DYNAMIC STABILITY STUDY AND SIMULATION OF THE SYNCHRONOUS MACHINE COUPLED WITH THE NETWORK BY A LINE AND A LOAD IN PARALLEL

Elfahem A., Sboui A. & Hadj Abdallah H.
Sfax National Engineering School, Electrical Department. BP W, 3038 Sfax Tunisia
Email *:* elfahem.abdelbaki @yahoo.fr

ABSTRACT
This paper investigates the dynamic behaviour of synchronous machine-network in transitory mode.
In addition, simulation in reduced time of the dynamic behavior of the machine will enable us to define the limits of its stability during several transient states.

Keywords: Synchronous Generator, Network, Dynamic behaviour, Transient stability.

1. INTRODUCTION
The use of a reduced order model of synchronous generator for simulation is inadequate for transient stability study of the machine. Consequently there is a need to analyse exclusively the model of synchronous machine in power system.

This fact the formed network of several inter-connected machines is regarded as a multi variable nonlinear system. Its modeling becomes very difficult and complex then, owing to the fact that each synchronous machine is described by a nonlinear state model of order seven and the equations of interconnection of the network which are also nonlinear functions of sizes characteristic of the network.[7]

A rigorous study of this process in transitory mode absolutely requires the taking into account of the transitory modes of all the machines on the one hand and a fine modeling on the other hand. However, it would be complicated to approach the study of this problem in the total form. A solution consists in considering the case encountered frequently in practice where the disturbance occurs in the vicinity of a synchronous machine which will be particularly affected; the effect of this disturbance on the other machines which can be considered negligible[6], [1]. Under these conditions, the network seen of the terminals of the machine considered can be replaced by an invariable three-phase f.é.m in amplitude and frequency, in series with an impedance. This impedance can be assimilated as a resistance in series with an inductance. [7]

2. MODELISATION OF SYNCHRONOUS MACHINE COUPLED TO THE NETWORK BY A LINE AND A LOAD
By adopting a reference frame *(d, q)* specific to the synchronous machine whose axis O_d is related to the axis of the primary circuit, the V_r voltage of the network node have two components according to two axes' (O_d, O_q) given by the following equations [5]:

$$\begin{cases} V_{rd} = -V_r \sin\delta_r \\ V_{rq} = V_r \cos\delta_r \end{cases} \quad (1)$$

These expressions will be used later in the formulation of electric equations of the connection: synchronous generator_ grid_ parallel load (R_{ch}, l_{ch}).

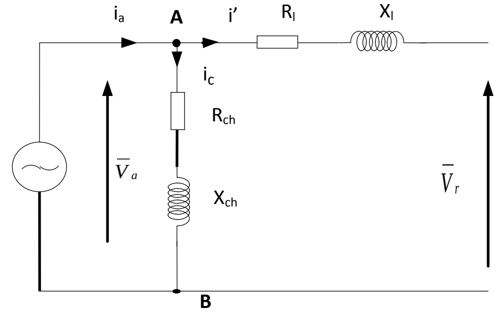

Figure1 : synchronous machine connected to the network by the intermediary of a line and a load

To simplify the study and handling, of the equations one by reducing the diagram of the figure1 to the following diagram under the condition which supposing that the frequency of the network is constant:

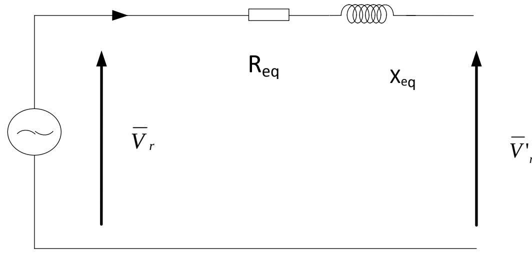

Figure2 : Thévenin equivalent Diagram of the synchronous machine connected to the network by the intermediary of a line and a parallel load.

Where R_{eq} , X_{eq} *et* V'_r are respectively; the resistance, the reactance and the Thévenin voltage obtained by applying the theorem of Thévenin between points A and B of the figure1.

The adopted mathematical model describing the machine depends on the nature of the problem to treat. Indeed, in a study concerning the machine coupled to an infinite power network, it is possible to consider the model of Park complet[8] :

$$\begin{cases} \frac{d}{dt}\psi_d = -\psi_q\,\omega_r - (R_a + R_{eq})\,i_d + V'_r \sin\delta'_r \\ \frac{d}{dt}\psi_q = \psi_d\,\omega_r - (R_a + R_{eq})\,i_q - V'_r \cos\delta'_r \\ \frac{d}{dt}\varphi_f = -R_f\,i_f + V_f \\ \frac{d}{dt}\varphi_{kd} = -R_{kd}\,i_{kd} \\ \frac{d}{dt}\varphi_{kq} = -R_{kq}\,i_{kq} \\ \frac{d}{dt}\delta'_r = \omega_r - \omega_0 \\ \frac{d}{dt}\omega_r = \frac{1}{J}(C_m - C_{em}) \end{cases} \quad (2)$$

With: $$\begin{cases} C_{em} = \psi_d\,i_q - \psi_q\,i_d \\ \psi_d = \varphi_d + l_{eq}\,i_d \\ \psi_q = \varphi_q + l_{eq}\,i_q \end{cases} \quad (3)$$

The system of equations obtained represents a description of the system by a nonlinear model of state of order 7 which has the following form:

$$\frac{d}{dt}X = f(X) + BU$$

Where:

$X = [\psi_d \quad \psi_q \quad \varphi_f \quad \varphi_{kd} \quad \varphi_{kq} \quad \delta_r \quad \omega_r]^T$ is the state vector.

$U = [C_m\,V_f]^T$ is the command vector

Calculation of the various variables of state in permanent mode

a calculation of the variables of state in permanent mode is obligatory to study the state of the machine after such a perturbation[3].

This calculation returns to solve:

$$\frac{d}{dt}X = 0 \qquad (4)$$

3. SIMULATION OF A SERIES OF DISTURBANCES AND COMMENTS

Parameters of the machine which has nominal apparent Power S=88MVA	***Data of the netwok***
l_d=1.36 p.u	V_r=1p.u
l_q=0.8 p.u	$\alpha = 0$
l_f=1.317 p.u	
l_{ad}=1.159 p.u	*Line of transmission*
l_{aq}=0.599 p.u	R_l=0.01p.u
l_{kd}=1.196 p.u	X_l=0.2p.u
l_{kq}=0.6295 p.u	
R_f=0.004313 p.u	*Permanent mode*
R_a=0	P_r=1p.u
R_{kd}=0.00699 p.u	Q_r=0.4p.u
R_{kq}=0.006714 p.u	
J=2000 p.u	

3.1. Calculation of the initial conditions:

By the resolution of the système :

$\frac{d}{dt}X = 0$ and from the values specified on the preceding table the values of the permanent mode are the following:

$$\begin{cases} V_{f0} = 0.0083\,p.u \\ i_{f0} = 1.9261\,p.u \\ \psi_{d0} = 0.8226\,p.u \\ \psi_{q0} = 0.5860\,p.u \\ \varphi_{f0} = 1.4893\,p.u \\ \varphi_{kd0} = 1.1850\,p.u \\ \varphi_{kq0} = 0.3510\,p.u \\ C_{m0} = 1.0 \\ \delta_{r0} = 0.6150\,p.u \end{cases}$$

3.2. Presentation of the disturbances simulated:

one proposes to study by simulation by means of Simulink, the stability of the machine after the following various types of disturbances:

-1. *Influence impedance of the parallel load with* $\cos\varphi_{ch} = C^{ste}$

- 2. *Influence impedance of the line with* $\cos\varphi_l = C^{ste}$

The study comprises the numerical integration of the differential equations of the nonlinear model by the means of Simulink and tracing of the temporal evolution of the state variables. All this study was carried out with software *MATLAB (routineODE4 (Runge-Kutta)).*

3.3. Qualitative analysis of the results:

the disturbance	**Case**	**Quality of stability**
1	1.1	kept stability
	1.2	stability completely lost
2	2.1	kept stability
	2.2	stability found but no acceptable

3.4. Quantitative analysis of the results:

1.1/ Transitory evolution of the variables of state following the perturbation in parallel load *:(Rch, Xch from 50pu to 1pu)*

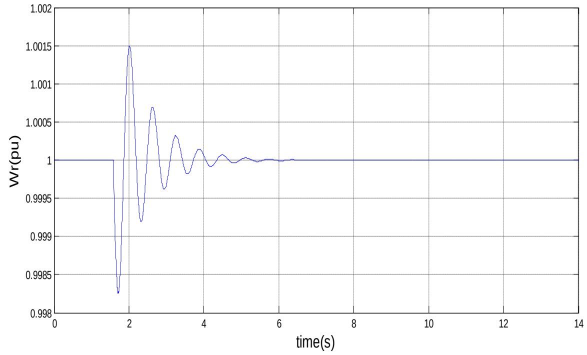

Fig1.1.a.rotor speed after a load variation

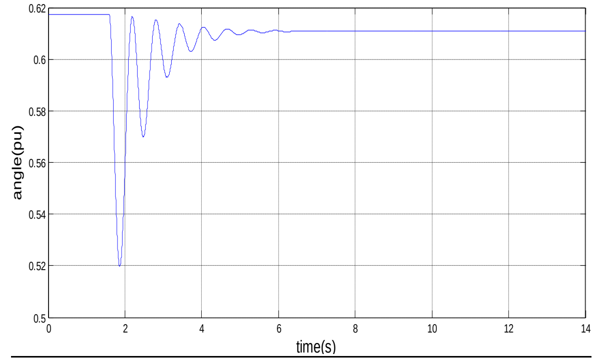

Fig1.1.b.rotor angle after a load variation

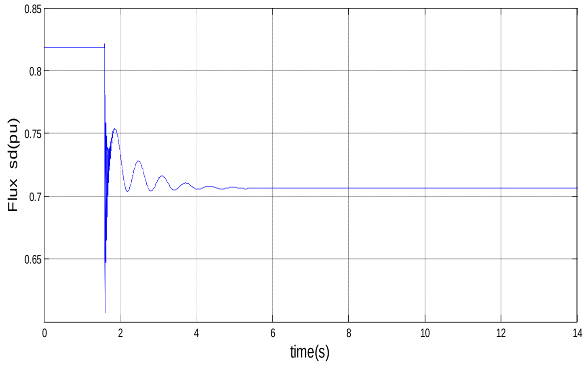

Fig1.1.c. stator flux after a load variation

Following this disturbance, one sees that the system finds another stable mode (after 3 seconds).

1.2/ Transitory evolution of the variables of state following the perturbation in parallel load*:(Rch, Xch from 50pu to 0.2pu)*

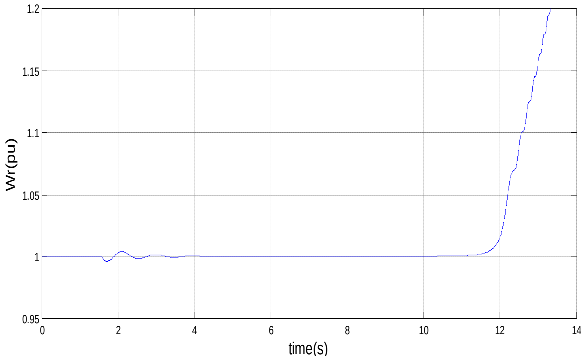

Fig1.2.a.rotor speed after a load variation

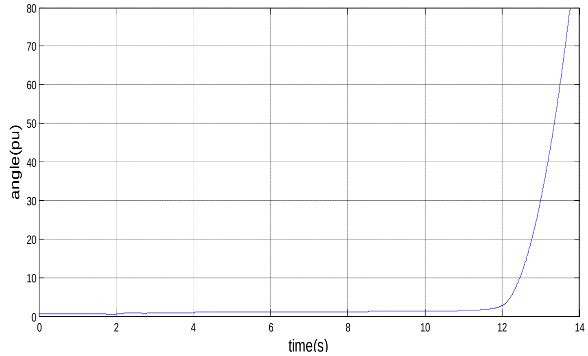

Fig1.2.b.rotor angle after a load variation

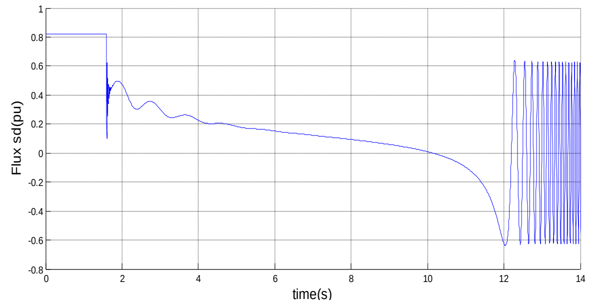

Fig1.2.c. stator flux after a load variation

The minimal value of the impedance which allows the instability of the system is $R_{ch} = X_{ch} = 0.2\,pu$. It then constitutes a critical limit for the load. The following figures show that the system starts to diverge starting from 11.8s.

<u>2.1/ Transitory evolution of the variables of state following the perturbation:*(R*</u>

2.1/ Transitory evolution of the variables of state following the perturbation:*(R_l from 0.01pu to 0.02pu, X_l from0.2pu to 0.4pu)*

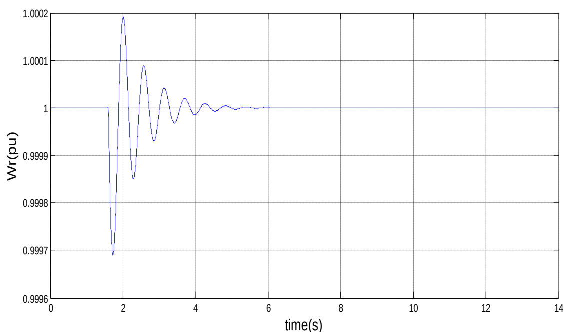

Fig2.1.a.rotor speed after a line impedance variation

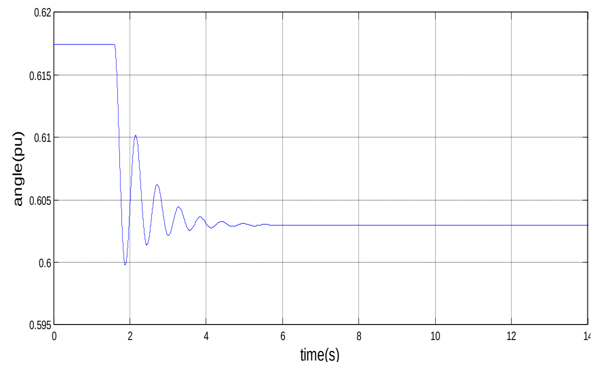

Fig2.1.b .rotor angle after a line impedance variation

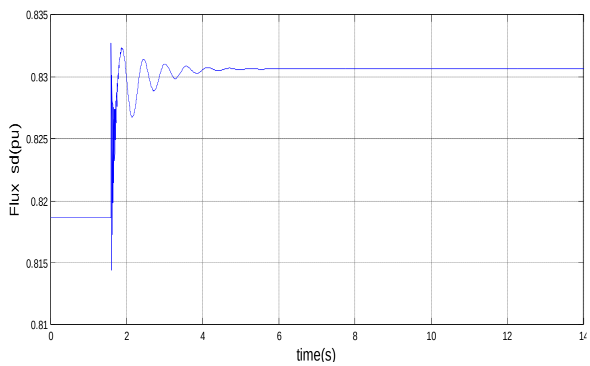

Fig2.1.c .stator flux after a line impedance variation

2.2/ Transitory evolution of the variables of state following the perturbation:*(R_l from 0.01pu to 0.25pu, X_l from0.2pu to 4pu)*

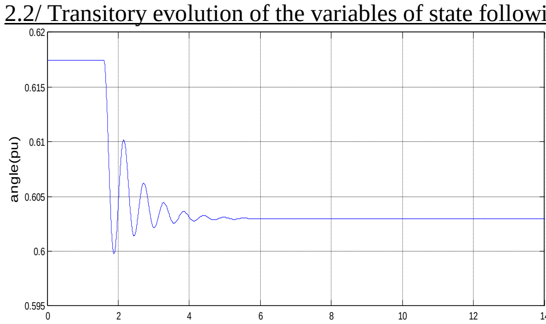

Fig2.1.b .rotor angle after a line impedance variation

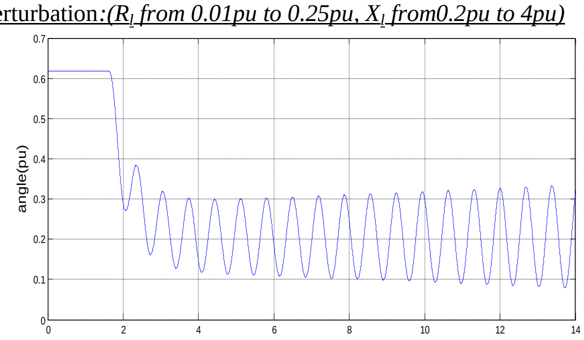

Fig2.2.b .rotor angle after a line impedance variation

X

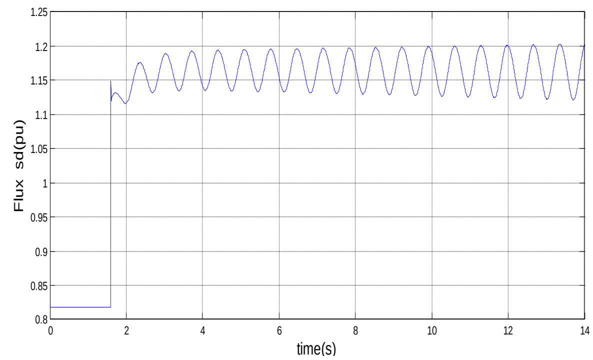

Fig2.2.c .stator flux after a line impedance variation

It is noticed that for a great increase in the line impedance (Rl=0.13pu, Xl=2.6pu) stability of the system is found but after an enormous time (the system carries out several oscillations before joining its new permanent mode).

4. DISCUSSION OF RESULTS

First we were particularly interested by the most significant phenomenon of transitory stability, i.e. the possible keeping of stability could be regarded physically as acceptable; qualitative judgment on the level of the maximum amplitude or minimal attack by the variable considered. As can be observed for example cases where stability is maintained whereas the impedance of the line reaches a very low level, whereas other disturbances, even weak, generate the instability of the machine.

By analyzing the curves (1.1, 1.2, 2.1, 2.2) one sees that the increase in the impedance of the line or the reduction in the impedance of the load (Rch, Xch) often constitutes a constraining disturbance for the stability of the mode. Indeed such a disturbance is practically equivalent to a reduction in the grid voltage Vr, which generates a degradation of the machine voltage level and consequently a brutal fall of the electromagnetic internal force; this is translated by a reduction in the resist electric torque and thus an honest divergence of the rotor of the machine compared with the synchronous axis of the network.

5. CONCLUSION

In this article, one was interested in the study of the stability of a synchronous machine coupled with an infinite power network by the intermediary of a line and a load .

A study was made in a first place has fine to lead to a physical model of order seven describing the dynamics of the synchronous machine when it is coupled with the infinite network by a line in parallel with a load (R_{ch}, l_{ch}). Then one was interested has to make a qualitative and quantitative analysis results of simulation obtained by the means of study of the temporal variations of the various variables of state for various disturbances on the parameters of the line and the parameters of the parallel load. One always tried to limit the stable operation range of the machine while fixing the critical cases.

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