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MODELLING OF FACTS FOR POWER SYSTEM ANALYSIS

by

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SUMMARY

Due to their fast dynamical response and the lack of standard design, modelling of FACTS in power system simulation requires software with new capabilities. The user needs sufficient modelling to be able to introduce new types of FACTS in his or her simulation environment. Introducing such fast acting devices in the network model asks for particularly robust interfaces. New solution algorithms enable to integrate very effectively algebraïc-differential equations systems in short-, mid- and long-term simulations. An important question remains and concerns the behaviour of FACTS when facing strongly disturbed conditions. This question is addressed to the manufacturers who have to describe precisely the operational limits of their new devices.

Keywords

Power System - Simulation - FACTS .

1. INTRODUCTION

Considering systems in general and power systems in particular as energy manipulators seems to be one of the most powerful concept which can be used in dynamic modelling [1]. Indeed, the dynamical behaviour of a physical system is the outward manifestation of energy transactions within that system.

Thus, a wide range of systems can be handled in a common framework, energy playing the central role.

Limiting the scope to lumped parameters models in the field of power system analysis, the most common way followed to build dynamic models is based on physical analysis of limited subsystem like a transformer, a synchronous generator, ... at a fundamental level.

By using adequate simplifications, a model in differential equations form can be deduced, whose parameters are then computed by suitable theoretical methods or determined by standard or more specific tests (transformer short circuit test for example). The methods, the simplifications which are used during this process imply generally the definition of a domain of validity for that model.

In the case of power systems, the process which has to be modelled, is the whole network comprizing sometimes hundreds of power stations, thousands of lines and transformers ... each being itself a model like the one mentioned above. This fact imposes a suitable modelling of system's components which have to be limited to their fundamental functions. The classical power system's component models like for example Park's synchronous or induction machine model, lines and transformers equivalent circuits illustrate clearly this topic.

Power electronics used in power system introduces new modelling constraints and asks for simulation tools with new capabilities. To illustrate this topic, the modelling process will be reviewed in this paper, from basic components (section 2) up to FACTS models (section 3). Finally, we present simulation results obtained from a general purpose simulation software (section 4).

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2. LARGE POWER SYSTEMS MODELLING

2.1. Components modelling

Component modelling can be symbolically viewed as a nest of Russian dolls. The external doll represents the main operational characteristic in normal operating conditions : a synchronous machine converts mechanical into electrical power or vice versa, a phase shifter transformer introduces voltage phase shift and transmits power between two busses, ...

Successive inner dolls correspond to problems becoming progressively less coupled with the fundamental operational characteristic, or to abnormal operations during transient situations. To make power system modelling possible, only the more external dolls, the fundamental device characteristics, should be considered.

2.2. Basic concepts

Power System dynamic phenomena are usually classified according to two different axes. The first one concerns the frequency range , the second one concerns the scale, i.e. the number of elements to be considered to obtain a suitable global model. Fortunately, high frequency phenomena do not propagate easily in the system so that the complexity, defined as the product of the "scale" and "frequency range" of the resulting model, can be considered as relatively constant.

The most important phenomena encountered in system operation are classified in decreasing frequency order and in increasing scale order as follows [2] :

- electromagnetic transients in the transmission network (surge analysis) (10^3 to 10^5 Hz);
- harmonics in the transmission network (10^2 to 10^3 Hz);
- sub-synchronous resonance (10 to 10^2 Hz);
- transient stability (0.1 to 1 Hz);
- long term dynamics (10^{-3} to 10^{-1} Hz);
- voltage stability.

Following the state of the art in power system simulation, all these phenomena can be classified into two distinct groups.

The first one, up to the sub-synchronous resonance, corresponds to electromagnetic transients and can be studied by electromagnetic transient programs. The second one, comprising electromechanical transients, and voltage phenomena, can be considered as stability problems which can be studied by transient, mid-and long-term programs.

2.3. Phasor modelling

Power systems consist mainly in alternating current operated equipment. Voltages and currents are characterized by their near sinusoidal wave shapes. Hence, the system is permanently in transient state, but due to the similarity of the successive cycles, it can be considered in quasi steady-state and thus modelled using phasor quantities.

The phasor representation is of standard use for stability problems. Its principal drawback however is that information inside the cycle is partly lost. This becomes crucial for the study of power electronics devices, like the well known problem of commutation failure in HVDC inverters.

The electromechanical transient power system model is made of two parts : the network, represented by a system of algebraic equations (the Kirchhoff laws), and the dynamic part which is represented by a system of differential equations i.e. process, generating units and motors with their control systems.

Traditional methods which solved both systems alternately, are valid because the flux linkage in rotating machines acts like a “filter” between the differential and algebraic systems.

New algorithms ([3], [4], [9]), enable to solve the whole algebro-differential system simultaneously.

The introduction of FACTS on the power system scene, due to their fast dynamical response as compared to fluxes variation in synchronous machines, will make the traditional numerical methods less usable, whereas by using a suitable algorithm, it is possible to integrate very effectively algebraic-differential equations systems in short-, mid- and long-term simulation.

3. FACTS MODELLING

3.1. Introduction

FACTS (Flexible Alternating Current Transmission System) generally cover thyristor controlled equipment. Most of the FACTS already proposed , not yet already built, comprise power electronics. Different types exist like Static Var Compensator (SVC), variable series compensation or, as prototype, Advance Static Var Compensator. But other are proposed, like the Universal Power Flow Controller (UPFC) [5], the ones based on Superconducting Magnetic Energy Storage (SMES) or the Interphase Power Controller (IPC). The latter being the only one which can be built without power electronics while exhibiting an intrinsic constant active power flow characteristic [6] [7].

The flexibility of FACTS is commonly related to the capacity of controlling power flow through AC link. Simulation programs used to model FACTS, have to be flexible too. Indeed, no standard design exist so far, so the user must have sufficient modelling capability to be able to introduce a new type of FACTS in his simulation environment. Interfacing such fast acting devices with network model asks for particularly robust interfaces and for an integration method able to afford the stiffness of the differential model.

Algorithms which solve simultaneously the algebraic and differential equations with variable step size numerical integration method are mandatory to solve this question on an algorithmic point of view. Furthermore, in order to be able to model future FACTS developments, some modelling flexibility is needed, like for example a graphical interface which allows for direct building of new models on the screen of a workstation.

As mentioned earlier two different levels of complexity can be considered. The first takes into account the fundamental function only. In that case, most dynamics can be simulated . The second level of modelling has to be sufficiently detailed, as far as the different components are concerned, to be able to represent adequately the constraints related to operation under short circuit conditions. Series compensator is a good example to illustrate this topic : the series capacitor can work as long as the capacitor terminal voltage remains within suitable limits, otherwise the capacitor is paralleled by a metal oxyde varistor or short circuited by an air gap. Variable series compensator is still more complex ....

3.2. The shunt model

The classical SVC can be considered as a variable shunt susceptance. This shunt susceptance is driven by a suitable controller taking into account voltage droop, PID regulator and auxiliary loops active temporarily during disturbances. Coupling to the system is realized through "monitoring" of the bus voltage, and by "driving" the equivalent susceptance.

Advanced SVC would be modelled similarly but would use equivalent current injection as coupling variable.

The FACTS of the "transverse" type which in fact would be modelled adequately by transverse equivalent injector, can be reduced to two coupled shunt injectors, as shown hereafter.

3.3. "Transverse" model

A very simple version of series compensator will be considered as an example . Considering two busses S and R which are linked by an admittance y_c, the admittance matrix of this sub-system is :

$$y = \begin{vmatrix} y_c & -y_c \\ -y_c & y_c \end{vmatrix}$$

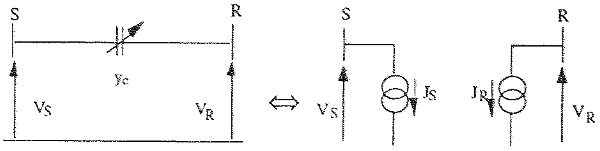
The link y_c can be replaced by two coupled equivalent injectors J_S and J_R. If voltages of bus S and R are V_S and V_R respectively, these currents are given by

$$\begin{vmatrix} J_S \\ J_R \end{vmatrix} = \begin{vmatrix} y_c & -y_c \\ y_c & y_c \end{vmatrix} \begin{vmatrix} V_S \\ V_R \end{vmatrix}$$

i.e.

$$J_S = y_c\,(V_S - V_R)$$

$$J_R = y_c\,(V_R - V_S) = -J_S \quad (1)$$



Both modelling are equivalent if the current J_S and J_R are computed following equation (1).

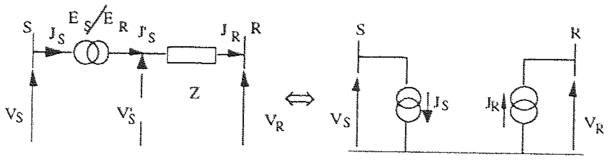
It is of interest to consider an incremental modelling, i.e. a model composed of a fixed admittance modelled in the network and an incremental part in parallel simulated by two coupled injectors. In that case the J_S and J_R currents are :

$$J_S = \Delta y_c (V_S - V_R)$$

$$J_R = - J_S$$

This type of modelling is particularly suited for testing the effect of additional compensating signals. The steady state value of Δy_c being zero, the transition from initial load flow to the dynamic simulation is straightforward.

The modelling of an electronically controlled phase shifter, is developed hereafter in a very similar manner.



$$\begin{vmatrix} V'_S \\ J'_S \end{vmatrix} = \begin{vmatrix} 1 & Z \\ 0 & 1 \end{vmatrix} \begin{vmatrix} V_R \\ J_R \end{vmatrix}$$

$$\begin{vmatrix} V_S \\ J_S \end{vmatrix} = \begin{vmatrix} E_S / E_R & 0 \\ 0 & R_J \end{vmatrix} \begin{vmatrix} V'_S \\ J'_S \end{vmatrix}$$

where E_S/E_R is the no load complex transformer ratio and R_J is the current transformer ratio. In the phase shifter (it can be quite different in a UPFC) there is no energy storage possible, thus considering an ideal transformer, the powers are equal on both sides and

$$\overset{*}{J_S} V_S = \overset{*}{J'_S} V'_S$$

when the * indicates a complex conjugate value.

i.e. $R_J = J_S/J'_S = (V'_S/V_S)^* = (E_R/E_S)^* = R_V^*$

The two complex equations describing the model are then :

$$V_S = V_R/R_V + Z_{J_R}/ R_V$$

$$J_S = \overset{*}{R_V} J_R$$

and the equivalent coupled injectors :

$$J_R = (V_S R_V - V_R) / Z$$

$$J_S = \overset{*}{R_V} J_R$$

Here too, it is possible to build an incremental model with obvious advantages.

Quasi static or dynamic operations of an electronically controlled phase shifter can be studied, the flow through the transformer being controlled by continuous adjustment of complex transformer ratio . A tapped modelling can be deduced easily. It will permit for example to check the adequacy of a particular control law when the detrimental action of a stepwize control is present.

4. EXAMPLE : THYRISTOR CONTROLLED SERIES COMPENSATION

The system considered is composed of 2 regions interconnected through two intertie lines and exchanging 700 MW. A 15 % series compensation is used.

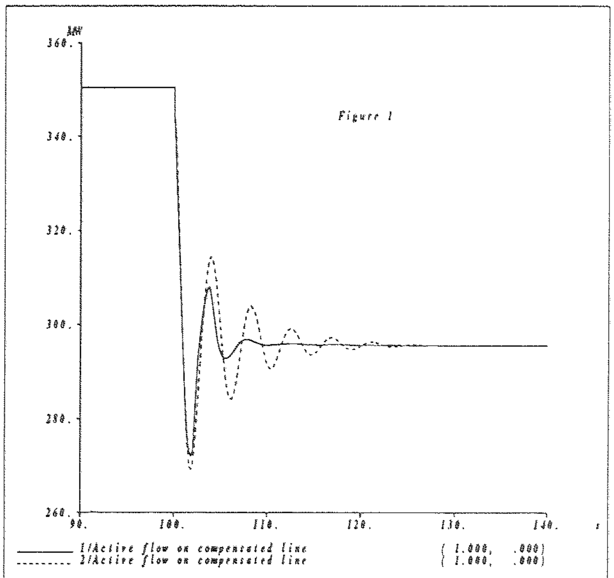
The Thyristor Controlled Series Compensation model implemented takes into account :

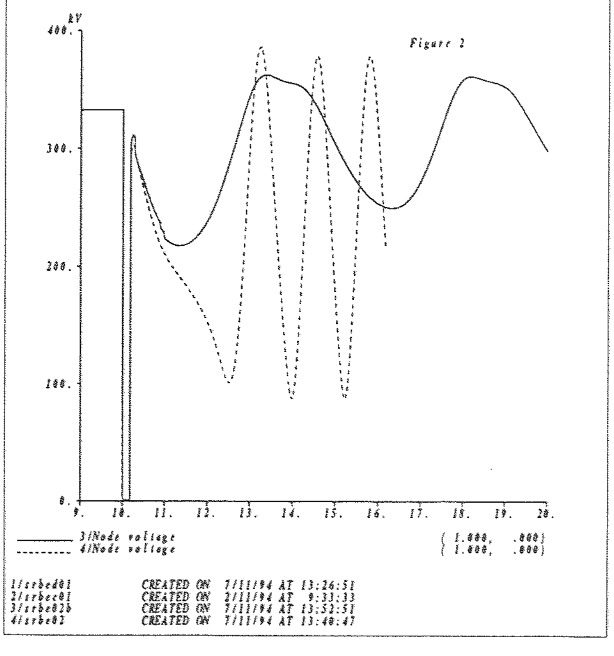
- the variable reactance at fundamental frequency;
- metal oxyde varistor in parallel with series capacitor;
- the limiters corresponding to the minimum and maximum thyristor firing angles;
- the limiter corresponding to the control of the voltage across series capacitor.

The implementation in EUROSTAG [3], [4], [8] is made thanks its macrolanguage and is based on the coupled current injectors concept described above.

The simulations display two technical benefits which can be achieved with the device :

- the improvement of the system natural damping which is obtained thanks to the presence of a damping loop based on the measured frequency. Figure 1 shows the active power flowing through the line. In solid line, the response with a Power Oscillation Damper additional control loop.
- the improvement of stability which results from a transient overload capability of series capacitor. A 3 phase fault of 180 ms is simulated. Figure 2, showing the node voltage near the fault, indicates in solid line that the boosting action is sufficient to avoid a loss of synchronism.





5. CONCLUSIONS

This paper summarizes some fundamental features a simulation program should have to be able to represent easily and accurately FACTS devices in large power system modelling.

An important question remains and is addressed to the manufacturers. Beyond the fundamental characteristic of a particular FACTS, some operation limits have to be considered, for example the behavior in case of low or high voltages or currents. Power system dynamics are often checked by short circuit test simulation. It is thus important to have a modelling able to represent faithfully such disturbance.

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RESUME

Pour pouvoir étudier l'intégration des FACTS dans un réseau interconnecté, il faut disposer d'une modélisation adéquate. Vu l'état actuel de la question, une grande souplesse de modélisation est indispensable car :

- beaucoup de ces dispositifs d'électronique de puissance n'existent pas encore de façon courante;
- la modélisation, peu répandue aujourd'hui, ne sera pas standardisée avant un certain temps;
- les exigences de modélisations impliquent la prise en compte des réglages locaux, régionaux et centraux intervenant éventuellement sur différents FACTS.

La résolution simultanée des équations algébriques décrivant le réseau et des équations algébriques et différentielles décrivant les dispositifs de puissance et de contrôle d'une part, et la modélisation souple par l'utilisateur final d'autre part sont des voies difficilement contournables.

Le programme Eurostag, par ses caractéristiques algorithmiques et la modélisation par l'utilisateur lui-même répond à ces exigences. Cela permet aux exploitants de réseaux d'envisager le test pour ces nouveaux dispositifs de schémas de régulation inédits , et cela de façon indépendante des constructeurs.