CHEMICAL ENGINEERING TRANSACTIONS
VOL. 59, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Zhuo Yang, Junjie Ba, Jing Pan

ISBN 978-88-95608- 49-5; **ISSN** 2283-9216
DOI: 10.3303/CET1759135

Modelling and Operation Analysis of Electromechanical Transient- Electromagnetic Transient Hybrid System

Fengling Fang

Fujian Polytechnic of Information Technology, Fuzhou 350003, China
FenglingFang@126.com

The electromechanical-electromagnetism hybrid simulation technology combines the advantages of electromechanical transient simulation and electromagnetic transient simulation. It can coordinate the simulation scale, precision and speed and provide new ideas and ways to study the stability and dynamic of large-scale power system characteristics. Aiming at the shortcomings of the existing hybrid simulation method, this paper presents a method of mechanical-electromechanical transient hybrid simulation based on socket technology. First of all, using the PSCAD with the component graphics library to build flexible AC transmission system (FACTS) components, its controller circuit, and its precise electromagnetic transient simulation; using the PSAT toolbox of MATLAB to build a conventional AC network for its mechanical and electrical transient simulation. Secondly, the hybrid simulation interface algorithm is improved. The hybrid simulation method simplifies the interface design, which can be flexible and efficient to carry out mechanical and electrical transient - electromagnetic transient hybrid simulation, and has a high degree of scalability. Finally, a three-machine nine-node system with SVC is used to simulate the electromechanical transient-electromagnetic transient simulation algorithm of power system based on socket technology. By comparing and simulating the three-machine 9-node system, the simulation results show that the proposed method can accurately simulate the FACTS-based simulation method, and the simulation results show that the proposed method can accurately simulate the FACTS Physical and dynamic characteristics of fast transient processes after disturbing AC systems.

1. Introduction

The history of power system hybrid simulation research has been 30 years, and develops step by step to today. In the 70s of last century, Siemens successfully developed a software named NETOMAC (Liu et al., 2014; Mohammad et al., 2017), opened the prelude to a hybrid simulation.
Subsequently, the hybrid simulation system with the HVDC device is established by Heffernan et al. The HVDC model is used to establish by method of the state variable, and the converter AC bus is defined as the interface location. And use the conventional transient stability simulation program to simulate other parts of the system. Since the 1990s, the research team led by Kevin and Snider from the Hong Kong Polytechnic University has also worked on mixed simulation studies and achieved satisfactory results. It has implemented conventional electromechanical transients and the interface of the electromagnetic transient model (Peralta et al., 2012; Hegazy et al., 2012). In the literature Wu et al. (2012) and Ye et al. (2012), it designed the interface data interaction protocol using a parallel approach. In the literature (Gee et al., 2-13), it analyzed the real-time and parallel computing problems in hybrid simulation, and some mainland universities have established cooperative relations with them, and some achievements have been achieved some results through research (Li et al., 2012). In the literature, it proposed a hybrid simulation algorithm based on simulation software PSCAD/EMTDC. The algorithm uses the existing mature commercial electromagnetic transient simulation software PSCAD with the component library to build HVDC or FACTS system model, and carrying on its precise electromagnetic simulation; At the same time, the use of flexible software achieve its main program in EMTDC and MATLAB language prepared by the TSP program interface, the remaining part achieve the exchange of mechanical and electrical transient simulation, and a certain time interval for two parts of the data exchange, in order to achieve the entire network of digital simulation. In the literature (Tabarraee et al., 2012),

Please cite this article as: Fengling Fang, 2017, Modelling and operation analysis of electromechanical transient- electromagnetic transient hybrid system, Chemical Engineering Transactions, 59, 805-810 DOI:10.3303/CET1759135

FDNE is used to represent the effect of electromechanical transient side harmonics on the electromagnetic transient side, to improve the method of calculating the equivalent current of electromagnetic transient, and to improve the FDNE in the electromagnetic transient process in the time domain application method, and based on the pipe (pipe) way, a set of electromagnetic - electromechanical transient decoupling hybrid simulation system is developed.

2. Hybrid simulation of the basic principles

Power system hybrid simulation through the interface technology combines electromechanical transient simulation and electromagnetic transient simulation. It takes the exchange of conventional power system in the network as an external network for electromechanical transient simulation, and takes a specific power grid components or local network as an internal network for electromagnetic transient simulation.

2.1 Theoretical principles

Figure 1 shows the basic principle of electromechanical transient-electromagnetic transient simulation, and the dynamic response of the conventional AC network is slow. It is used as an external network to simulate the electromechanical transient program. At this time, only the fundamental wave is included in the simulation data. The specific grid element or local network is focused on the internal network as the electromagnetic transient simulation. The simulation data is based on three phases instantaneous value.

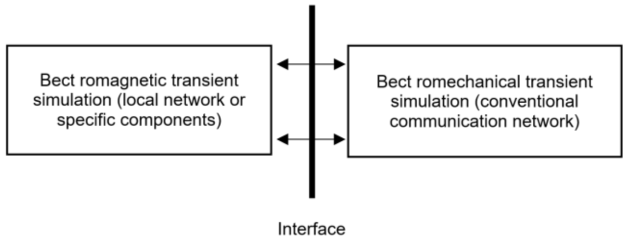

Figure 1: Schematic diagram of electromechanical transient and electromagnetic transient simulation

The process of hybrid simulation can be described as: when one side is in the simulation, the other side needs the correct and appropriate equivalent circuit equivalent replacement. Since the setting of the electromechanical transient step is an integer multiple of the electromagnetic transient step, the data exchange time is fixed at the step point of the electromechanical transient simulation. According to the simulation time step assumed later, the time interval for the occurrence of a data interaction is 10 milliseconds. In the process of mixed simulation of one electromechanical step, there is no data exchange on both sides, and one step is simulated on the electromechanical side, and the electromagnetic side simulates 200 steps in the same time period. Although most of the time the current and voltage values at the interface are treated as exchange variables, the actual impedance and power are also correctly selected for data exchange (Prokhorov et al., 2013).

2.2 Core technology

The core technology of electromechanical transient - electromagnetic transient simulation of is how to correctly and properly handle the interface, so the interface technology is a hybrid simulation of the premise of success. There are many tasks in the design interface, including the correct choice of the interface location, the equivalent circuit of the interface on the interface, the interface timing, and the conversion method of the interactive data.

(1) The choice of interface location

It is necessary to perform a hybrid simulation of a hybrid power system with FACTS components and HVDC DC devices. The interface locations are generally selected by connecting the power electronics such as the FACTS to the primary bus side of the transformer or to the AC side bus of the HVDC converter for the following reasons:

a) The simulation scope of the electromagnetic transient program can be reduced, the number of interfaces can be reduced, and the calculation task and burden of the electromagnetic transient simulation program can be reduced;

b) Can make the electromagnetic transient simulation program, such as SVC devices, filters and other devices in the converter at the bus, more convenient for their dynamic characteristics of the analysis;

c) The voltage or current value at the bus is relatively stable, improving the stability of the numerical calculation.

(2) Electromagnetic transient simulation of external network equivalent circuit

In the case of electromagnetic side simulation, the electromechanical side is replaced by the equivalent circuit equivalent. Because the electromechanical side network is usually the active system, and the simulation scale is relatively large, from the electromagnetic side of the point of view, the parameters of the network to meet the basic linear relationship. So, you can use the Thevenin (or Norton) equivalent circuit directly equivalent to replace the external network. The Thevenin circuit is connected in series by the voltage source and impedance. In Figure 2, the equivalent impedance is denoted by Zk, and the equivalent voltage source is represented by Ea.

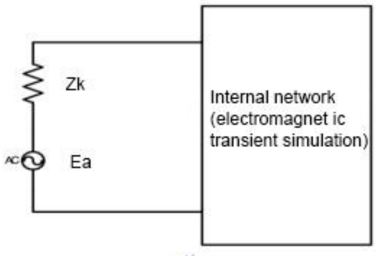

Figure 2: Electromechanical transient simulation of the electromechanical side of the use of Thevenin equivalent circuit

(3) Electromechanical transient simulation of internal network equivalent circuit

In the electromechanical side simulation, the electromagnetic side also need to be equivalent to the equivalent circuit replacement. The electromagnetic side may contain FACTS, HVDC and other non-linear power electronic components, so the components and network structure is more complex, the electromagnetic side of the equivalent circuit form is also more diverse. If the electromagnetic side network is only a conventional AC network, the equivalent circuit can be used in the form similar to the electrical side of the Thevenin or Norton equivalent; if the electromagnetic side network contains FACTS components, according to the side components and network characteristics, constant current source, constant impedance, constant power load or other similar form can be used as an equivalent circuit; if the electromagnetic side contains HVDC system, the equivalent circuit form can be a constant high resistance parallel current source approximation Norton equivalent circuit. The system studied in this paper contains the FACTS element, so the selected equivalent circuit is a constant power load. The electromagnetic side uses constant power load equivalent circuit as shown in Figure 3, Where P + jQ represents the power of the load and Iemt represents the current flowing to the interface.

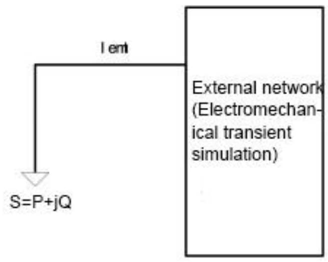

Figure 3: Electromechanical transient simulation of the electromagnetic side of the constant power load equivalent circuit

(4) Timing interaction

Electromechanical side and electromagnetic side in the hybrid simulation is to carry out both sides of the data interaction. Assuming that the electromechanical side external network is equivalent to the Thevenin equivalent circuit, the voltage instantaneous value Un(t) is transmitted to the electromagnetic side at the time step point of the electromechanical transient simulation. The internal network of the electromagnetic side is equivalent to the constant power load, and the fundamental wave P(t) and Q(t) are also transmitted to the electromechanical side at the time step of the electromechanical transient simulation. The time step of electromechanical transient simulation is ΔT, and the time step of electromagnetic transient simulation is Δt. In the following graphs, the order of the data is represented by the numbers ①②③④. In addition, EMT

(Electromagnetic Transient) is used to represent the electromagnetic transient simulation, and TS (Transient Stability) is used to represent electromechanical transient simulation.

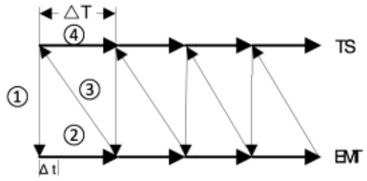

Figure 4: Serial interactive mode on both sides

Figure 4 shows the data interaction process, as follows:
Step 1: At the time of t, the TS transmits the voltage Un(t) to the EMT to update the equivalent voltage source of the external network.
Step 2: During the period: [t, t+ΔT], the EMT calculates N times in time step until time is t + ΔT.
Step 3: At the time of t+ΔT, the EMT extracts the fundamental power S (t+ΔT) based on the power instantaneous value calculated from the previous cycle and passes it to the TS to update the power of the equivalent load.
Step 4: During the period of [t, t+ΔT], the TS calculates the new equivalent voltage Un (t+ΔT) by the step ΔT simulation, and continues the data at the time of arrival at the next electromechanical step interaction. If there is no other operation and no failure, it is necessary to cycle ① ② ③ ④ simulation process.
The functional relationship of the serial interaction mode can be expressed by the formula (1), (2), (3)

$$U_c(t+\Delta T) = g(U_c(t), S(t+\Delta T)) \tag{1}$$

$$S(t+\Delta T) = f(U_c(t), S(t+\Delta T)) \tag{2}$$

$$S(t+n\Delta T) = f(U_c(t), S(t+(n-1)\Delta t)) \tag{3}$$

This formula describes the serial calculation process: the electromagnetic side receives the equivalent parameters of the electromechanical side t-ΔT, and then performs the solution in the period of [t-ΔT, t].The electromechanical side is waiting during the time. The electromechanical side then receives the equivalent parameters of the electromagnetic side at the time of t, and then performs the corresponding during the period of [t-ΔT, t], and the electromagnetic side waits for a period of time. The current hybrid simulation in most cases use this way of interface timing interaction.
In the above serial interaction mode, the electromechanical side delays ΔT over the electromagnetic side. If, in turn, the electromagnetic side delay is used to perform serial interaction, the equivalent power S (t) from the electromagnetic side at the time of t is used at the time of calculating the voltage at time t+ΔT, but the time of ΔT for the electromagnetic transient process is already a long time to perform a 200-step simulation calculation. During this time, the dynamic characteristics of the components change quickly, the result will result in the same computing efficiency, there is a big error in the exchange of data, so the actual mixed digital simulation rarely uses this serial interactive mode to design interface.

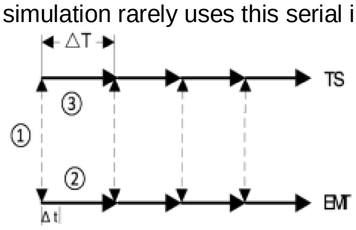

Figure 5: On both sides of the parallel interaction

Figure 5 shows the data interaction process, the specific steps are as follows:
Step 1: At the time of t, the TS sends the interface information to the EMT to update the Thevenin equivalent circuit parameters, and the EMT sends the interface information to the TS to updates the equivalent load power, maintaining the load power parameter during the mixed simulation in the time of [t, t+ΔT]. Similarly, the maintenance of the Thevenin equivalent circuit parameters does not change.

Step 2: The second step of the parallel mode describes the process of parallel simulation in the time of [t, t+ΔT] . During this period TS is simulated from the time of ΔT to t+ΔT, and the new interface variable data information is calculated. At the same time, the EMT simulates N times until t + ΔT with the time step Δt, and calculates the new interface variable data information. If there is no other operation and no failure, it is necessary to cycle ① ② simulation process.
The function formula of the parallel interaction mode can be expressed by the formula (4), (5), (6):

$$U_c(t+\Delta T) = g(U_c(t), S(t)) \tag{4}$$

$$S(t+\Delta T) = f(U_c(t), S(t+\Delta T\text{-}\Delta t)) \tag{5}$$

$$S(t+n\Delta T) = f(U_c(t), S(t+(n-1)\Delta t)) \tag{6}$$

This formula describes the parallel characteristics of the calculation process: the advantages of mechanical and electrical side and the electromagnetic side of the parallel real, in the calculation process does not wait for the other to complete the calculation, so it can meet the real-time exchange of data on the basis of improved computing speed; The disadvantage is that there is a slight handover error, because the equivalent information of each side application is transmitted on the opposite side at the time of t during the simulation time of [t, t + ΔT], so the simulation accuracy is affected.

3. Modeling simulation analysis

The simulation example used in this paper is to install a static var compensator (SVC) in parallel with the bus 8 of the 3-system and 9-system system. Therefore, the bus 8 is set as the interface bus, SVC is the internal network, and the rest of the conventional communication network is the external network, the example model shown in Figure 6:

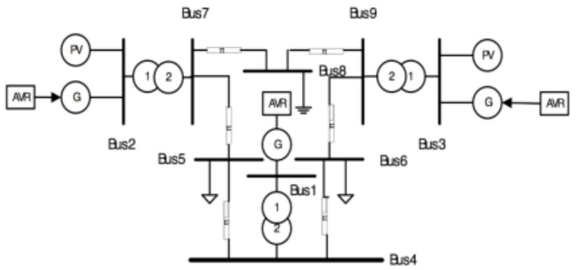

Figure 6: Nine nodes with SVC Model diagram

Set the time for the hybrid simulation to 3 seconds, the bus 8 of the system occurs three pairs of short circuit when t = 0.5 seconds, and when T = 0.6 seconds the fault is cleared. Before the hybrid simulation, PSAT calculates the power flow of the example, and obtains the value of the equalization circuit of the external network according to the steady state solution. The output result is as follows: the equivalent voltage is Veq = 246.67k V, the phase angle Ph = 11.574º, Equivalent Impedance Zeq = 5.552 [ohm] + j56.658 [ohm]. After building their own network models in PSAT and PSCAD, run mixed simulations. The simulation time of PSCAD is 1 second, the simulation time is 3.5 seconds; the failure time of PSAT waveform display is 0.5 seconds, the simulation time is 3 seconds. PSCAD simulation time is set to 0.5 seconds. Figure 7 is the equivalent voltage waveform of the external network measured by PSCAD. It can be seen from the figure that the equivalent voltage after 0.5 seconds of hybrid simulation and the equivalent voltage calculated by the steady-state solution are completely equal and correct. It reflects the corresponding changes in the occurrence and removal of the equivalent voltage with the fault, which proves that the calculation method and program of the Thevenin equivalent circuit are correctly written.
The simulation results are as follows: (The blue line in the figure represents the serial / parallel hybrid interaction mode, the green line represents the parallel interaction mode, and the yellow line represents serial interactive mode)
Compared with the simulation results of three kinds of interactive modes, the simulation time of the parallel interaction mode is the shortest and the simulation time of the serial interaction mode is the longest, which proves that the actual situation is consistent with the theoretical knowledge.

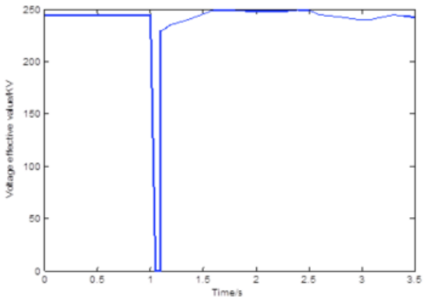

Figure 7: The equivalent voltage waveform of the external network

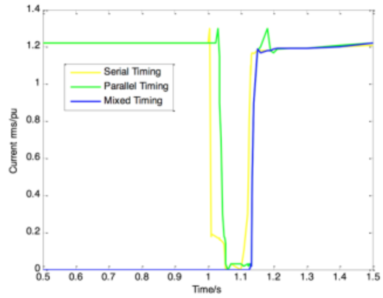

Figure 8: SVC injection of the effective value of the bus current (amplified waveform)

4. Conclusion

In this paper, we propose a kind of electromechanical transient-electromagnetic transient mixing simulation method based on socket technology for the shortcomings of the existing simulation methods, such as large number of coding programs, heavy interface design, large amount of data and lack of flexibility in timing matching. The simulation method uses the component library of the PSCAD software to build the HVDC and FACTS system model and carry out the electromagnetic transient simulation. The simulation process is simplified by writing a large number of complicated electromagnetic transient code. Second, the simulation method uses PSAT toolbox of MATLAB software to program code. It makes full use of the advantage of graphical interface visualization, and use its own component library to build a conventional AC network for electromechanical transient simulation.

Reference

Borovikov Y.S., Gusev A.S., Sulaymanov A.O., 2014, Hybrid real-time simulator of power system for advanced simulation of the FACTS and HVDC system based on Voltage Source Converter, Systems and Informatics (ICSAI), 2014 2nd International Conference on, IEEE, 148-152, DOI: 10.1109/ICSAI.2014.7009276.

Gee A.M., Robinson F.V.P., Dunn R.W., 2013, Analysis of battery lifetime extension in a small-scale wind-energy system using supercapacitors. IEEE transactions on energy conversion, 28(1), 24-33. DOI: 10.1109/TEC.2012.2228195.

Hegazy O., Van Mierlo J., Lataire P., 2012, Analysis, modeling, and implementation of a multidevice interleaved DC/DC converter for fuel cell hybrid electric vehicles. IEEE transactions on power electronics, 27(11), 4445-4458, DOI: 10.1109/TPEL.2012.2183148

Liu S., Xu Z., Hua W., 2014, Electromechanical transient modeling of modular multilevel converter based multi-terminal HVDC systems. IEEE Transactions on Power Systems, 29(1), 72-83, DOI: 10.1109/TPWRD.2012.2188911.

Mohammad Rozali N.E., Wan Alwi S.R., Ho W.S., Manan Z.A., Klemeš J.J., 2017, Popa-sharps: a new framework for cost-effective design of hybrid power systems, Chemical Engineering Transactions, 56, 559-564, DOI:10.3303/CET1756094.

Peralta J., Saad H., Dennetière S., 2012, Detailed and averaged models for a 401-level MMC–HVDC system. IEEE Transactions on Power Delivery, 27(3), 1501-1508.

Prokhorov A.V., Gusev A.S., Borovikov Y.S., 2013, Hardware-in-the-loop testbed based on hybrid real time simulator. Innovative Smart Grid Technologies Europe (ISGT EUROPE), 2013 4th IEEE/PES. IEEE, 1-5.

Tabarraee K., Iyer J., Atighechi H., 2012, Dynamic average-value modeling of 120 VSI-commutated brushless DC motors with trapezoidal back EMF. IEEE Transactions on Energy Conversion, 27(2), 296-307, DOI: 10.1109/TEC.2012.2188032.

Wu P., Lin W., Sun H., 2012, Research and electromechanical transient simulation on mechanism of commutation failure in multi-infeed HVDC power transmission system, Power System Technology, 5, 048.

Zahedi B., Norum L.E., 2013, Modeling and simulation of all-electric ships with low-voltage DC hybrid power systems. IEEE Transactions on Power Electronics, 28(10), 4525-4537, DOI: 10.1109/TPEL.2012.2231884.

Zhang Y., Gole A.M., Wu W., 2013, Development and analysis of applicability of a hybrid transient simulation platform combining TSA and EMT elements, IEEE Transactions on Power Systems, 28(1), 357-366, DOI: 10.1109/TPWRS.2012.2196450.