 3 and 4 in ARISTO and in PowerFactory. The model used is the two simple area system and the event is a fault. The damping parameters are $D=0.02$ in ARISTO and $D=0.002$ in PowerFactory.

In conclusion, it seems not possible to achieve the same damping behaviour in ARISTO and in PowerFactory

4.6. THE LOAD

In ARISTO and in PowerFactory the load can be defined in different ways and in function of how it is defined the performance of this load will be different. To be sure that both systems are working in the same way it is necessary to know how to define this load.

In ARISTO the characteristics and the dynamics of the load are affected by a number of factors:

- The voltage and the frequency
- The dynamics properties
- The spontaneous variations (to simulate consumers actions)

To define these factors a number of models can be defined. These models are summarized in the table below.

| Type of function | Name | Description |
|---|------|---|
| Original nominal Load | | Load as defined in original load flow |
| Load admittance calculation | LAC | The load admittance in being calculated from factors below. |
| Load level calculation. | LLC | Change of load level |
| Static frequency-load characteristics | SFC | The quasi-static frequency dependence |
| Slow external load dynamics | SLD | The recovery of the load after voltage decay, due to tap-changer operation |
| Quasi-static voltage load characteristics and dynamics | SLC | Voltage characteristics after long term recovery and slow internal dynamic. |
| Fast internal dynamics | FLD | Fast dynamic due to motor load etc. |
| Re-energized load dynamics | REL | Defines the dynamics of the load after reconnection of the load |
| Stochastic load variations | STL | Stochastic variations of the load are calculated. |

Table 2. Types of Loads in ARISTO

The performance of each model can be represented in the following figure.

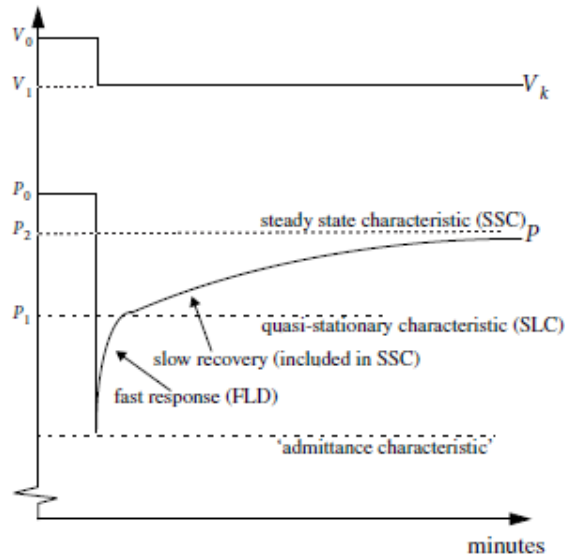


Figure 48. Types of Load response to disturbances. This graphic is taken from [5].

In PowerFactory the load is modelled as a Voltage dependency using an exponential approach as shown in the equations below taken from [4]:

$$P = P_0(aP \cdot \left(\frac{v}{v_0}\right)^{e_{aP}} + bP \cdot \left(\frac{v}{v_0}\right)^{e_{bP}} + (1 - aP - bP) \cdot \left(\frac{v}{v_0}\right)^{e_{cP}}) \quad (4.12)$$

Where:

$$1 - aP - bP = cP \quad (4.13)$$

And:

$$Q = Q_0(aQ \cdot \left(\frac{v}{v_0}\right)^{e_{aQ}} + bQ \cdot \left(\frac{v}{v_0}\right)^{e_{bQ}} + (1 - aQ - bQ) \cdot \left(\frac{v}{v_0}\right)^{e_{cQ}}) \quad (4.14)$$

Where:

$$1 - aQ - bQ = cQ \quad (4.15)$$

In this equation the sub index zero indicates the initial operating condition as defined in the input dialogue box of the Load Element.

The models that have been used above in the different tests are models in which the load is always working as a constant admittance. In ARISTO the load will behave as constant admittance if no load models are applied and in PowerFactory we only has to adjust the third exponent equal to two.

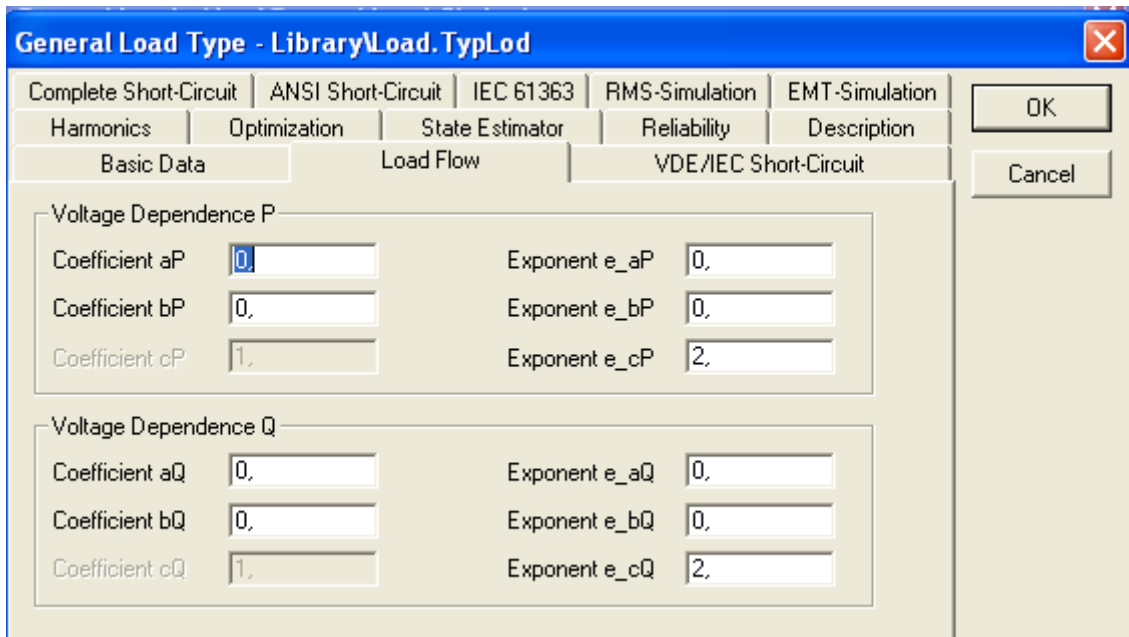


Figure 49. Definition in PowerFactory of a constant impedance Load

The test carried out in this case is with a simple model formed by one generator and one Load connected by a short line. In this case, the behaviour of the load is not influenced by others elements like others loads, others generators, transformer, etc. The event executed in this model is an increment to 30% in the load to the initial value.

The voltage and the Active Power in the Load are presented in the next figures.

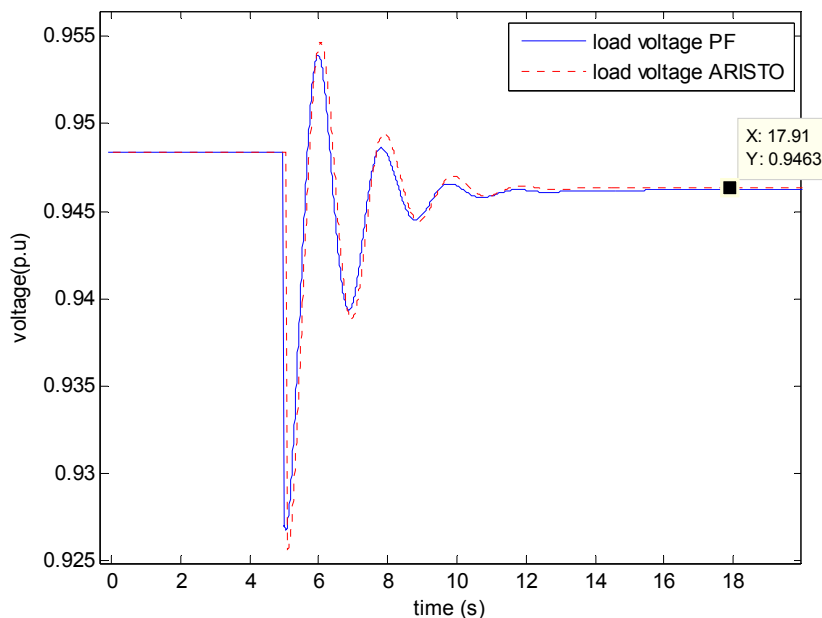


Figure 50. Voltage in the Load when the model is a simple generator connected to a load and an increment of 30% in the load in executed.

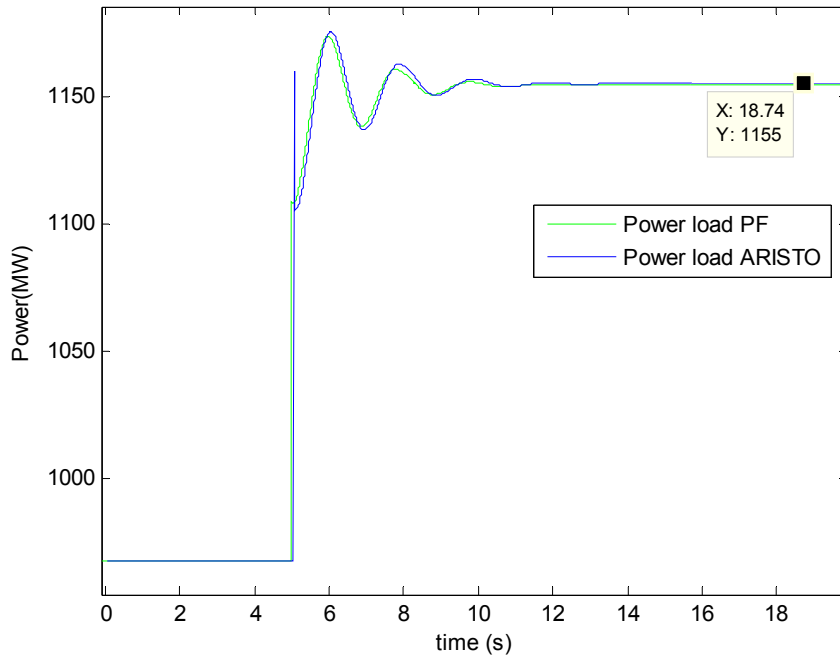


Figure 51. Active Power in the Load when the model is a simple generator connected to a load and an increment of 30% in the load is executed.

The peak appear in this graphic is due to the method used in ARISTO to solve the event, this peak is just in one step point and it must be neglected.

With the result obtained the impedance can be calculated. In PowerFactory the values reached when the event is executed is voltage $V=0.9462$ p.u and the Power $P=1155$ MW. In the ARISTO case the voltage is $V=0.9463$ p.u and the Power $P=1155.3$ MW. Therefore the impedance:

$$Z_{PF} = \frac{(0.9462 \text{ p.u} \cdot 400 \text{ KV})^2}{1155 \text{ MW}} = 124 \Omega$$

$$Z_{ARISTO} = \frac{(0.9463 \text{ p.u} \cdot 400 \text{ KV})^2}{1155.3 \text{ MW}} = 124 \Omega$$

In conclusion, the loads are correct and the same in both simulators.

4.7. ROTOR ANGLE

To check the rotor angle it is necessary to compare the behaviour in both simulators to a theoretical situation which will be considered as a reference.

The theoretical case has been chosen from [1]. The model is described in [8] and it is a simple model consisting of one generator connected by a transformer and two lines to an infinite bus. The event is executed to simulate a fault at 1 seconds of 0 Ohms and with a fault clearing time of 0.07 seconds.

ARISTO cannot reproduce the simulations in [8] because the voltage control and the PSS cannot be defined exactly in the same way and with the same parameters as in [8]. To be sure that PowerFactory is working properly, the simulation will first be run to compare PowerFactory to [1] and after that, PowerFactory will be compared to an ARISTO model that is as close to [8] as possible.

The first case is printed in the following graphics is the result from PowerFactory when the system is defined following the parameters and controllers from [1].

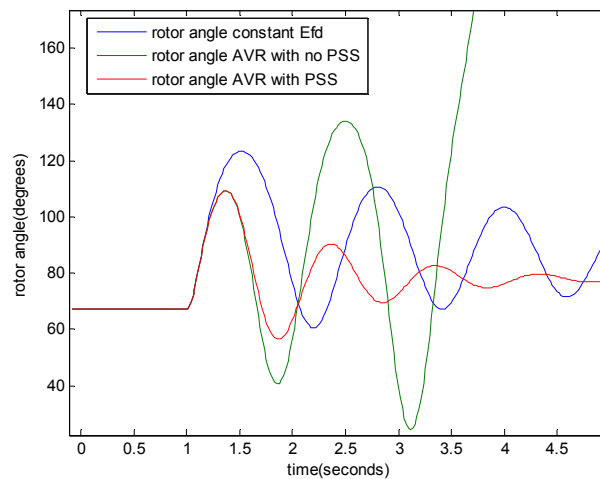


Figure 52. Rotor angle response with a fault cleared in 0.07 seconds in [1] model

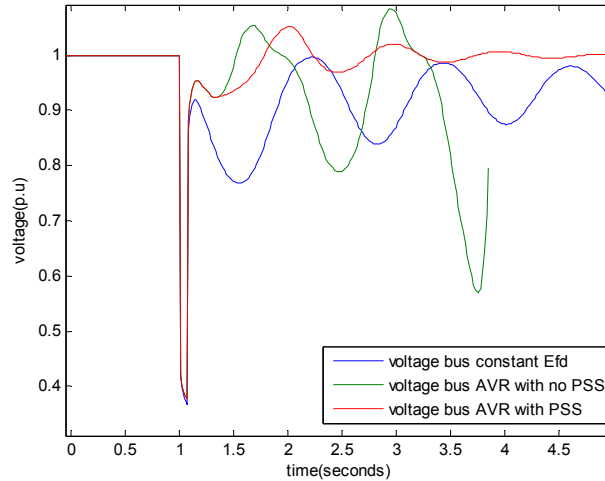


Figure 53. Terminal voltage response with a fault cleared in 0.07 seconds in [1] model

The previous figures are the result for the rotor angle of the synchronous machine and the voltage on the generator bus in three different situations. The first situation is defined with a constant excitation voltage, represent by E_{fd} , the second one is the same situation but adding the voltage control AVR defined in the book and in the last one the Power system stabilizer PSS is also added.

The following graphs represent in the same three cases but in those plots the output Active Power from the generator and the excitation voltage are presented.

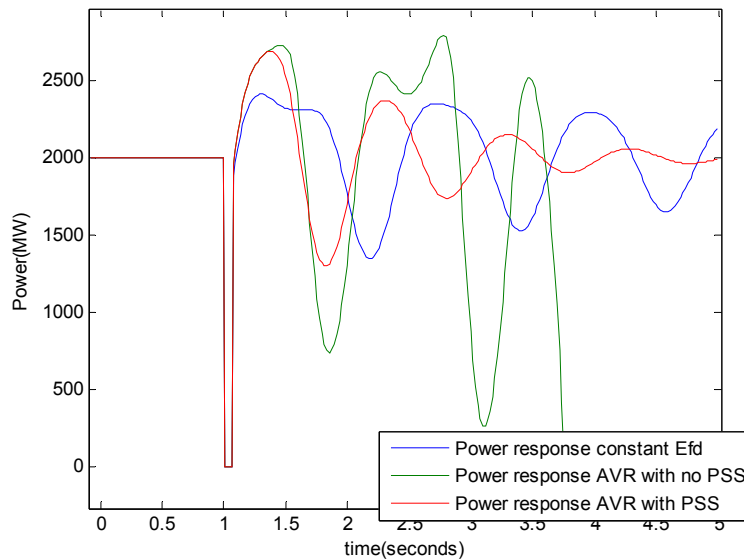


Figure 54. Active power PowerFactory response with a fault cleared in 0.07 seconds in [1] model.

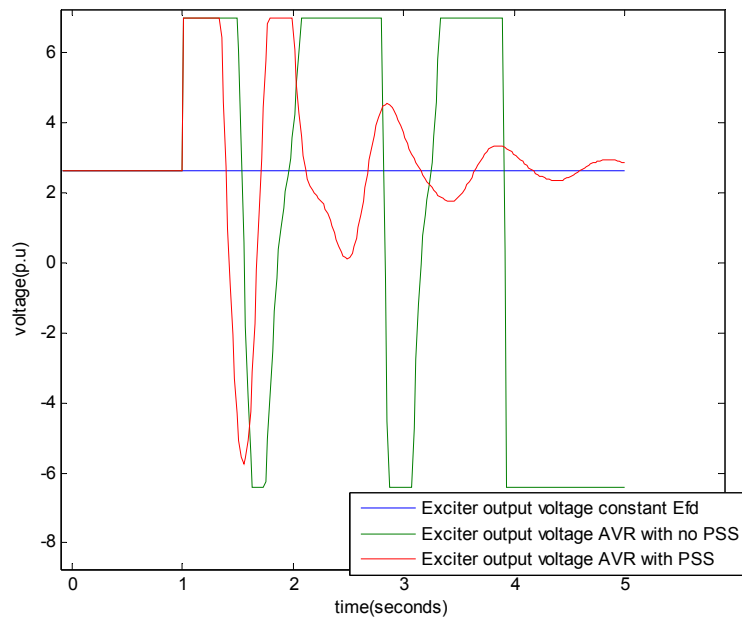


Figure 55. Exciter output voltage PowerFactory response with a fault cleared in 0.07 seconds in [1] model.

The results obtained from PowerFactory are the same as in [1]. Therefore, PowerFactory is working correctly.

To build this system in ARISTO, which has no infinite bus model, it is necessary to define a system with the characteristics defines below:

- The external grid will be defined as a synchronous machine with large S, small H and a governor working with this machine to fix the frequency to a constant value.
- In the case the system must work with constant excitation the value of the excitation voltage is $E_{fd}=2,64$ p.u

First of all, it is interesting to comment that in ARISTO is not at steady state at the beginning. While the system in PowerFactory and in [1] start at steady state, on the contrary, ARISTO needs around 18 seconds to reach steady state. In the graphics the start point is printed to show the frequency before the fault.

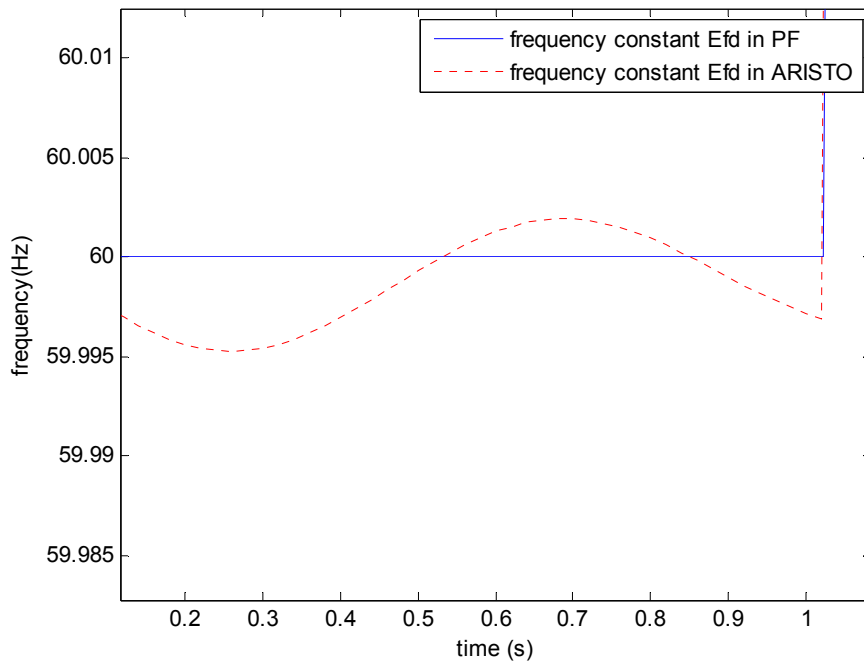


Figure 56. Frequency ARISTO and PF response with a fault cleared in 0.07 seconds in [1] model.

The same oscillations are found in the Active Power and the Voltage of the generator.

Disregarding the oscillations shown above because these variations are negligible, the test is executed and the following results represent the model described at the beginning without controllers and with a constant excitation voltage. The graphics compare ARISTO to PowerFactory.

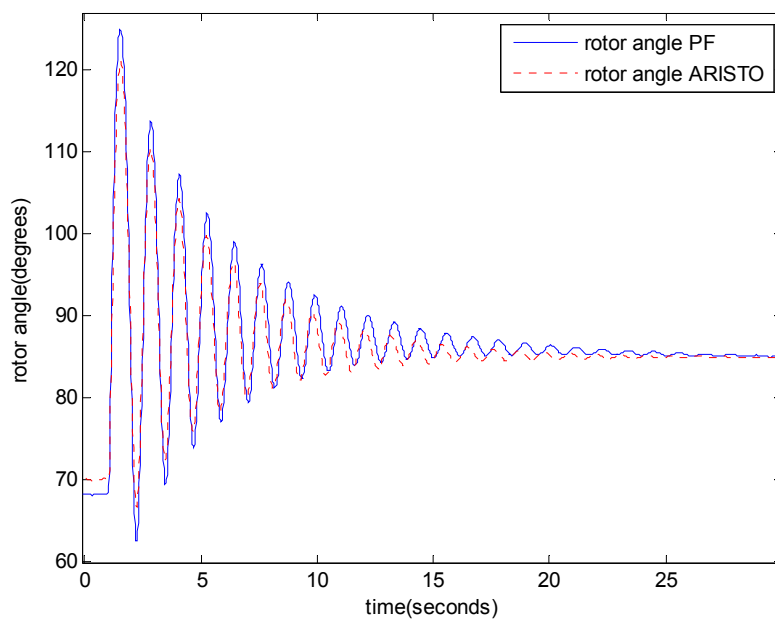


Figure 57. Rotor angle ARISTO and PF response with Efd constant in [1] model.

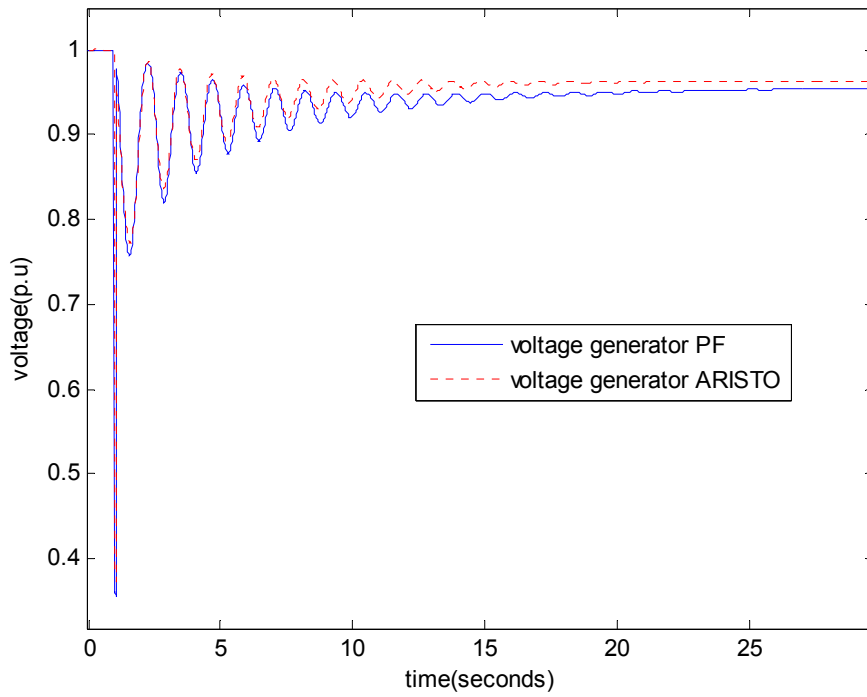


Figure 58. Terminal voltage ARISTO and PF response with Efd constant in [1] model.

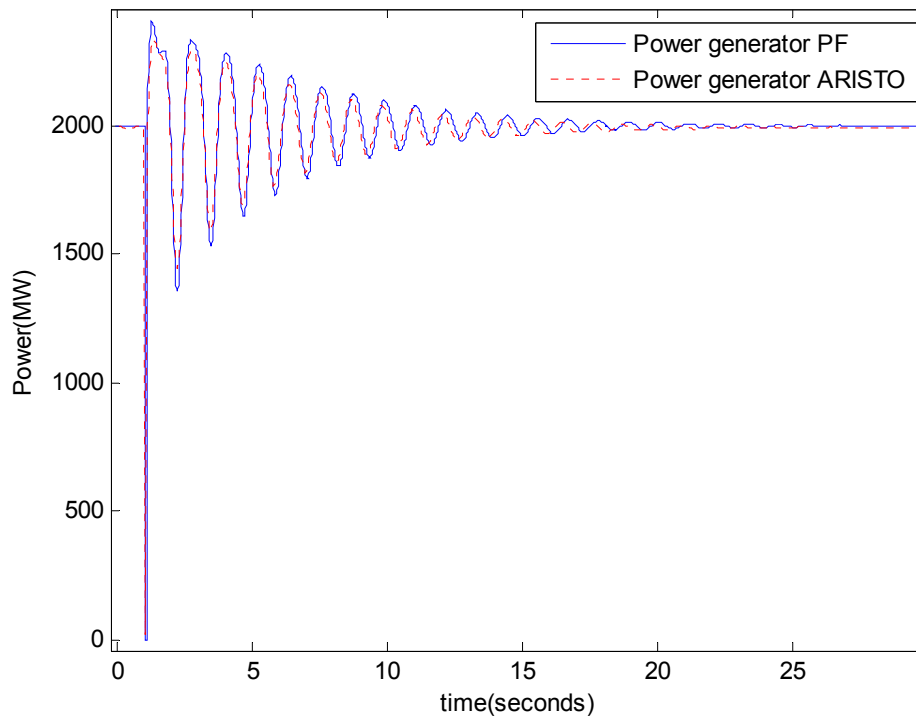


Figure 59. Active power ARISTO and PF response with Efd constant in [1] model.

The results are similar in both simulators without controllers.

Adding the voltage control and a variable excitation voltage the results obtained are the next ones.

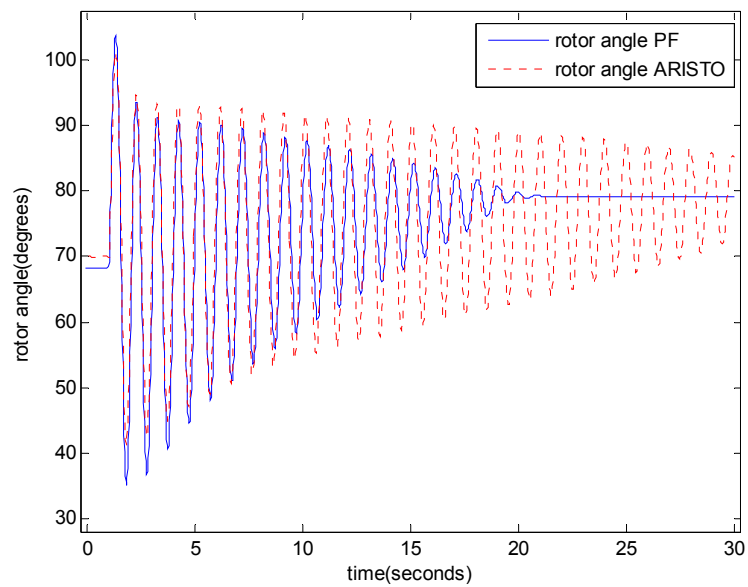


Figure 60. Rotor angle ARISTO and PF response with voltage controller in [1] model.

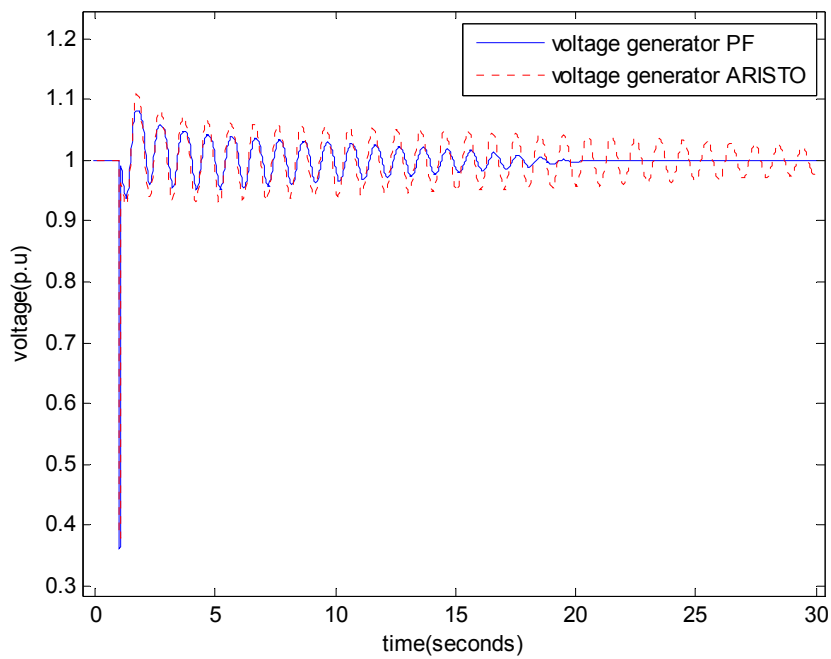


Figure 61. Terminal voltage ARISTO and PF response with voltage control in [1] model.

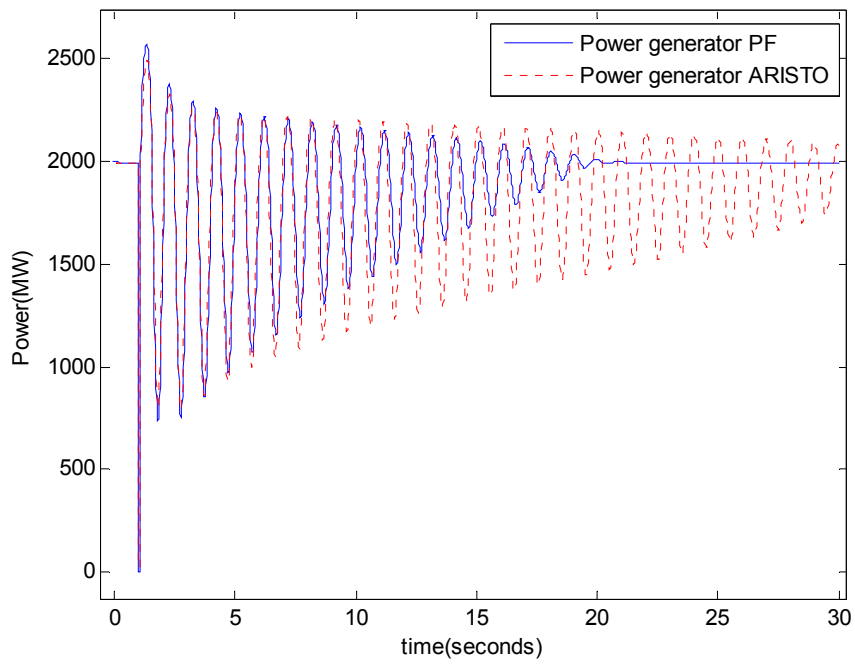


Figure 62.Active power ARISTO and PF response with voltage control in [1] model

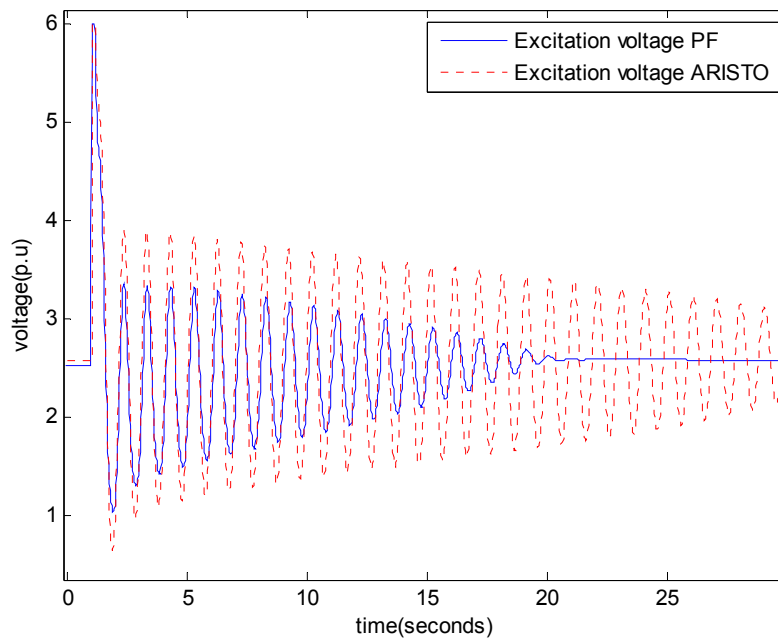


Figure 63.Excitation output voltage ARISTO and PF response with voltage control in [1] model

In this case the results are not the same in PowerFactory as in ARISTO. The controllers added in this situation are the only difference to the previous one without controllers, which was checked in earlier point and known to work properly.

In this point it is also interesting to try adjusting the damping parameter because in this model there are less the influence of others elements and it is a valid reference which is useful to compare. Adding a D value of 0.01 in ARISTO gives the results shown in the following graphics.

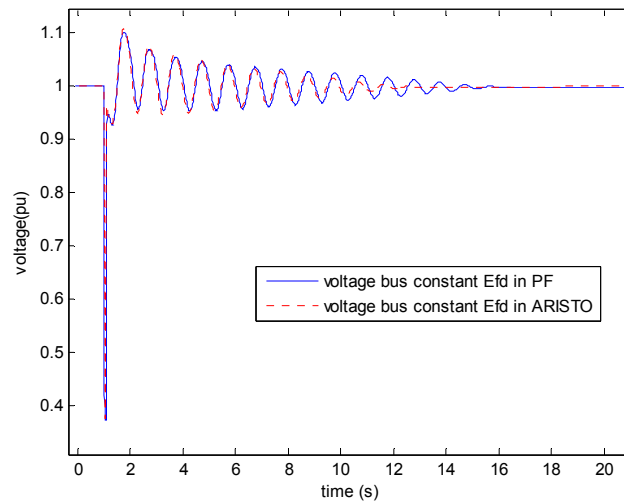


Figure 64. Terminal voltage ARISTO and PF response with damping factor in [1] model.

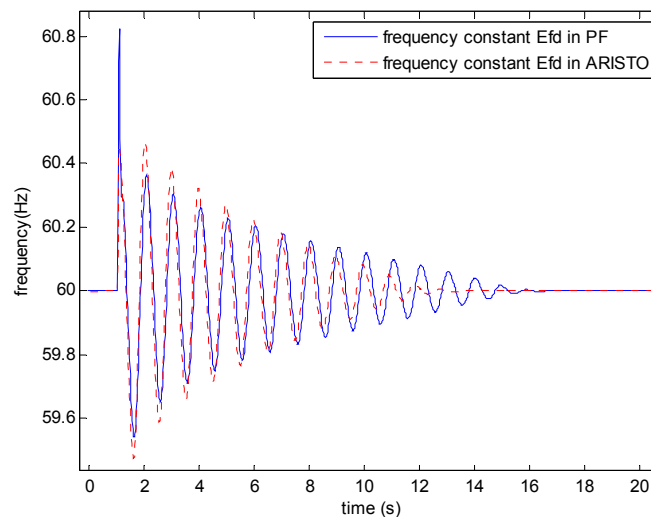


Figure 65. Frequency ARISTO and PF response with damping factor in [1] model.

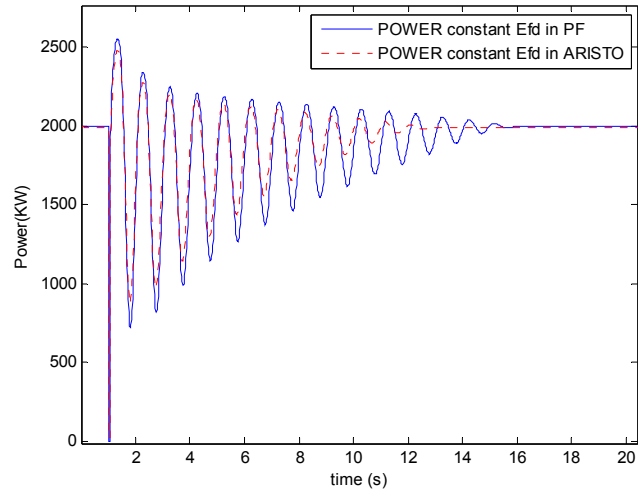


Figure 66.Active power ARISTO and PF response with damping factor in [1] model.

As was tested in the previous point about the damping parameter, it influenced in different way both simulators. While in ARISTO a damping factor of 0.01 is a large value, in PowerFactory this value is almost negligible. Without damping factor the oscillations in ARISTO was larger than in Power Factor but adding the damping factor this oscillations in ARISTO decreases a lot and are even less than in PowerFactory which almost is not influenced by this factor.

The next table represent the result obtained and the conclusion carried out.

The letter X means the case has been simulated by this simulator.

| Case | Kundur Book[1] | Power Factory | Aristo | Comments |
|---|----------------|---------------|--------|---|
| Generator and infinite bus without controllers. | X | X | X | The book and PF have the same results. However, the result from ARISTO is not as close as the previous case, because at the initial point ARISTO is not stable but during the event the difference between them is negligible. Furthermore, the rotor angle in ARISTO is not the same as PF and the book. |
| Generator and infinite bus with controllers from [1] example. | X | X | | The results are quite similar, the difference between them is around 0,1 % and could be as a result of the error in the different methods. |
| Generator and infinite bus with controllers from ARISTO. | | X | X | The results are different because the definition about the synchronous machine is not the same in both simulator and the damping in the system cannot be the same. |
| Generator and infinite bus with controllers from ARISTO and damping factor. | | X | X | Results are more similar than the previous case which means the damping factor has different influence in both simulators. In Aristo small variations in the damping factor makes large variations in results, however, this value is negligible in PF when the damping factor is as small. |

Table 3. Comparison between [1], PowerFactory and ARISTO. The model is a single generator connected to a infinitive bus by a transformer and two lines. A fault in 1 second is executed and the clearing time is 0.07 seconds.

4.8. THE SUBTRANSIENT REACTANCE

The subtransient reactance is an important parameter which influences the dynamic behaviour of the synchronous machine and therefore, the behaviour of the whole system. This parameter cannot be defined in ARISTO and to check it the test carried out is executed comparing the dynamic behaviour from ARISTO to PowerFactory in different cases when the subtransient reactance is varied.

The system used in this test is a system formed by one generator connected directly to an infinite bus by a very short line to be sure that other elements are not influencing the result. The event which is run is a fault in the middle of this line at 1 second during 0.07 seconds.

In the first case the subtransient and the transient reactance are the same in PowerFactory and, in turn, the same as the transient reactance in ARISTO. In this situation the dynamic behaviour of the system must be the same in both simulators because the synchronous machine sees the same reactance during the transitory period.

However, the result obtained is the following one.

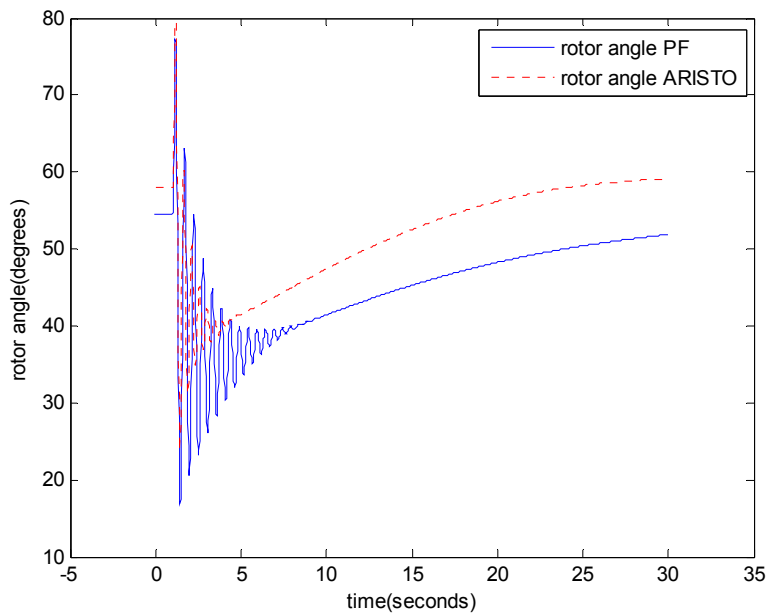


Figure 67. Rotor angle response in ARISTO and PF in a simple model formed by one generator and infinite bus when a fault is executed

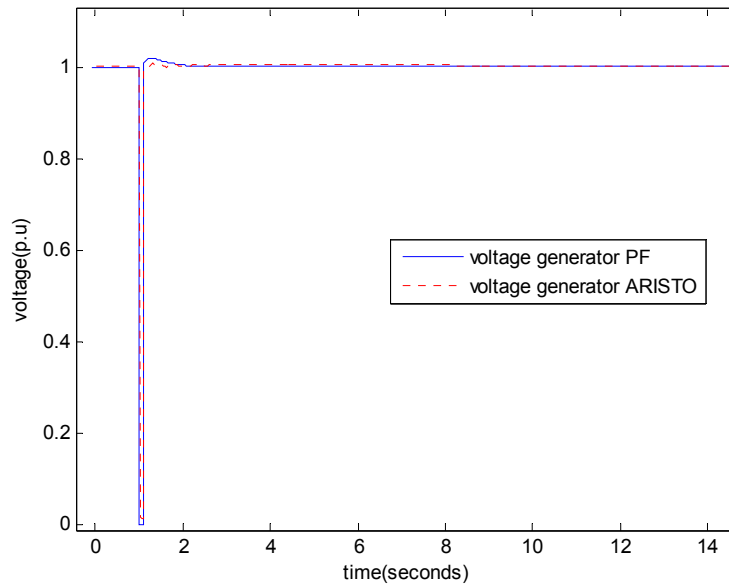


Figure 68. Terminal voltage ARISTO and PF response in a simple model formed by one generator and infinite bus when a fault is executed

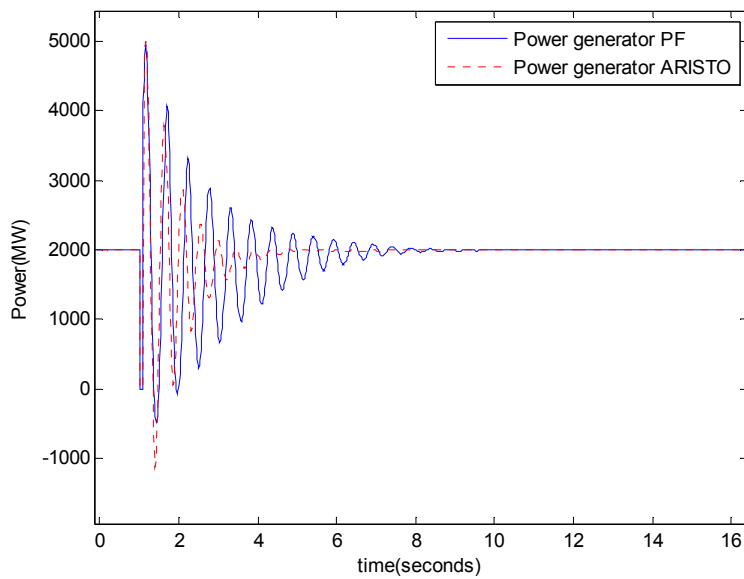


Figure 69. Active power ARISTO and PF response in a simple model formed by one generator and infinite bus when a fault is executed

The transitory period in ARISTO is faster than in PowerFactory. The oscillations disappear before in ARISTO than PowerFactory.

The next step is decreased the subtransient reactance in PowerFactory a little bit. The results are the next ones

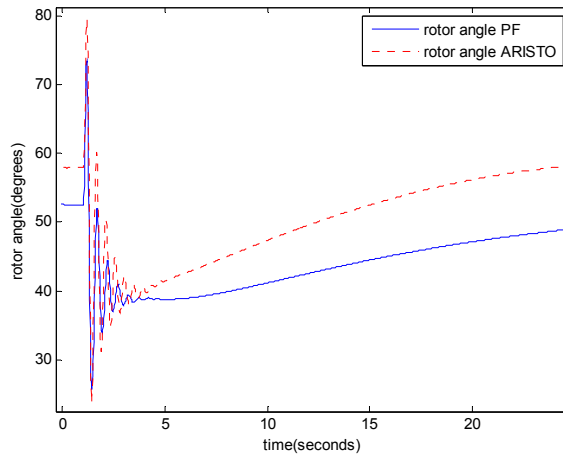


Figure 70. Rotor angle ARISTO and PF response in a simple model formed by one generator and infinite bus when a fault is executed. Different admittances

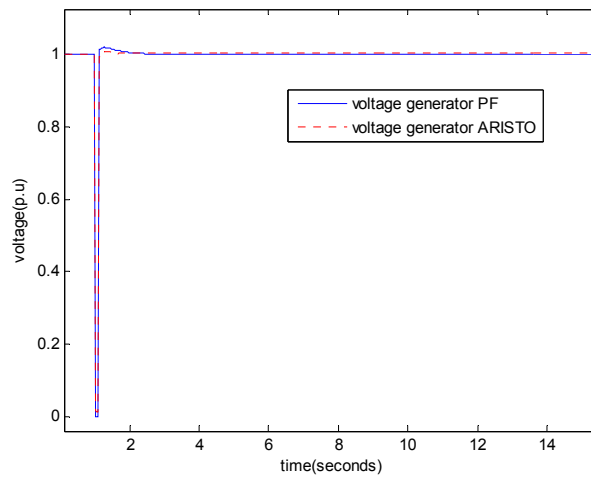


Figure 71. Terminal voltage ARISTO and PF response in a simple model formed by one generator and infinite bus when a fault is executed. Different admittances

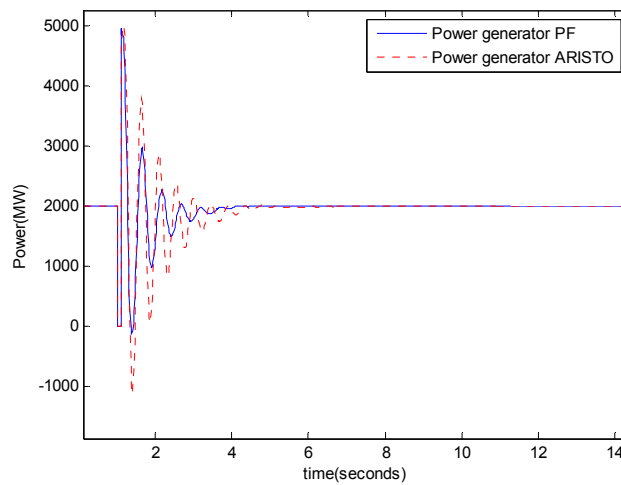


Figure 72. Active power ARISTO and PF response in a simple model formed by one generator and infinite bus when a fault is executed. Different admittances

In this case, PowerFactory is faster than ARISTO. The oscillations decrease when this reactance is changed, which means that the dynamic behaviour is influenced a lot by this factor.

In conclusion, the subtransient reactance cannot be defined in the same way in PowerFactory as in ARISTO. The subtransient reactance is defined in PowerFactory as X''_d but in ARISTO this reactance is defined in different way. To build the same model in PowerFactory and in ARISTO is not enough to define in PowerFactory the same transient and subtransient reactance to represent constant impedance seeing from the terminal of the generator.

Chapter 5

5. Differences between ARISTO and PowerFactory

This chapter describes the several differences found between both simulators during the different tests. The previous chapter described the tests carried out and how these differences have been found.

5.1. Modelling

5.1.1. DAMPING TERM AND SUBTRANSIENT REACTANCE

In the previous chapter was checked that the damping factor in both simulators affects different parts of the synchronous machine. The damping factor in PowerFactory represents a component of the damping torque proportional to the speed deviation, this damping represent the mechanical damping in the machine. However, in ARISTO the damping factor represents the damper winding, it means, this damping factor represents an electromagnetic damping.

Furthermore, the subtransient reactance cannot be defined in ARISTO. But this does not mean that in ARISTO the simulator is working without this reactance. If this was true setting the subtransient and the transient reactances equal in PowerFactory, would produce equal results in both simulators, which is not the case.

The subtransient reactance is thus defined in ARISTO by other parameters. In PowerFactory this parameter is X_d'' and in ARISTO it is the damping factor D .

The equivalent reactance in the d-axis of a synchronous machine in a subtransient-state is defined in [2] by the next equation.

$$X_d'' = X_l + \frac{1}{\frac{1}{X_a} + \frac{1}{X_D} + \frac{1}{X_f}} \quad (5.1)$$

Where :

- X_l correspond to the path the armature leakage flux takes around the stator winding and is referred to as armature leakage reactance

- X_a correspond to the flux path across the air-gap and is referred to as the armature reaction reactance.
- X_D corresponds to the flux path around the damping windings
- X_f corresponds to the flux around the field damping

The same definition is carried out to define it in the q-axis.

In PowerFactory this subtransient reactance is directly defined by X_d'' and X_q'' . However, in ARISTO it is defined by the damping winding factor which represents X_D and X_f in the equation 3.1. Therefore, the damping factor in ARISTO does not represent the same damping as PowerFactory, instead of that, this damping factor represent the damping windings in the machine which defines the subtransient reactance.

Although the difference in both simulators is found, defining these damping windings in ARISTO to give the same results as PowerFactory was not possible. The documentation about this simulator is not deep enough to know this equivalence. X_D to define the subtransient reactance in p.u impedance, however the value which is added in ARISTO is in p.u torque/p.u elect. torque/s. Therefore, the system cannot work exactly the same in both simulators.

5.2. A list of differences due to definitions

5.2.2. DATA

ARISTO has different methods to print and collect the data. One of these methods is the Trend Recording, using this tool the system converts the output from this space to the format chosen, Matlab, excel, etc, and it prints the values that have been selected in the Curve Diagram.

However, ARISTO can use another program to communicate directly with Matlab. This communication program developed at Lund University does not use the tool Trend Recording, instead of that, it takes directly the values from the internal result of the program and these results are from the network buses. That means, when the program should print the values of angle, speed, frequency from the generator for example, the values which are sent to Matlab are the results from the buses it is connected with, and these values are different in some situations.

5.2.3. TIME STEPS AND EVENTS

The two simulators specify time of events in different ways. PowerFactory is working with absolute time, that means when an event is defined at some specific time the program executes the event exactly at this time.

However, ARISTO uses relative time, which depends on the first point and it is always the point used for the Load flow. That means the events occur at a certain time but when the data is printed this first point is not considered. Therefore, the output data has always a delay of one step coming from the Load Flow which must be remembered.

5.2.4. FREQUENCY

The frequency is also different in PowerFactory and in ARISTO. The documentation acquired is not enough to define the frequency in both programs but it seems that in ARISTO this frequency is defined depending on the angle on the bus, however, in PowerFactory it is defined as a result from the impedance matrix. Even the frequency is defined in different ways and the result should be the same if the angles are developing in the same way. When a certain event is executed the behaviour of the angle is the same in ARISTO and in PowerFactory, that should produce the same result from the frequency in both programs but this result is not obtained.

5.2.5. ROTOR ANGLE

The rotor angle is also defined in different ways in PowerFactory and in ARISTO. A theoretical case was run and the results in ARISTO and PowerFactory are the same as the theoretical case, with the results for the generator bus (voltage, angle, etc) being the same in the three cases.

However, the rotor angle in PowerFactory is the same as the rotor angle defined in [1], where the theoretical case is taken, but both are different from ARISTO. In this situation, the behaviour of the system is the same in the three simulators, looking from the terminal of the generator to the rest of the system, but the differences appear inside the generator. That means this difference should depend on the definition of the internal parameters of the generator. It does not come from the subtransient reactance because it influences only the dynamic simulations.

5.3. A list of bugs in release 4.4.1

5.3.6. THE LOAD FLOW

The Load Flow in ARISTO has different behaviour compared to PowerFactory. Theoretically, in a Load flow the system should be defined by PV, PQ, SL buses. When a bus is defined as a PQ bus, the Load flow should fix the Active and Reactive Power at this bus. This situation is always true in PowerFactory but it is not in ARISTO.

Furthermore, in different cases, the result from ARISTO is not exactly the same as the theoretical. These theoretical cases are taken from [1] (two area system model) and are checked using other simulators than PowerFactory that gives the same result as the book but ARISTO does not reach this value. Instead of that, ARISTO starts with different values than the theoretical one but it needs some seconds to reach the stable values. After these seconds it maintained at this value as the stable one which is not the same value as the book.

Moreover, in some situations the simulator does not adjust the Power to the correct value. The sum of the power from the whole system should be zero, the generators feed the system with the same power it should consume, and this sum sometimes is not zero in ARISTO.

Events were also executed and the result has some difference between both simulators. The next plot describes better the situation.

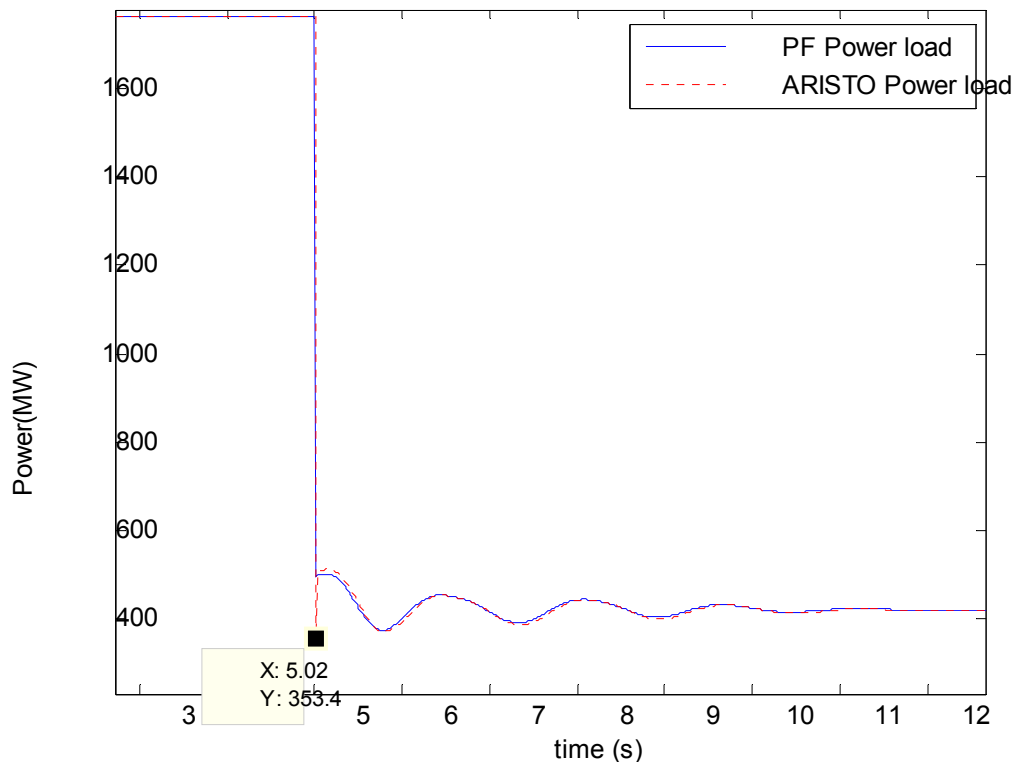


Figure 73. Active Power response of one Load. Two area system when Load 9 decreased the Load 80%

In this situation the model used to develop the event is the two area system model from [1]. The previous graphic represents the Active Power of one of the loads when it decreases to 80% of the initial value. To reach instantaneously this value the voltage and the frequency must drop a lot but if the system is correctly controlled this value cannot be reached directly. The real behaviour should be the blue one which is coming from PowerFactory but in ARISTO it assumes that the system could reach this Power and the result has a peak that is not correct. After the next time step this error is fixed and the behaviour from the system is as it should be.

This problem could come from the way to solve these events, at the first point the system take the output from the value is define in the event definition, without checking if the system could take these values. After this step it calculates the remaining values as the voltage, the current, etc. It seems that the simulator solves these events as the Load Flow, adjusts this bus as a PQ bus and calculates the rest of the system depending on this result.

Chapter 6

6. Stability limit of small test system

This chapter evaluates the transient stability of a small test system in both simulators. Study slow dynamics of the system is not the aim of this chapter, that study will be developed in the next chapter. On the contrary, this chapter is focused on the study of the behaviour against disturbances, how the system responds and recovers after fault clearing, to check the damping of the system and the oscillations when an event is executed, but all of this in a short time frame.

To reproduce these situations the model will be used to is taken from [1]. The simple two area system model is further described in [8].

Critical situations will be executed to stress the system as much as possible and because of that, critical clearing time studies will be made to study the transient stability.

6.1. Load Flow

It is important to check the state of the system at the beginning. For this reason, a load flow is necessary as first step.

The next table shows a brief review of both simulator Load Flows. A more complete list of the Load Flow could be found in [8].

| Bus | PowerFactory | | ARISTO | |
|-----|--------------|----------|-------------|----------|
| | Voltage(KV) | Angle(°) | Voltage(KV) | Angle(°) |
| 1 | 20.6 | 28.49 | 20.6 | 28.01 |
| 2 | 20.20 | 18.68 | 20.20 | 18.2 |
| 3 | 20.6 | 0 | 20.6 | 0 |
| 4 | 20.2 | -9.63 | 20.20 | -10.30 |
| 5 | 230.79 | 22.01 | 230.78 | 21.53 |
| 6 | 223.39 | 11.85 | 223.38 | 11.37 |
| 7 | 218.3 | 3.3 | 218.26 | 2.82 |
| 8 | 212.71 | -11.01 | 212.6 | -11.5 |
| 9 | 220.6 | -25.17 | 220.44 | -25.68 |
| 10 | 224.62 | -16.61 | 224.48 | -17.10 |
| 11 | 231.28 | -6.48 | 231.13 | -6.67 |
| | | | | |

Table 4. Comparison between PF and ARISTO Load Flow in two area system model.

As the result of the comparison it can concluded the result for both simulator are equal, and then, also that the initial stage for both are the same.

6.2. Critical clearing time

The critical clearing time is the principal criterion to transient stability assessment. This time means the maximum period of time which the fault can be actuated on the system without generating an unstable behaviour. The relays and the circuit breakers must work faster than this time.

Different situations are developed with a three-phase fault in several parts of the system.

6.2.1. Three-phase fault in the middle of one line

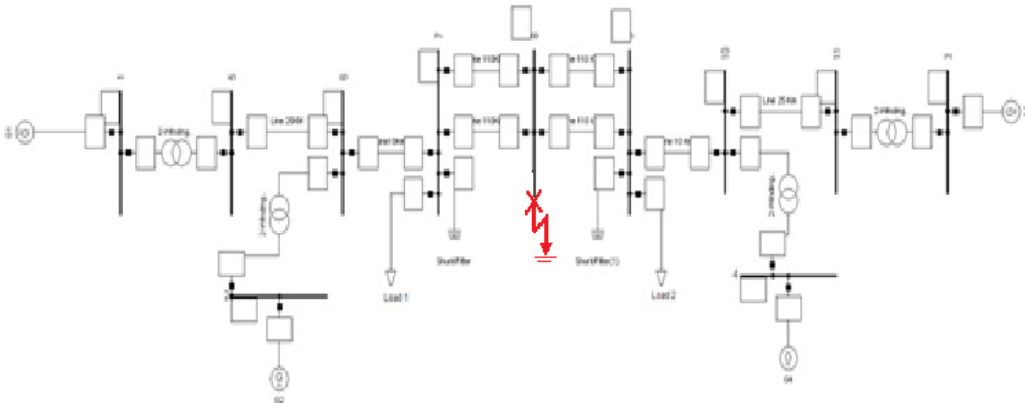


Figure 74. Three-phase fault in the middle of the line which connects Load 1 to Load 2.

In this situation a critical clearing time does not exist. The fault can be affecting the system until 10 seconds and the system is able to recover after the fault. There is not a critical time to isolate the fault.

One case that can be shown to compare the behaviour from both simulators is the situation when the time to open the breaker is 300 milliseconds after the fault occurs. Different quantities are shown.

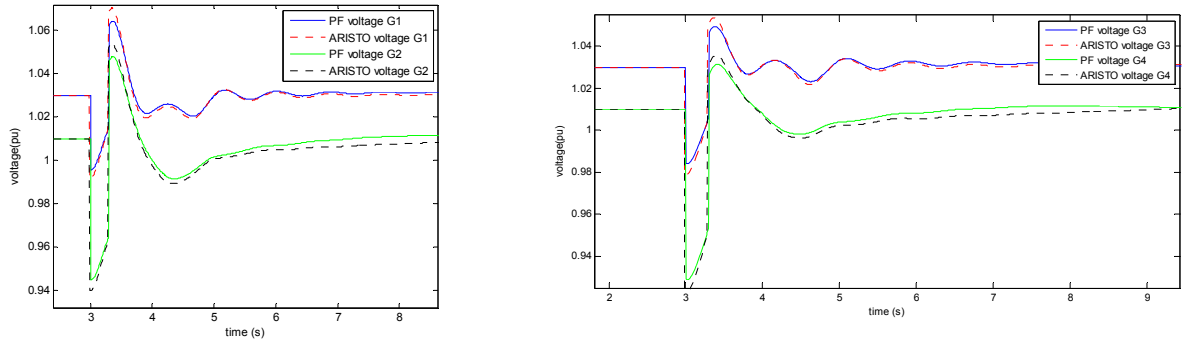


Figure 75. Terminals Voltage response with a fault cleared in 0.3 s when the fault is in the middle of one line.

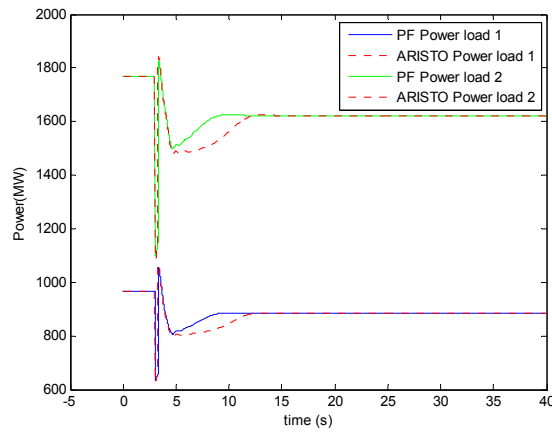


Figure 76. Active power response from the Loads with a fault cleared in 0.3 s when the fault is in the middle of one line.

The results from both simulators are pretty close. The difference is due to the definitions of the dynamic load that are not exactly the same. However, ARISTO and PowerFactory reproduce the same behaviour for the event on the line.

6.2.2. Three-phase fault on the line close to Load 2

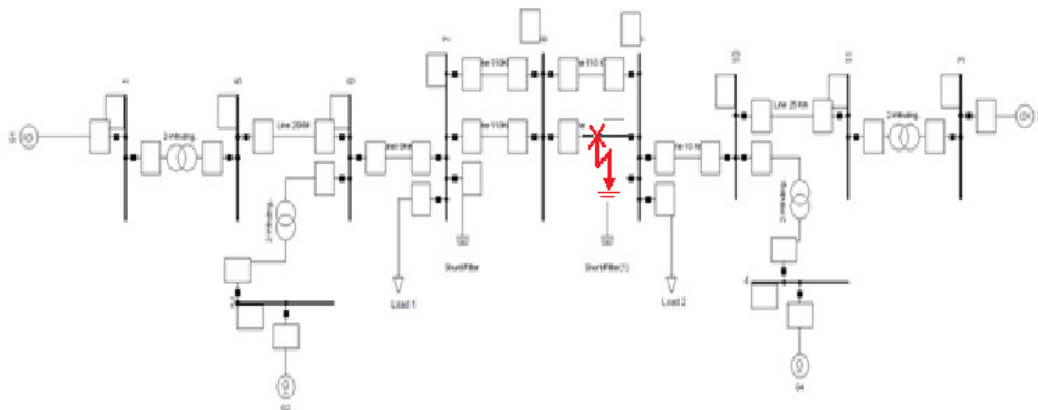


Figure 77. Three-phase fault in the lines close to Load 2

In this case, the fault is located in a distance of 55 km from the load 2. In this situation there is a critical clearing time although it is different for PowerFactory and ARISTO. The critical clearing time for ARISTO is 0.07 second and in PowerFactory is 0.08 seconds. The difference is not significant, therefore it can be concluded that both simulator reflect the same result.

Below is shown the behaviour of the system in ARISTO at the critical clearing time.

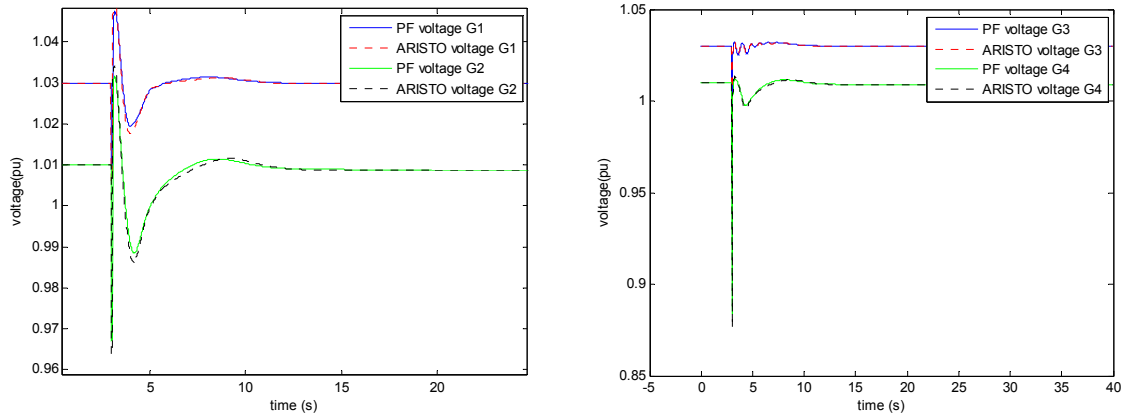


Figure 78. Terminals Voltage response with a fault cleared in 0.07 s when the fault is 55km from the load 2

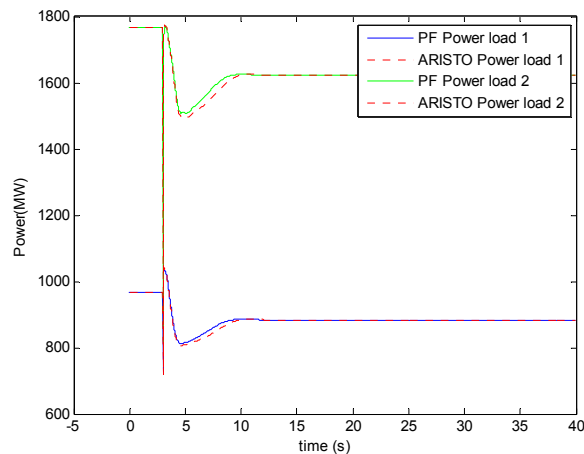


Figure 79. Active power response from the Loads with a fault cleared in 0.07 s when the fault is 55km from the load 2

The peak which appears in the load 1 is due ARISTO calculation methods that were previously described.

6.2.3. Three-phase fault on the line close to Load 1

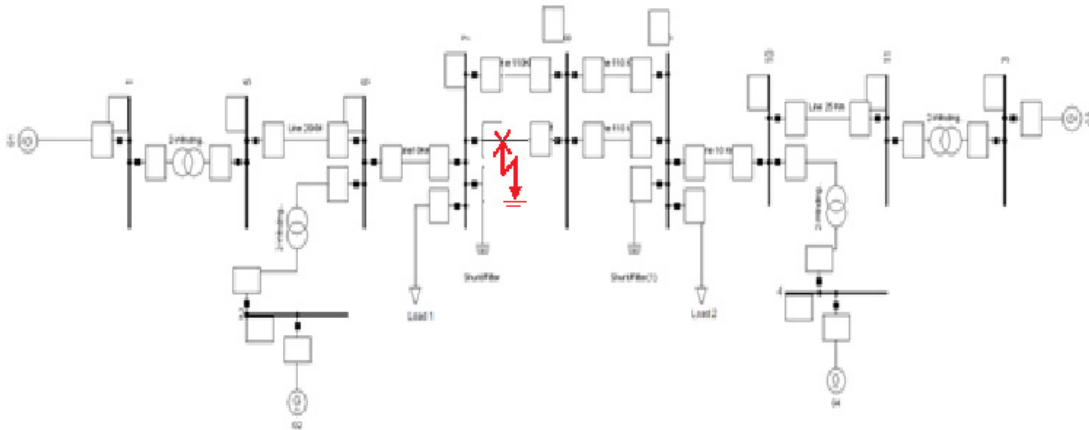


Figure 80. Three-phase fault in the lines close to Load 1

The result in this case is similar to the previous one. Both simulators have not exactly the same critical clearing time but it is close enough. The critical time in ARISTO is 0.4 seconds, while in PowerFactory this time is 0.5 seconds.

The results of a clearing time of 0.4 seconds are shown below.

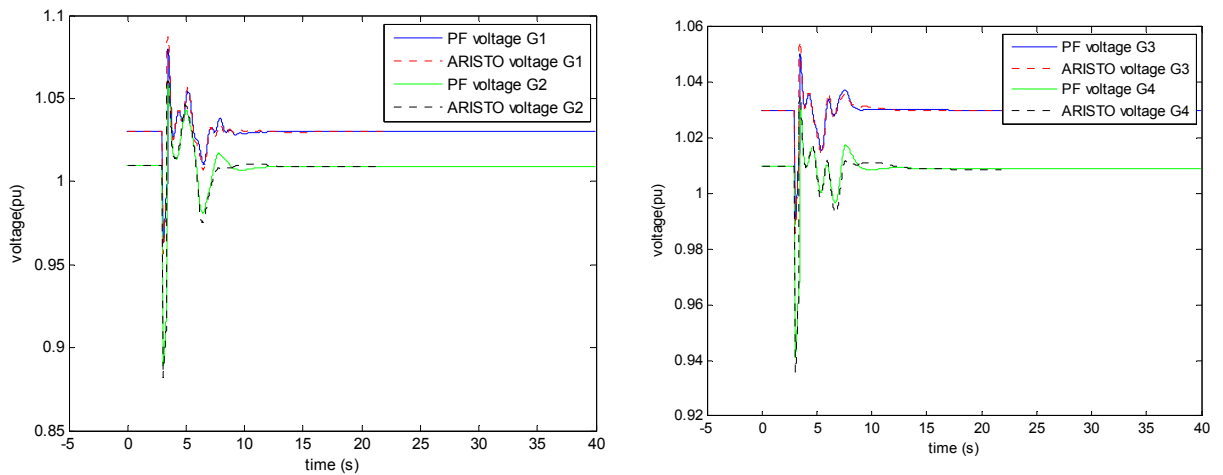


Figure 81. Terminals Voltage response with a fault cleared in 0.5 s when the fault is 55km from the load 1

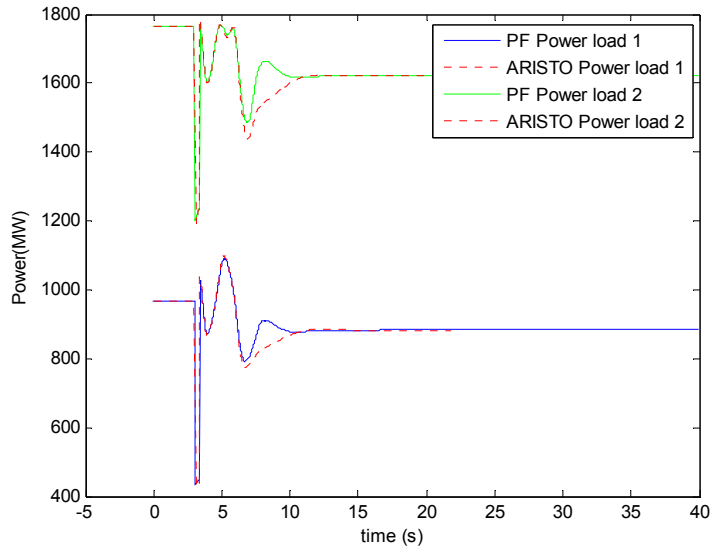


Figure 82.Active power response from the Loads with a fault cleared in 0.07 s when the fault is 55km from the load 1.

6.2.4. Three-phase fault on the line between bus 5 and 6

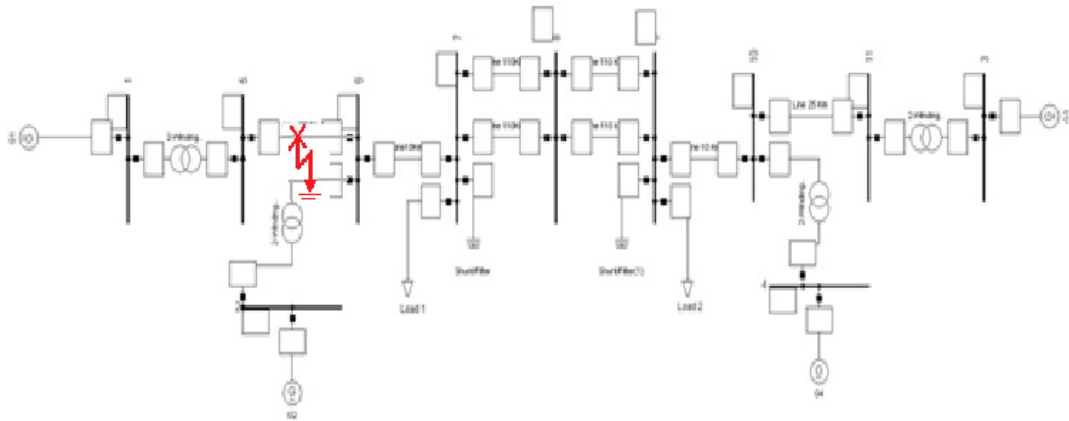


Figure 83.Three-phase fault in the lines which connects bus 5 and bus 6

The fault in this event is placed in the middle of the line which connects the buses 5 and 6. As in the previous tests the result from ARISTO and PowerFactory differ. The critical time in ARISTO is 0.12 seconds while in PowerFactory it is 0.14 seconds. The difference, therefore, is not significant.

Particular for this case is that the dynamic part in the voltage is more different than in the previous case.

The critical time gives the following result.

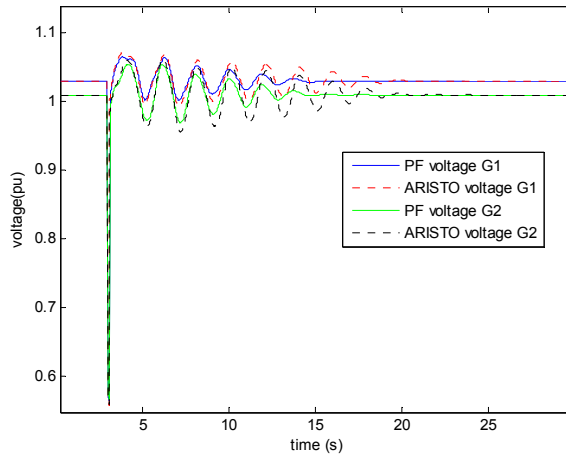


Figure 84.Terminals Voltage response from generator 1 and 2 with a fault cleared in 0.12 s when the fault is between the bus 5 and 6.

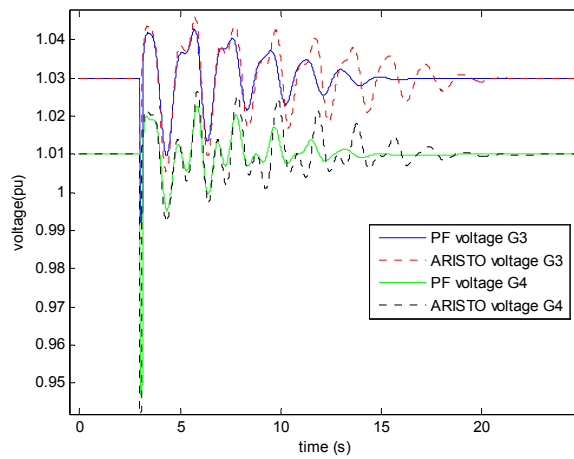


Figure 85.Terminals Voltage response from generator 3 and 4 with a fault cleared in 0.12 s when the fault is between the bus 5 and 6.

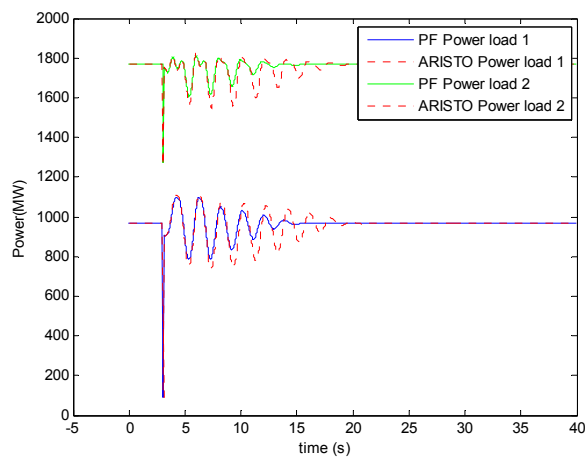


Figure 86.Active power response from the Loads with a fault cleared in 0.12 s when the fault is between the bus 5 and 6.

As it can be seen the oscillations are bigger than the previous tests. This phenomenon is due to the damping in the system that is different in both simulators. The disturbance is close to the generator and the influence of it is more important. The subtransient reactance which damps the generator and the system is not defined in the same way in ARISTO as in PowerFactory as was described in the previous chapters and this influence can be reflected in this event.

It is also useful to plot the situation when the system in ARISTO loses the synchronism. The following situation that is shown it is when the fault is cleared at 0.13 seconds.

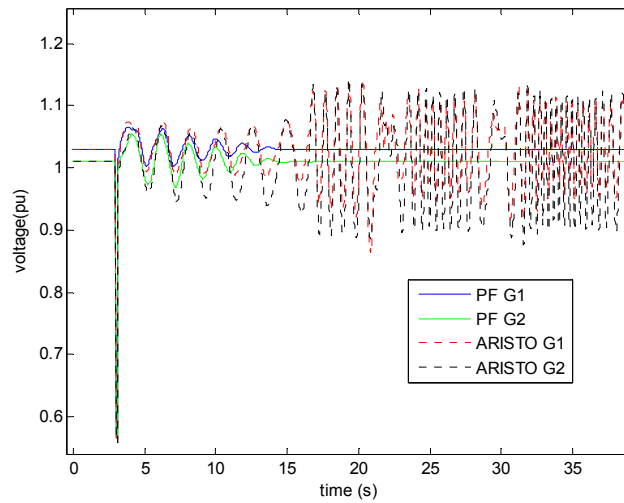


Figure 87. Terminals Voltage response from generator 1 and 2 with a fault cleared in 0.13 s when the fault is between the bus 5 and 6.

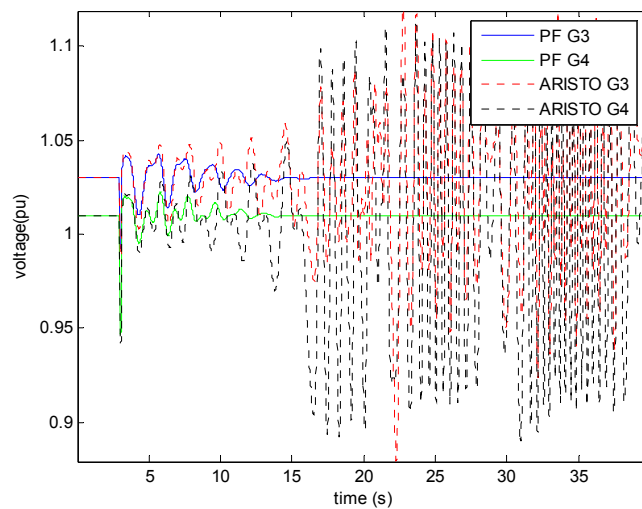


Figure 88. Terminals Voltage response from generator 3 and 4 with a fault cleared in 0.13 s when the fault is between the bus 5 and 6.

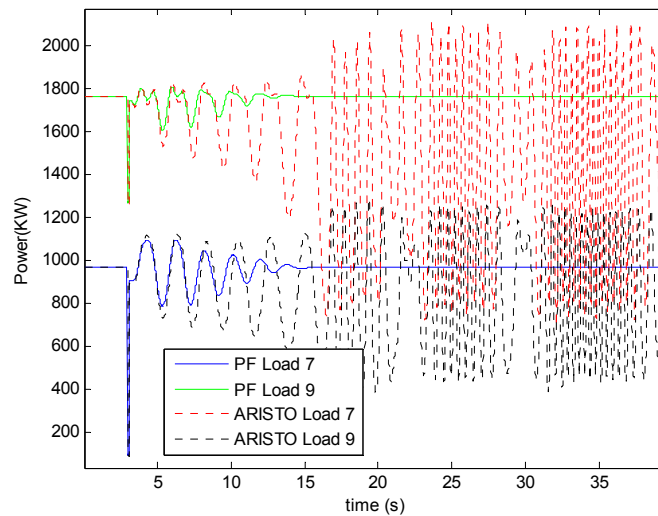


Figure 89.Active power response from the Loads with a fault cleared in 0.12 s when the fault is between the bus 5 and 6.

6.3. Discussion

The small test is developed to check if the differences between the simulators affect the results.

In this test is demonstrated that the differences between the damping term and the subtransient reactance influenced the result. PowerFactory damps better the disturbance than ARISTO due to these parameters, for this reason the critical clearing time is always smaller in ARISTO.

After several tests, it was concluded that different definition in the subtransient reactance gives as result that damping is always less in ARISTO and therefore, the oscillations due to disturbances are larger and the system loses the synchronism earlier in ARISTO than in PowerFactory.

However, in a real system this behaviour will never occur because the protection against the loss of synchronism, named Out of Step, will work before the voltage oscillates as in the plot.

Chapter 7

7. Stability limit of large test system

In this part the system to test is a Swedish system which is a fictitious system but it has dynamic properties that are similar to the real Swedish and Nordic power system. The system is intended for simulation of transient stability and long term dynamics. This model is based on the model described in [3], which uses a standardized Network data and PSS/E as simulation tool [3]. The data implement in this model is described in [8].

The purpose of this part is to test if both simulators are working properly in a situation with larger model and slower dynamics.

7.1. The initial values and the Load Flow

First of all it is necessary to check the initial values in both simulators and make sure that the results are the same as in [3]. To develop the same behaviour is important that the starting points are the same. This is straightforward in PowerFactory but more difficult in ARISTO.

The Load Flow in ARISTO differs from the reference; however, the result in PowerFactory is the same as in [8]. This means the conditions defined as initial point must be reached in both simulators because the system could work with those values as it is demonstrated with the result in PowerFactory.

The complete Load Flow from ARISTO and PowerFactory is added in [8] but to easily contrast the differences between both simulators the next table is shown.

| Bus | PowerFactory | | ARISTO | |
|------|--------------|----------|-------------|----------|
| | Voltage(KV) | Angle(°) | Voltage(KV) | Angle(°) |
| 4011 | 404 | 0 | 402,2 | -0,3 |
| 4012 | 404 | 1,93 | 404 | 4,3 |
| 1011 | 145,91 | 1,06 | 146 | 0,8 |
| 1012 | 146,9 | 4,63 | 146,9 | 4,3 |
| 1013 | 148,85 | 7,91 | 148,8 | 7,6 |
| 1014 | 150,8 | 10,5 | 150,8 | 10,2 |
| 4021 | 403,26 | 27,72 | 400 | -28,4 |
| 4022 | 397,54 | -12,87 | 394,6 | -13,2 |
| 1021 | 143 | 8,84 | 143 | 8,6 |
| 1022 | 138,23 | -10,78 | 137,2 | -11,1 |
| 4031 | 404 | -31,08 | 398,7 | -31,8 |
| 4032 | 405,45 | -36,31 | 400,7 | -37,1 |
| 2031 | 231,71 | -28,13 | 229,6 | -28,8 |
| 2032 | 242 | -16,09 | 242 | -16,7 |
| 1041 | 124,89 | -74,95 | 126,2 | -76 |
| 1042 | 130 | -58,35 | 130 | -59,6 |
| 1043 | 128,63 | -69,31 | 130 | -70,4 |
| 1044 | 127,85 | -60,24 | 129,4 | -61,5 |
| 1045 | 128,82 | -64,57 | 129,6 | -65,8 |
| 4045 | 398,68 | -61,79 | 397,1 | -63 |
| 4051 | 408 | -64,22 | 408 | -65,5 |
| 4061 | 392,89 | -50,14 | 393 | -51,3 |
| 4062 | 400,21 | -46,04 | 400,2 | -47,2 |
| 4063 | 400 | -41,97 | 397,6 | -43,1 |
| 4071 | 404 | 0,9 | 405,9 | 0,6 |
| 4072 | 404 | 0,89 | 404 | 0,6 |
| 4041 | 400 | -46,4 | 400 | -47,5 |
| 4042 | 400 | -49,69 | 396,5 | -50,8 |
| 4043 | 396,14 | -56,19 | 392,8 | -57,4 |
| 4044 | 395,29 | -56,83 | 392,5 | -58 |
| 4046 | 396,33 | -56,86 | 392,9 | -58,1 |
| 4047 | 408 | -51,92 | 404,6 | -53 |
| | | | | |

Table 5.Comparison between the Load Flow from PowerFactory and ARISTO

The result from the Load Flow in ARISTO is not the same as in PowerFactory while this last one has the same values as the reference. In the previous table it is demonstrated that some values differ more than others.

For example, while the bus 4051 has values pretty close when it is compared in both simulators, the bus 4046 differs around 4 kV between PowerFactory and ARISTO. The result obtained from ARISTO is not the expected one. Like mentioned in the previous chapter the Load Flow in ARISTO does not take the values that are expected.

In several cases, the buses are defined as a PV bus, which means when Active Power and Voltage are set and the program must vary the Reactive Power and therefore the angle to obtain the selected Active Power and the Voltage. However, the program takes other values and the voltage and the active power are not the same as in the reference and consequently neither the reactive power nor the angle are correct which means an error that may influence the whole system.

In addition, the Load Flow should define the first step in the program. The result that ARISTO shows in the screen is the result for the next step which means the values from the system at 0.01 seconds. The graphics below show that the values from the Load Flow are not the same as the next step.

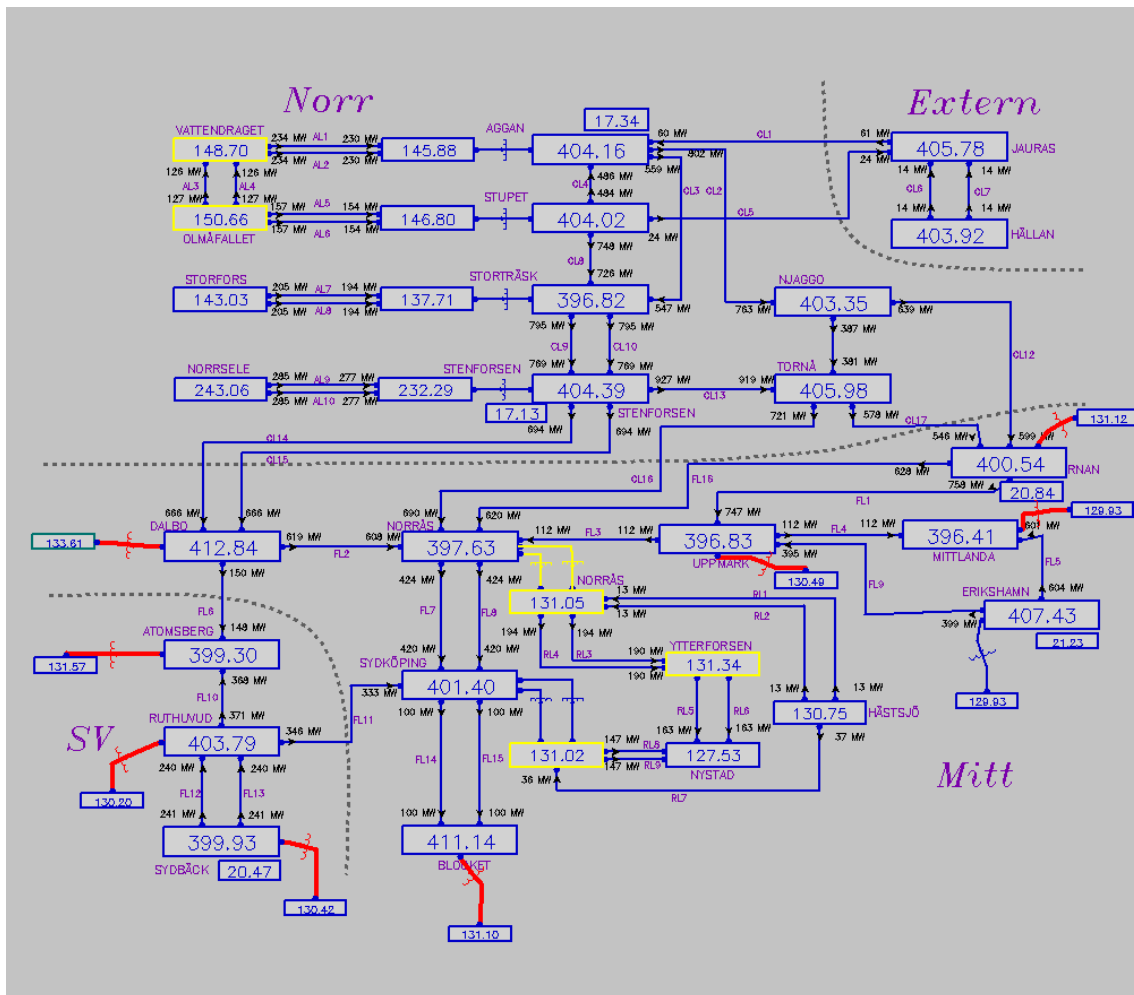


Figure 90. First step result in Nordic 32.

In the graphics each Switchyard shows the Voltage in the corresponding bus. The buses are named in different way. In ARISTO each bus is called with names, however, in [3] the buses are called with numbers. The bus called DALBO in ARISTO

corresponds to the bus 4041. This bus in the Load Flow has a value of 400 kV but in the next step the value of the voltage increases to 412.84 kV.

This result could be due to that ARISTO does not use the Load Flow values for the initial values or because these values change in a faster way. Both situations are not correct because if it is caused by the wrong initial values and the behaviour of the system is not appropriate since steady state is expected.

A second error occurs in the system when Not a Number (NaN) appears in the result. This value belongs to the device SVC (Static Var Compensators) which is not connected to the system, therefore the result must be zero. In the graphic below the object list from the Switchyard RUTHUVUD (bus 4062 in the reference model) is printed and NaN appears when the SVC is disconnected.

| RUTHUVUD_4_FT62 | | | | | | 12-04-23 21:27:56.00 | |
|------------------|---|-------------------------------------|-------------------------------------|--------|--------|----------------------|--|
| Busbars | | 1 | 2 | V | f | | |
| FT62_A400_RUTHUV | 1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | +403.8 | +50.0 | | |
| FT62_B400_RUTHUV | 2 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | +403.8 | +50.0 | | |
| Objects | | | | P | Q | | |
| FL10 | | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | -370.6 | -2.4 | | |
| FL11 | | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | -346.2 | +114.3 | | |
| FL12 | | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | +239.5 | -19.5 | | |
| FL13 | | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | +239.5 | -19.5 | | |
| TRAF0_LOAD_62 | | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | -305.4 | -101.4 | | |
| FT62_SVC_SHUNT | | <input type="checkbox"/> | <input type="checkbox"/> | -NaN | -NaN | | |
| FT62_X1 | | <input type="checkbox"/> | <input type="checkbox"/> | -0.0 | -0.0 | | |
| FT62_X2 | | <input type="checkbox"/> | <input type="checkbox"/> | -0.0 | -0.0 | | |
| FT62_X3 | | <input type="checkbox"/> | <input type="checkbox"/> | -0.0 | -0.0 | | |
| FT62_T1_LAST | | <input type="checkbox"/> | <input type="checkbox"/> | -0.0 | -0.0 | | |
| FT62_T2_LAST | | <input type="checkbox"/> | <input type="checkbox"/> | -0.0 | -0.0 | | |
| FT62_T3_LAST | | <input type="checkbox"/> | <input type="checkbox"/> | -0.0 | -0.0 | | |
| RUTHUVUD_G1 | | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | +181.4 | +9.5 | | |
| RUTHUVUD_G2 | | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | +181.4 | +9.5 | | |
| RUTHUVUD_G3 | | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | +180.4 | +9.5 | | |

Figure 91.Object List from 4062 when NaN appears in the reference model.

It is important to mention that in several cases one more error in the calculation occurs when the data is changed. In one situation when the data from the generator 4062 is changed the result of the power is not correct. The total power must sum to zero in the bus because of the principle of the conservation of the energy but in this case this does not happen. The changes in the generator are the reactance of the transformer in the generator of the bus 4062 and the voltage defined in the initial conditions. The power in the same bus is printed and it can be seen that the sum of the power generated and the power consumed is not the same, therefore the sum of power is not zero.

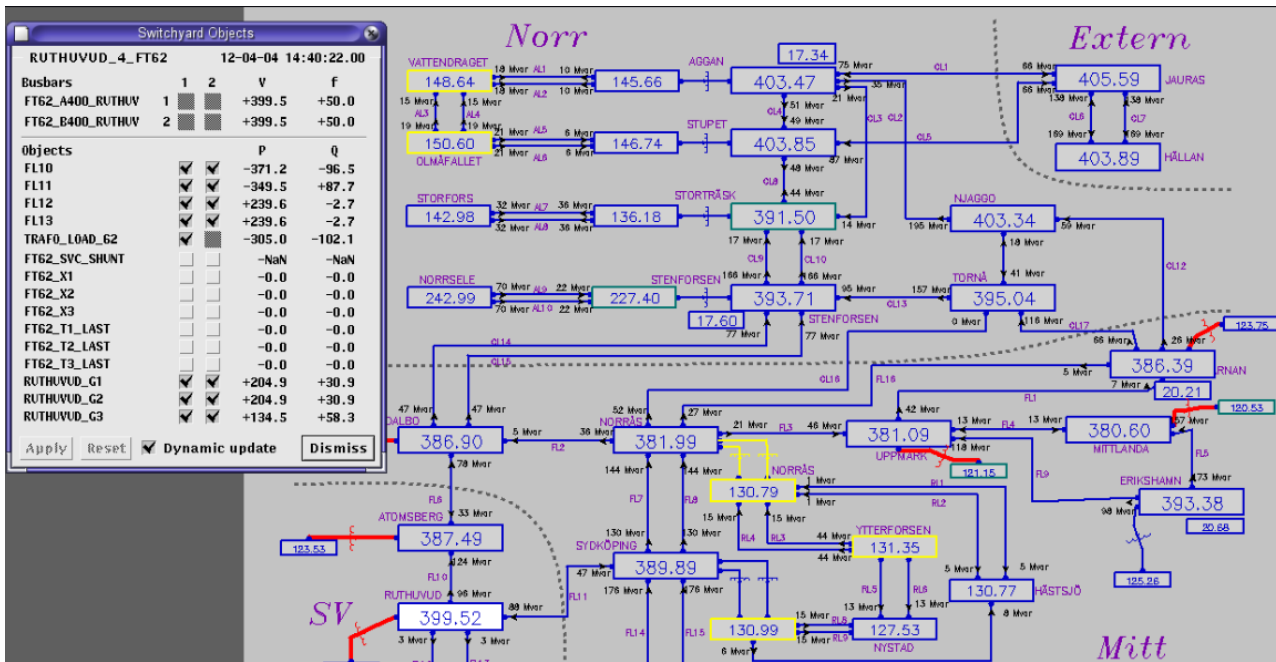


Figure 92. Result from ARISTO when NAN appears and the sum of power is not zero. The model used is NORDIC 32 when the generator from 4062 is changed.

However, when a copy of this model is executed, this error is fixed and the sum of the power is zero. When the data of the system is changed again this error appears, the next figure shows the result.

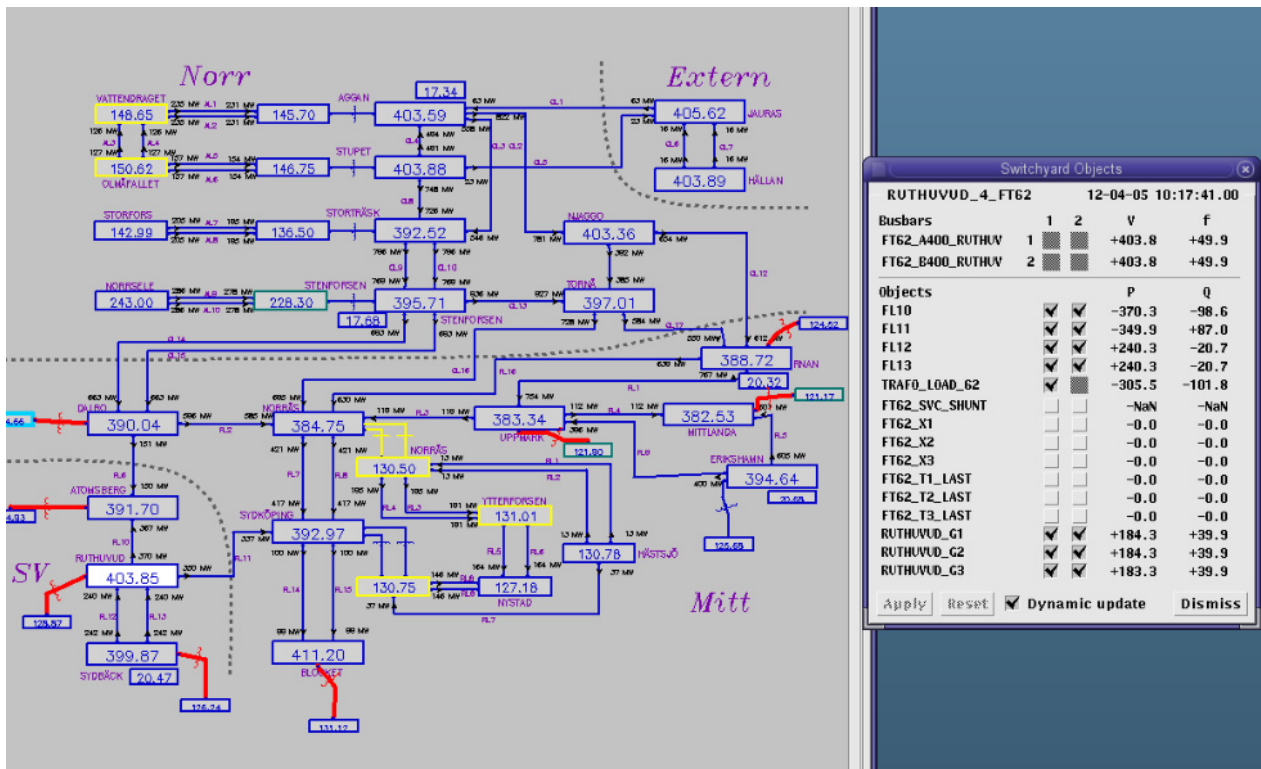


Figure 93. Result from ARISTO when NAN appears and the sum of power is not zero. The model used is NORDIC 32 when the generator from 4062 is the original one but the situation is not the same as the reference.

In this case the result is even worse than the first case. But when a new copy is executed the error is fixed again. In a real situation the model is changed without any copy and without checking the values from the whole system, therefore, in a real situation these errors are not fixed and the model could be incorrect.

7.2. The steady state

The initial values in PowerFactory and in Aristo are different for the same situation. The result obtained in PowerFactory is the same as in the reference while it is not the same in ARISTO. It is possible that, after some time, ARISTO reaches the same stable values as in the reference. After this time it needs to stabilize the system the situation before an event could be the same in both simulators.

To check this it is necessary to run the model in PowerFactory and in ARISTO at least 60 second to reach a stable situation in ARISTO. The voltages at some buses have been collected and compared between both simulators.

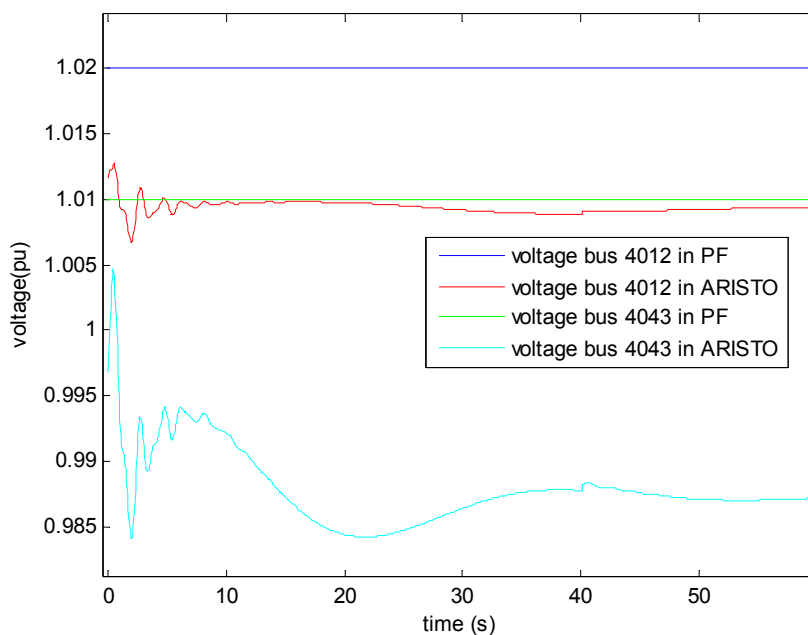


Figure 94. Voltages in both simulators (ARISTO and PowerFactory) from buses 4014 and 4043 when the system tries to reach the steady state in ARISTO.

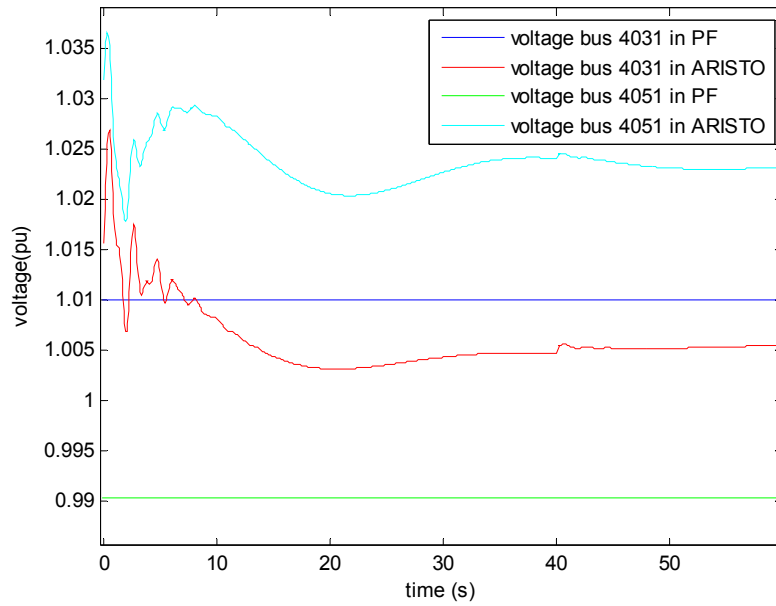


Figure 95. Voltages in both simulators (ARISTO and PowerFactory) from buses 4014 and 4043 when the system tries to reach the steady state in ARISTO.

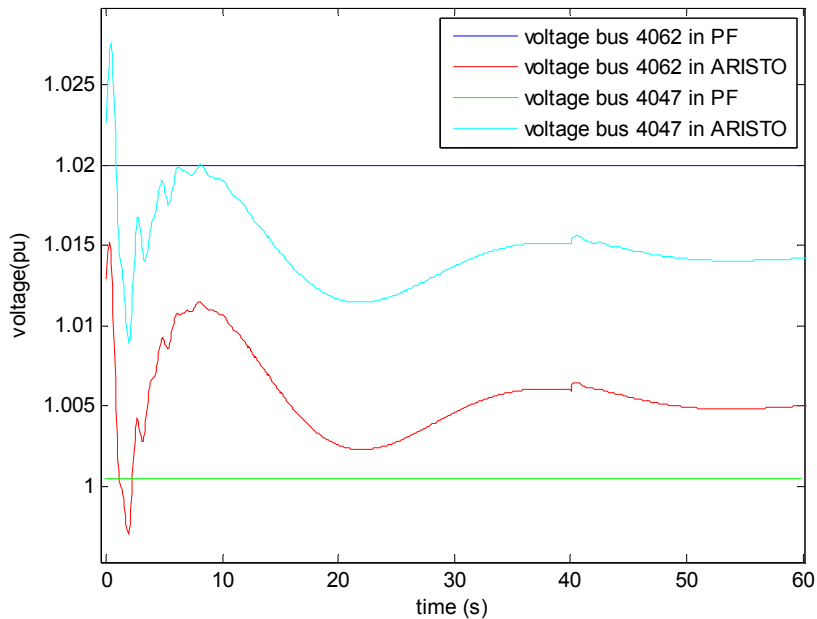


Figure 96. Voltages in both simulators (ARISTO and PowerFactory) from buses 4014 and 4043 when the system tries to reach the steady state in ARISTO.

The result showed in the previous figures however demonstrates that the steady state reached in the simulators is not the same. PowerFactory works from the beginning with constants stable values coming from the Load Flow, however ARISTO needs time to reach a stable situation which it is not the same as it is expected. This means that ARISTO consider as steady state different from the reference.

7.3. Simulating a Voltage collapse

To see if the deviations in the initial state are important, a voltage collapse event is simulated. The simulation is one of the cases taken from [3] when one of the generators at bus 4047 is tripped.

The result from PowerFactory is the following one.

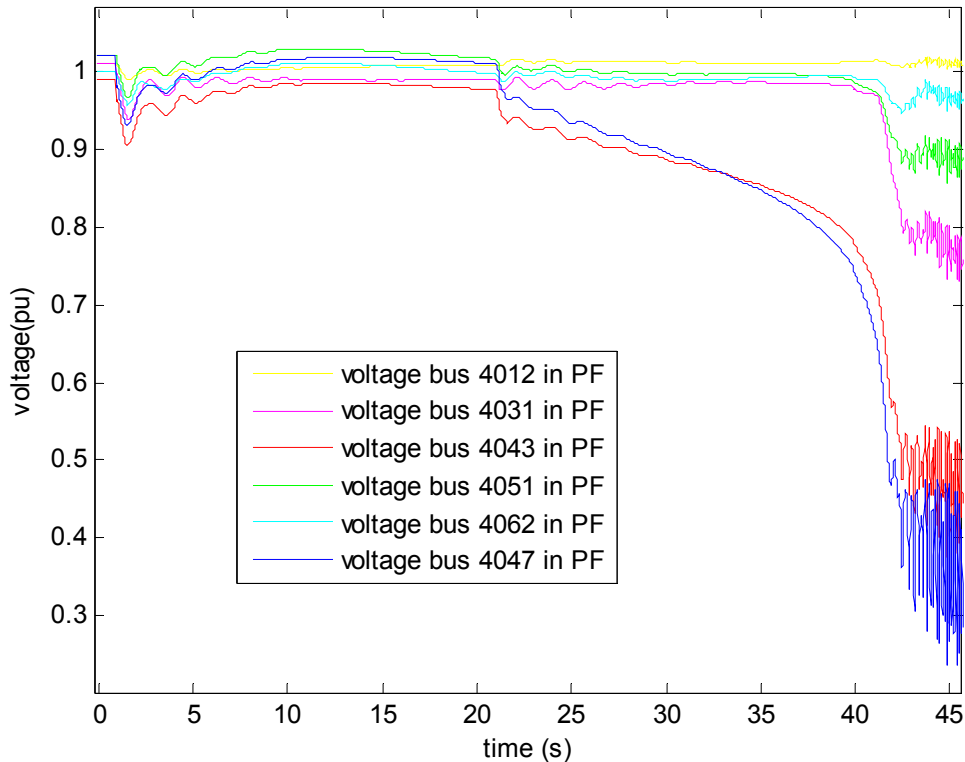


Figure 97. Voltages in several buses in the system Nordic 32 after tripping generator 4047. Result from PowerFactory.

In the previous graphic several voltages in various parts of the system are plotted. The behaviour in PowerFactory is very close to the reference.

In the first seconds an initial transient is managed but the oscillations are damped after around 13 seconds. Suddenly, the voltages start decreasing due to current limiters acting. The current limiter which starts to operate is the stator current limiter at generator 1043 as in [8]. When this current limiter acts the voltage in this bus decreases, and therefore, the voltage at the other buses decrease as well.

The change in the voltages causes a slow decrease in different buses which finally results in a collapse when the tap-changers start reacting at 40 seconds. The final collapse incorporates loss of synchronism, which appears as large oscillations.

The situation from ARISTO is shown in the plot below.

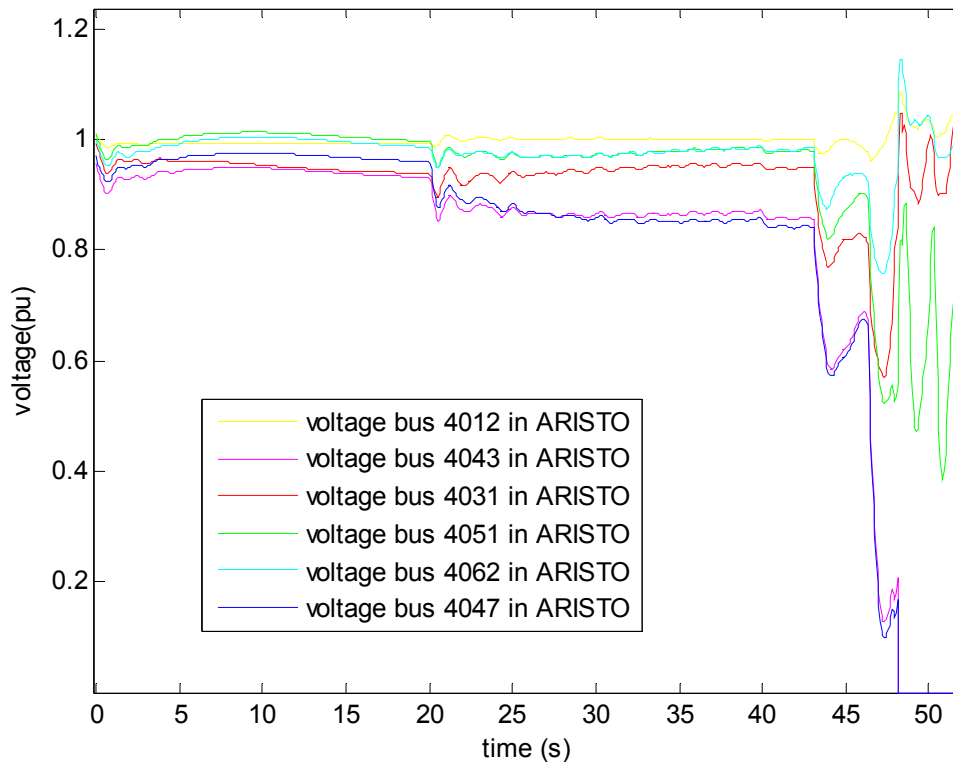


Figure 98. Voltages in several buses in the system Nordic 32 after tripping generator 4047. Result from ARISTO.

The result obtained show that the behaviour in ARISTO is also similar as the reference and as PowerFactory. The initial oscillations are damped after around 10 seconds and after 20 seconds when the currents limiters start to operate the voltages decrease. The current limiter which is actuating is the stator current limiter from generator connected to bus 1043 which is the same as in the PowerFactory simulation.

The voltage decreases again at 40 seconds when the tap-changers work and few seconds after voltages collapse with larges oscillations at the same time. In ARISTO, the voltage collapse after 45 seconds, instead of PowerFactory in which the voltages collapse before 45 seconds. This difference is not significant because the global behaviour is the same.

7.4. Discussion

Although the initial conditions are not exactly the same from the beginning in the three simulators, the overall dynamics are quite close. The current limiters and the tap changers are crucial in the reference and it is also in PowerFactory and in ARISTO.

The important point here is not that the results are exactly the same, but rather realistic models of the components are the same. This means, the goal in the simulation is not if the time when the voltage collapses occurs at exactly the same time, or if the voltages at the initial points are exactly the same. The important point here is that ARISTO and PowerFactory must reproduce a voltage collapse as a result of tap changers and currents limiters to consider that both simulators are working correctly. Some discrepancies are obtained due to different simulators are used, for example in the voltage collapse time, but both of them are give realistic results.

Chapter 8

8. Conclusions

Today the knowledge about the Electric Power System is an important issue. Tools to test and train are therefore indispensable to verify and predict system behaviour.

When power system behaviour is not fully known, a simulator that reflects the real performance with accuracy is a necessary tool.

This project is a close comparison between PowerFactory and ARISTO to test this last one. The differences that have been found can be categorized as depending on definitions, modelling and software bugs:

8.1. Definitions

- **Frequency:** The documentation acquired is not enough to define the frequency in both programs but it seems that in ARISTO the frequency is defined depending on the angle on the bus, however, in PowerFactory it is defined as a result from the impedance matrix. Although the frequency is defined in different way the result must be the same but it is not the same for one time step.

8.2. Modelling

- **Damping factor:** Damping definition is different in ARISTO and in PowerFactory. The damping in PowerFactory represents the mechanical damping in the synchronous machine while the damping in ARISTO, represent the damper windings- It seems impossible to make these representations equivalent.
- **The subtransient reactance:** The lack of a subtransient reactance in the synchronous generator model in ARISTO is a simplification. During the first seconds after a disturbance, the subtransient reactance is a crucial parameter related to damping. As a result, the models run in ARISTO have always less damping and therefore, the system becomes unstable faster.

- **Peaks appear in plots that could not appear:** In several situations, as it is the case when a Load is quickly changed, a peak in the Power plot appears. The error appears just in one step and then disappears. It could be due to the methods for solving the system equations.
- **Modelling flexibility:** PowerFactory and ARISTO have different way to build systems and define the components. ARISTO includes controllers, limiters, and everything necessary to build a complete model, however it is less flexible. The models cannot be changed and new models cannot be included in the libraries as in PowerFactory.
- **Solution methodology:** PowerFactory and ARISTO have different solution methodology and therefore exactly equal results are not necessarily expected. There are differences in the results but these are not significant, around 0.1% in some cases.

8.3. Software bugs in release 4.4.1

- **The Load Flow and the initial values:** ARISTO and PowerFactory give, in some cases, different result for this issue. When ARISTO and PowerFactory are compared with a benchmark, ARISTO sometimes does not reach the preset values while PowerFactory gives the same values as the reference. This is serious since with different initial points the simulator may develop different behaviour. ARISTO also reaches an equilibrium point with different values than the reference.
- **Not a Number:** In some cases the value of NAN (not a number) appears in the result of the program, which must be incorrect.
- **Injections to a node do not sum up zero:** In few cases, the sum of power from a node in ARISTO is different to zero, which is incorrect.
- **Required components:** It is important to know that the system model needs a load and a shunt added otherwise the simulator is not able to run the Load Flow. Both elements will work with zero Power and it may also be disconnected from the system after initialization.

8.4. Discussion

This project has demonstrated that ARISTO and PowerFactory are two simulators which are defined and work in different ways. There are differences between them due

to different solving methods, different numerical methods, etc. It is important to bear in mind that each simulator is build for different task.

Despite of all these differences, as a general point, both simulators reflect similar system behaviour. There are differences between them due to different numerical methods but realistic models and data are the result from both of them.

Nevertheless, the ARISTO user must be aware that certain modelling details are not the same as in e.g. PowerFactory. This gives some differences in simulation results that have been exemplified in this thesis.

8.5. Future work

For the future a large amount of research and further improvements can be carried out.

First of all, the software bugs found must be fixed. There are some errors which it is necessary to fixed as it is the case of the sum on the buses, the initial points, etc. A detailed study is needed to find out where the problem is.

Secondly, it is important to figure out a method to verify ARISTO. ARISTO has the advantage of working in a real-time, therefore, if it was proved that this simulator works properly, the simulator would be more competitive in the marketplace. One option that could be explored could be to compare the result from the simulator to a real situation and to check if the results are similar.

Finally, the internal values from the synchronous machine are different. It is possible to build in Simulink a model which represents the synchronous machine, could be interesting to build a model in Simulink to find out the differences with ARISTO.

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