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Modeling of Power System Components During Electromagnetic Transients

[1]Paweł Sowa, [2]Rafał Kumala and [3]Katarzyna Łuszcz

[1, 2 ,3] Faculty of Electrical Engineering, Silesian University of Technology/
Institute of Power Systems and Controls
Gliwice, 44-100/ Silesia, Poland

Abstract

This paper presents a practical approach to electromagnetic transient study. After describing many cases of simulations the modeling requirements for selected power system elements are shown. In this paper, there are also compared the results of investigations on correct and incorrect power system models during electromagnetic transients.

Keywords: *electromagnetic transients, power system modeling, model requirements.*

1. Introduction

The modeling of modern power systems is the first and most important step during the analysis of disturbance transients. The main idea of modeling is to highlight the significant features of the investigated element from the specified phenomena point of view. Due to it, the work connected with the analysis of the research results is accelerated and facilitated.

Selected elements designed for modeling should be assigned to appropriate replacement schemes [1, 4]. At the same time it is important to remember that, during the process of creating those schemes there should be taken into account only those parameters that are important from the analyzed phenomena point of view.

Proper selection of system elements is the essence of good modeling of those components whose models will be created. This is a very important aspect that should be taken into account because of the huge number and diversity of elements that appears in the contemporary power systems.

Another important aspect is the mapping of real functional connections occurring while creating models. It is also very important to remember that describing the analyzed elements with use of complex mathematical functions and, at the same time, using very simple models for the neighboring elements is incorrect. The most difficult task when constructing models of the power system is to find a balance between the simplicity of the model and the best representation of real parameters of a given element.

The next stage after the modeling during the process of analyzing the effects of disturbances is to carry out appropriate analyzes of simulation, which should allow for research of the dynamics and properties of the received waveform changes.

In practice, due to a very long duration time of particular transient phenomena, the analysis of disturbance has to be done in a narrow time interval. Assuming an appropriate calculation step and time duration of the simulation, it is possible to find hot spots in the test system in a precise way. Fig. 1 shows the way of analyzing the electromagnetic transients and creating the models of elements in the power system.

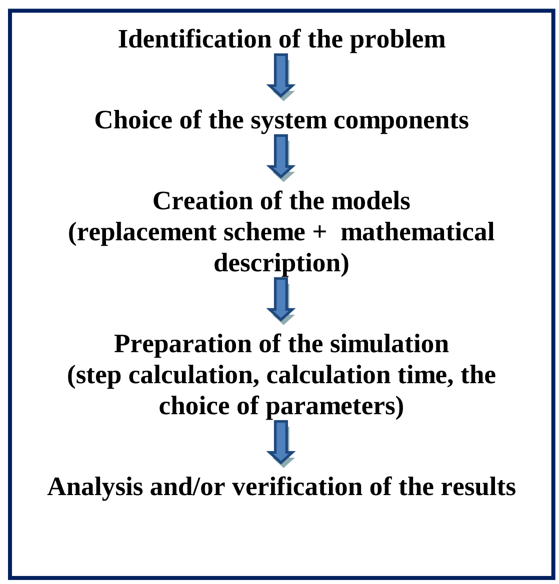

Fig. 1. Idea of the electromagnetic transient analysis

Today there are many types of EMTP software. As a matter of fact, almost all of them have been repeatedly verified in a two ways - by the comparison of the results obtained from different programs, and also with the data from real objects [3, 5]. For the purpose of this paper there was used the most popular simulation program which is EMTP-ATP (Electromagnetic Transients Program - Alternative Transients Program).

In the further part of this paper there are given the recommendations for the proper modeling of selected system components. In addition, the results of the analysis of how the model affects the quality of transient disturbances in the real network system during the simulation are presented.

2. Representation of models of selected power system elements

In real systems, the analysis of various types of transient phenomena is complex. That is why simulation models are used. To illustrate the methodology of the process shown in Fig. 1 an attempt was made to focus on the analysis and description of the most common models of elements which appear in power system. These elements are:

- power transformers,
- power overhead lines and cables,
- synchronous generators,
- induction machines.

It is obvious that the studies for other elements of the power system are performed. However, it should be noted that they less affect the accuracy of mapping the actual state of the tested network system. In order to create a correct representation of the models that are used in the process of simulation, in the first step there should be selected the right parameters and in the next step there should be determined the appropriate operating conditions. For the elements mentioned above there was performed the analysis of different types of disturbances, such as:

- symmetrical and asymmetrical short circuit in the transmission lines and busbars,
- switching of unloaded transmission lines,
- lightning strike to the lightning conductors and working and supporting structures,
- start up of high power asynchronous motors and influence of ground short circuit on the main busbars on operation of these machines (several MW),
- start-up and loss of excitation generators

Based on those analysis, the requirements for the system element models listed in the following tables were defined. Marking of electrical characteristics is consistent with the standard IEC 60909-0 and IEC 60909-1 [6, 7].

Table 1: Requirements for the models of lines and cables during the electromagnetic transients

Type of the study	Model requirements/features
Short-circuit	Single block model, frequency depends (Marti/ Noda)
Open/close operations	Single block model, frequency depends (Marti/ Noda), capacity and inductance of “neighbors” - very important
Lightning	7 segments on both sides, frequency depends (Marti/ Noda), pole model: complex (for $H > 30$ m), surge arrester model - yes, insulator model - not necessary [1)]

[1)] if the surge arrester model is representative

Table 2: Requirements for the models of transformers during the electromagnetic transients

Type of the study	Model requirements/features
Open/close operations	Simple model - S_r , X_r , R_r (u_{Rr} , u_{Xr}) parameters [2)]
Open/close operations	As above + magnetic core characteristics

[2)] if uRr is unknown, it is possible to determine this parameter based on ratio X/R and parameter Sr (e.g. IEEE St. C57.12.10-2010 [8])

Table 3:Requirements for the induction machines during the electromagnetic transients

Type of the study	Model requirements/features
Short-circuit	The most important parameter: I_{LR} / I_r
Dynamic motor starting analysis during start and load impact/ramp	Load characteristic model, kind of the start mode , operation mode of motor
Voltage drop	As above + include reactors model located to machine [3)] and cable connection with significant length [4)]

[3)] the value of reactor impedance is important (particularly for reactors with $u_{KR} \geq 4$ %) located to the two next nodes (bus)

[4)] for cables with length above 100 m (it is particularly important for low voltage networks)

Table 4: Requirements for the synchronous generators during the electromagnetic transients

Type of the study	Model requirements/features
Short-circuit	The most important parameter: I_{LR} / I_r
Dynamic motor starting analysis during start and load impact/ramp	1st type of faults [5)]: the most important parameters - X''_d and S_r (simple model) 2nd type of faults [6)]: as above + include armature resistance R_a, stator and rotor winding and dumping circuits (complex model) - represent by suitable time constants in d and q axis
Load dump and ramp, voltage changes, loss excitation, start mode	Load characteristic, type of generator regulator (which parameters are controlled), type of excitation
Island mode	As above + include power protection time settings and sequence of close/open operation

[5)] for remote faults

[6)] for close faults

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3. Analysis of impact of models on selected electromagnetic transient phenomena

For the purposes of this paper, the most commonly types of disturbances occurring in a modern power system were examined. The system components which influence the system operation in the deciding way were analyzed. The results of the analysis are summarized in Tables 1 to 4 (see Section 2). The investigations were performed for the real part of the power system. The most important elements of the modeled system during electromagnetic transient include:

- monorail lines 220 kV with lengths from several several tens of kilometers,
- block transformers and synchronous generators with power ratings of at least 190 MVA,
- asynchronous machines of high power (above 2...9 MW).

As an example which shows the effect of the proper models selection of the system, there was chosen a skew three-phase short circuit at the end of the 220 kV lines with a length about 92 km (Line1). The final transients waveforms were observed on the BUS 14 220 kV. The total duration time of the simulation in this case was t_{dot} = 0.3 s. The analyzed fragment of the network system is shown in Fig. 2.

For the assumed short-circuit interference two cases were compared:

- structure with the properly chosen models of selected elements of system components (labeled as JM), i.e.:
  - power lines represented by the model dependent on frequency (Marti with a suitably selected frequency range [2]),
  - model of the synchronous machine in which there is taken into account the resistance of the armature and the time constants in the d and q axis,
  - model of the asynchronous machine with the real I_g / I_r values depending on the power rating,
  - model of the transformer with the active component of voltage during the short circuit,
- structure with the wrongly chosen models of selected elements of system components (labeled as BE), i.e.:
  - power lines represented by the model with lumped parameters (Bergeron),
  - model of the synchronous machine without the resistance of the armature and the time constants in the d and q axis,
  - model of the asynchronous machine with the constant I_g / I_r values regardless of the power rating,
  - model of the transformer without the active component of voltage during the short circuit.

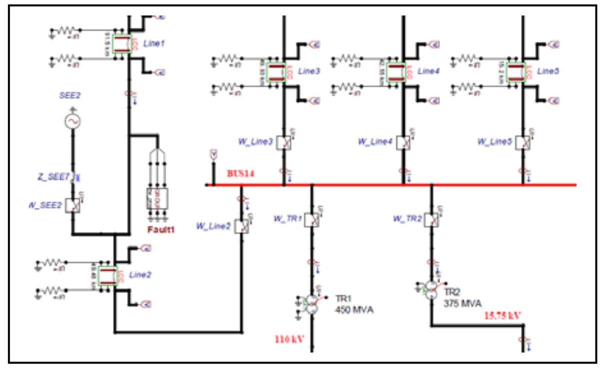

Fig. 2. Part of the analysis network - fault at the BUS 14.

During the analyzed type of short circuit the instantaneous waveforms of currents and voltages were verified. Figures 3 and 4 show the mentioned waveforms for the JM model. The corresponding waveforms for the BE model are shown in Figs. 5 and 6. To show precisely the differences in the dynamics of the waveforms of currents and voltages in Figs. 3 to 6, they are presented for t = 0.1 s.

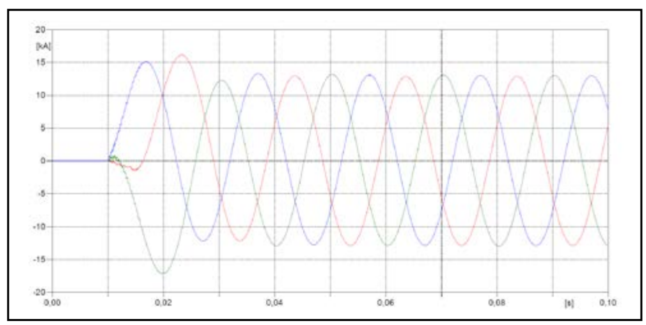

Fig. 3. Current transient for the JM model

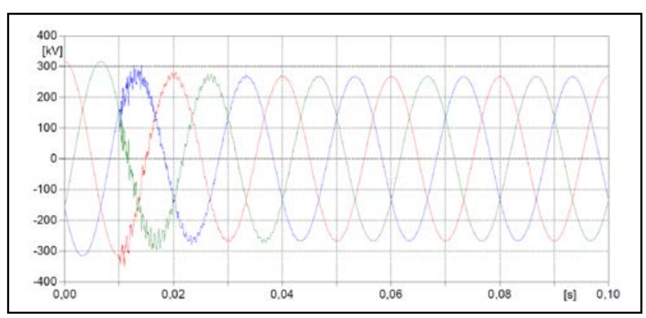

Fig..4. Voltage transient for the JM model

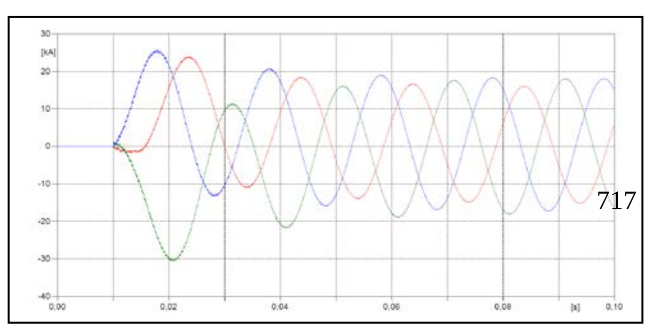

Fig. 5. Current transient for the BE model

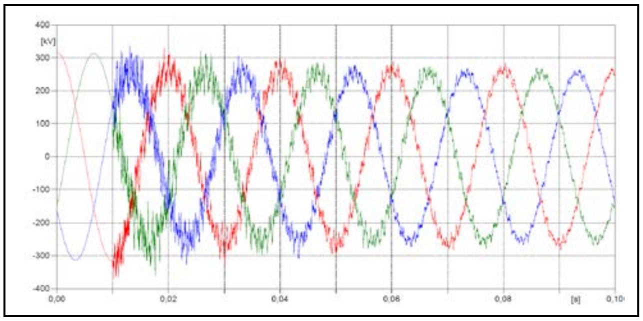

Fig. 6. Voltage transient for the BE model

In order to determine the difference between the results in a accurate way, specified the maximum of the instantaneous current and voltage values, and the total duration time of the electromagnetic transients for both models. The results are summarized in Table 5.

Tabel 5: Comparision of selected electromagnetic transient parameters for JM and BE models

Parameter →	u_{max} , kV	i_{max} , kA	t_{max} , s
Type of model ↓	-	-	-
JM	351.53	17.21	0.1
BE	369.79	30.58	0.3
Difference →	**5.19%**	**177.69%**	**300%**

u_{max} - maxium value of the voltage transient
i_{max} - maxium value of the current transient
t_{max} - maximum duration time of the transient

4. Conclusions

Development of the appropriate power system models during the electromagnetic transient analysis is the most important activity in the modeling process. Besides the proper determination of the real element parameters which should reflect the model, one should remember that some of the parameters are dependent on frequency. This is very important in the case of phenomena for which the frequency is expected to change in a wide range (generator island mode, frequency start-up motors especially for power more than 1 MW, etc.).

Determining universal models of the elements, depending on the investigated phenomena, creates a difficulty in the modeling process. The authors tried to unify selected models of the power system during testing various types of electromagnetic transients. Recommendations featured in Tables 1 to 4, have to be considered as a starting point, not as the only right approach. It is impossible to define a universal model which will take into account all the characteristics for the selected group of the power system elements. In many cases, the power rating of the element and the voltage level have a huge impact on the structure of the model. Therefore before the creation of models for the analysis of electromagnetic transients, the deep analysis of the problem has to be carried out. Also the proper selection of the time interval for which the given phenomena will be analyzed is extremely important. As shown in the example of non-simultaneous three-phase short-circuit for a 220 kV line in a real system, an incorrect choice of models of system components causes:

- obtaining wrong values of the analyzed electrical quantities (for the analyzed case, the biggest error of the instantaneous value of current exceeded 177% and in the voltage was about 5%),

- distortion of instantaneous waveforms - "falsification" dynamics of the trajectory,

- "artificial" increasing the duration time of the transient.

The biggest problem is always to determine the negative impact of incorrect choice of models. It is impossible to estimate at the beginning of whole process whether the wrong model is the result of an increase or decrease in the instantaneous amplitude value waveforms, and how it influences the decay time of the oscillations.

Optimally created models of the power system should be a compromise between the simplicity of the structure of the equivalent circuit (a mathematical description of the model) and the precision of mapping the most significant features of the selected element.

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First Author Graduated from Silesian University of Technology in Gliwice Dean of the Faculty of Electrical Engineering, Director of the Institute of Power Systems and Control, Silesian University of Technology.
Specialist in power engineering, power system modelling, and transient electromagnetic phenomena. Author of nearly 200 scientific publications.

Second Author Fourth year PhD student in Silesian University of Technology at Faculty of Electrical Engineering, current research and interests: multi-voltage lines, electromagnetic transients, intersystem faults, power plant design.

Third Author Fifth year PhD student in Silesian University of Technology at Faculty of Electrical Engineering, current research and interests: thermovision diagnostic, modeling and analysis of operating conditions in selected power systems, ferroresonance in transformers.