

A Computer Application for Power System Control Studies

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Abstract - This thesis presents studies related to Dynamic Power Systems. Conventional energy generators (steam turbine and hydro turbine), and renewable generators (wind and solar), requires control systems: frequency controller and voltage controller.

This work analyzes the classic models of frequency and voltage controllers, as well as interaction between them. Simulations are made for interconnected networks possessing generators with frequency and voltage control, and for generators only with frequency control. Thus, based on these simulations, an assessment of the dynamic behavior of the network facing variations in load power will be made. It will also be performed a sensitivity analysis to the parameter of the turbines.

Finally the obtained results will be analyzed, compared, and consequently will be made a critique of the approximations used

Key Words: Sensitivity Analysis, Frequency Controller, Voltage Controller, Dynamic Behavior.

I. INTRODUCTION

The operation of an Electrical Power System (EPS) aims to attend the criteria, sometimes conflicting, economic and security, in satisfaction the demand of the consumer market.

To realize their purpose, the generation system, transmission and distribution of electricity (which is obvious more complex when more diverse is the consumer market and production park) must have effective means to supervise and control the variables of interest.

The EPS operates at a nominal value of certain quantities that characterizes it, namely the nominal frequency f_0 , the rated voltage V_0 and the interconnected power P_{ij} . To maintain these values closer to their nominal values as require by the specification, it is necessary to control the frequency and the voltage. The load of EPS varies with time and is impose by consumption. Therefore, variations in the power generator must match the variation in load power, in order to keep quantities, which characterize the EPS, closer to their nominal values.

The EPS has some features that make it possible to study the frequency control independently of the study of voltage control. A disturbance in the balance of active power mainly affects the frequency, for this reason to control the active power is achieved by controlling the frequency. Otherwise, if the disturbance is in the balance of reactive power, this mainly affects the voltage amplitude in buses, and to control the reactive power is used the voltage amplitude. However, there is an interaction between frequency control system and voltage control system. This interaction result from the variation of active load (P_c) and variation of active power interconnection (P_{ij}) whit a voltage variation in the module.

II. CONTROL OF ELECTRIC POWER SYSTEMS

The large power plants that produce the most electricity are remote from the major consumption centers, typically in urban areas. The energy produced is delivered to the transmission network through lines of extra high voltage (EHV). Through transformers, the energy is distributed across networks at high, medium and low voltage (HV, MV, LV), until get the consumers [1].

A properly designed the EPS should be able to meet some basics requirements, among which stand out [2]:

- Ability to meet the continuous change in demand. The electrical energy can not be conveniently storage in large quantities, it is necessary to maintain and monitor an adequate “spinning” reserve of power all time;
- The quality of energy supply must meet adequate performance in relation to frequency variation, voltage variation and the level of reliability.

For EPS can meet the requirements mentioned above, were developed several control devices that operate at various levels.

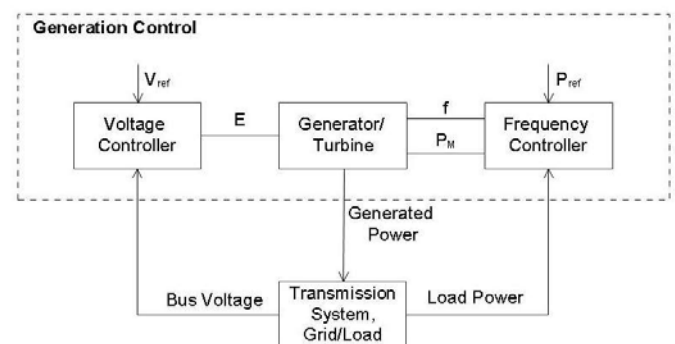


Fig. 1 – Electrical Power System and the Control Devices

In the Fig. 1 are represented the electrical power system and the control devices. These contribute for the operation of the energy system with safety, enabling voltage and frequency are within acceptable limits.

III. FREQUENCY CONTROLLER

The frequency is related with the balance of active power generated and consumed (network losses included), and since there is no possibility to store large amount of electricity, this balance must be maintained constantly.

When there is an increased load, generation must also increase. Since this increased load does not occur instantaneously, and while the balance is not established, the additional load will be satisfied by reducing the kinetic energy stored in the rotating masses.

The equation (1) represents the energy balance:

$$P_M - P_c = \frac{dW_{cin}}{dt} \quad (1)$$

Where:

$$W_{cin} = \frac{1}{2} I \omega^2 \quad (2)$$

If there is a change of power (load or mechanical), the kinetic energy also undergoes a change (increase or decrease depending of the sign of the difference of powers), which cause a change in angular velocity as well as in the frequency.

Thus, the frequency is an indicator of the power consumed and generated in the system, and the variation (relative to nominal value) is the input on frequency control system, which aims to restore this balance automatically.

As the frequency magnitude of a global character, it must be maintained within a very narrow range, typically $\pm 0,1\%$ of the nominal value (50Hz in Europe and 60Hz in U.S.A and Brazil)

A. Speed Governor

To ensure control of frequency, each group of generator needs a speed governor. This measures the rotation speed of the group, comparing it to a reference value.

If we consider small variations around a given operating point, the transfer function of the speed governor is given by:

$$Pv = \frac{K_G}{1 + sT_G} \left(Pref - \frac{1}{R} f \right) \quad (3)$$

The parameter R is referred to as speed regulation or droop and is expressed in Hz/MW or in p.u. on base of nominal power and nominal frequency of the machine, assuming typical values in the range from 0,03-0,06 p.u.

B. Hydro Turbine

In general, and for small variations around the operation point, the equation of the turbine can be linearized. The gate can be seen as hydraulic transmission line, terminated with an open circuit in the turbine and a short circuit in the reservoir.

Thus, through the approximate linear mode, the transfer function of the hydro turbine is given by [3]:

$$G_{Th}(s) = \frac{Pm}{P_V} = \frac{1 - sT_W}{1 + s \frac{T_W}{2}} \quad (4)$$

C. Steam Turbine

The most commonly used steam turbines are the turbines without reheating or with just one reheating.

Thus, and taking advantage of simplified models usually used, the transfer function of the steam turbine without reheating is given by:

$$G_T(s) = \frac{Pm}{P_V} = \frac{K_1}{1 + sT_1} \quad (5)$$

In turn, the steam turbine with reheat that possess a body of high pressure and other with low pressure, where the steam reheated between them, has the following transfer function:

$$G_T(s) = \frac{Pm}{P_V} = \frac{K_1}{1 + sT_1} \frac{1 + f_{AP}T_2s}{1 + sT_2} \quad (6)$$

The share of produced power in the body of high pressure (f_{AP}) takes a typical value of 0,3 p.u. (on base of nominal power).

D. Typical Value for the Constants

In TABLE I, are represented typical values for the time constants and gains shown in the models presented [5].

TABLE I – Constants Values

System Description	Time Constants(s)				Gains	
	T _G	T ₁	T ₂	T _w	K _G	K ₁
Speed Governor	0,1 - 0,3	x	x	x	1	x
Steam Turbine without reheating	x	0,2 - 0,5	x	x	x	1
Steam Turbine with reheating	x	0,1 - 0,4	4 - 11	x	x	0,3
Hydro Turbine	x	x	x	0,5 - 4,0	x	x

For the simulation results be consistent it is necessary that the values used in the parameters are equal. So in TABLE II are represented all values of constants that are used in several simulations.

TABLE II – Constants Used in Simulations

	Generation1	Generation2	Generation3
T [s]	0,3	0,5	0,2
K	1	1	1
R [p.u.]	0,05	0,06	0,06
H [s]	3	4	2

IV. VOLTAGE CONTROLLER

In order to be able to guarantee the power quality in electrical systems is essential the use of voltage controllers. It is crucial an effective compensation for any disturbance, thus ensure a proper operation of an electric power system. Being the voltage a local character magnitude, generally are accepted values in a band of variation of $\pm 5\%$ of its nominal value.

The excitation system provides direct current to the winding excitation of the synchronous machine. Through the adjustment of excitation, this system still performs a function of control and protection, essential for good performances of electrical system.

The Fig. 2 shows the schematic diagram of excitation system and voltage controller in closed loop of a synchronous generator.

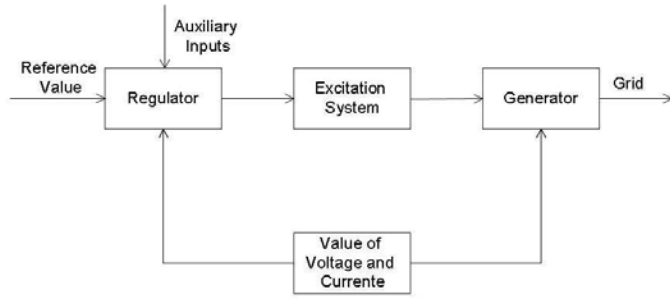


Fig. 2 – Schematic Diagram of Excitation System and Voltage Controller [1]

The output voltage of the generator is rectified and filtered, and led to the regulator that compares with the reference value. The error is amplified and applied to the excitation system, which constitute the power element of control system. In order to achieve better performance of the generator in transitional regime can also be applied to the regulator auxiliary inputs.

A. Block Diagram of Voltage Controller

The block diagram of voltage control represented in Fig. 3 is an adaptation of *IEEE Type I* excitation system [4]. The different blocks are:

- Exciter: provides the necessary power to the excitation winding of the synchronous machine;
- Amplifier: amplifies the loop signals;
- Power System Stabilizer (PSS): inject additional stabilizing signals in order to provide damping in the oscillations of power systems;

The additional term $S_E(E_{fd})$ that appears in the excitation correspond to saturation, if we consider small variations around the operating point is generally neglected [5].

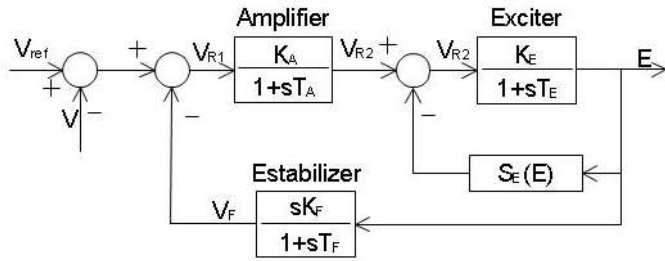


Fig. 3 – Block Diagram of Voltage Controller (Adapted from: [4])

The amplifier aims to amplify the value of V_{R1} and command the controlled rectifier which provides an excitation current of the exciter. The time constant associated with the regulator and rectifier is represented by T_A (assuming a typical value of less than 100ms) and the gain set by K_A [1]. The transfer function of the amplifier is given by:

$$\frac{V_{R2}(s)}{V_{R1}(s)} = \frac{K_A}{1 + sT_A} \quad (7)$$

The transfer function of the exciter is given by:

$$\frac{E(s)}{V_{R2}(s)} = \frac{K_E}{1 + sT_E} \quad (8)$$

Where $K_E = \frac{k_E}{R_E}$ e $T_E = \frac{L_E}{R_E}$ are the exciter gain and time constant (typical value of about 1s) respectively [1].

The transfer function of stabilization loop is given by:

$$\frac{V_F(s)}{E(s)} = \frac{sK_F}{1 + sT_F} \quad (9)$$

V. ANALYSIS MODELS

A. Three Generators Interconnected with Frequency Controller (Simple Model)

For this study it is considered that three steam turbines without reheating and with frequency controller are interconnected. The connection used is a simplified mathematical model that assumes that the interconnection lines have a small capacity transport, compared to the rotating power in each generation. Thus for small changes in frequency, the power transit is given by [6]:

$$P_{12} = \frac{T_{12}}{s} (f_1 - f_2) \quad (10)$$

To make a dynamic analysis is necessary to have the differential equations that describe frequency control and the interconnection between different generations. Thus the general equations representing this model are:

$$\dot{f}_i = \frac{1}{2H_i} Pm_i - \frac{1}{2H_i} P_{Di} - \frac{D}{2H_i} (f_i - f_0) - \frac{1}{2H_i} P_{ij} + \frac{1}{2H_i} P_{ki} \quad (11)$$

$$Pm_i = \frac{K_i}{T_i} P_{ref} - \frac{K_i}{T_i R_i} (f_i - f_0) - \frac{1}{T_i} Pm_i \quad (12)$$

$$\dot{\delta}_i = 2\pi(f_i - f_0) \quad (13)$$

$$\dot{P}_{ij} = T_{ij}(f_i - f_j) \quad (14)$$

Case 1:

In this case was imposed a change (increase of 0,1 p.u.) in the demand power of the turbine 3 when the network was in balance.

The results are in the following figures:

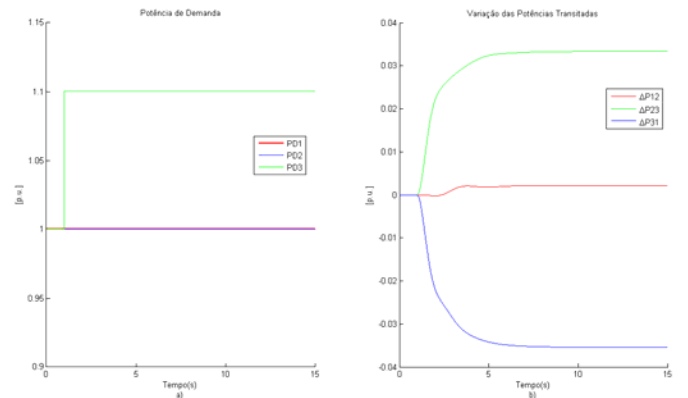


Fig. 4 - Results: a) Demand Power, b) Variation of Transited Power

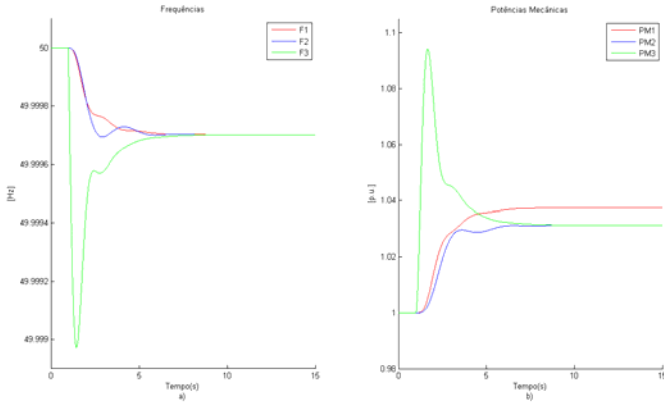


Fig. 5 - Results: a) Frequency, b) Mechanical Power

In a first analysis to Fig. 5 it is verified that the moment that gives the power demand increase (load increase) there is a decreased in frequency and an increased in mechanical power. There is also an increase in transited power from 2 to 3, and from 3 to 1 (Fig. 4 b)).

Once the change takes place in turbine 3, the drop in frequency in this generation is more marked at the beginning and stabilizes when compensated by the other generations. Generations 1 and 2 which will offset the increased power have different curves; this occurs due to the fact the values of times constants inherent in the generations differ.

Case 2:

In the second case study in again imposed a change in demand power in the turbine 3, with the particularity that this presents a very high value for the time constant ($T_3=1000s$), and a very low value for the inertia constant ($H_3=0,0001s$). The results are in the following figures.

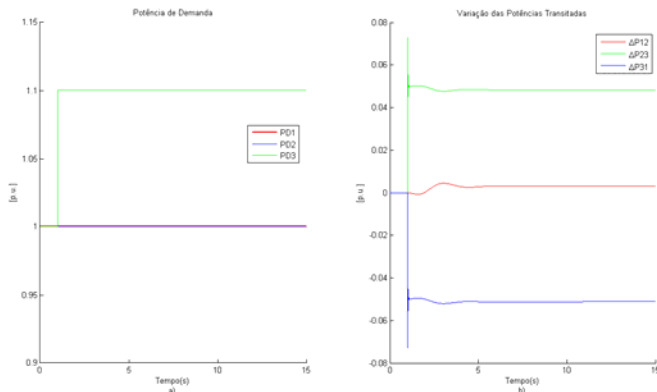


Fig. 6 - Results with $T_3=1000s$ and $H_3=0,0001s$: a) Demand Power b) Variation of Transited Power

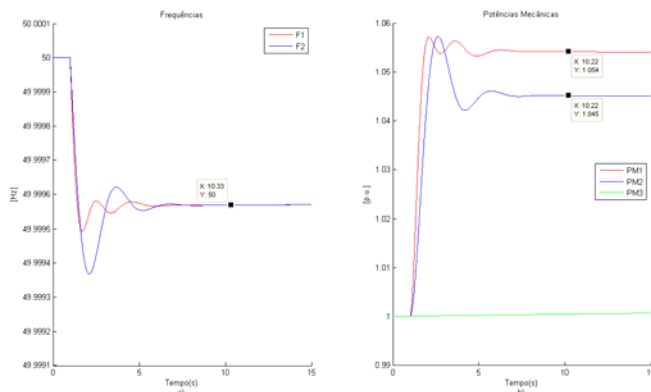


Fig. 7 - Results with $T_3=1000s$ and $H_3=0,0001s$: a) Frequency b) Mechanical Power

When considering the value of inertia is very low and that the time constant is very high, it is assumed (although in an approximated way) that the generator 3 is bus a connected to a load. Thus, analyzing the Fig. 7 a), it appears that there is a higher decrease in the frequency on the generation 1 and 2 since these are the ones that will compensate (in a short time) the increased load that the network suffered.

The generator 3 will compensate, but in a long time, because the time it takes to respond is very high.

Sensitivity Analysis:

To make the sensitivity analysis of this model assumes that the power demand of turbine 3 always suffer an increase of 0,1 p.u. What does vary are the constants parameters of the turbines, namely the time constant (T) and the inertia constant (H).

Change in inertia constant of turbine 3:

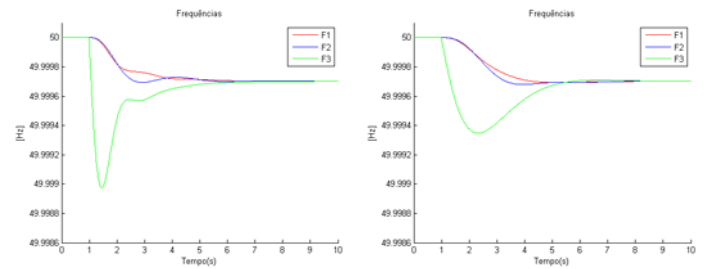


Fig. 8 - Result of Frequencies with $H_3=2s$ (left) and $H_3=8s$ (right)

As can be seen by the previous figures the variation of inertia constant affects mainly the peak of the fall suffered by frequency. This happens because the kinetic energy stored in the rotating masses is the first to satisfy the change in demand, so if the inertia constant is greater, there is a greater response capacity.

Change in time constant of turbine 1

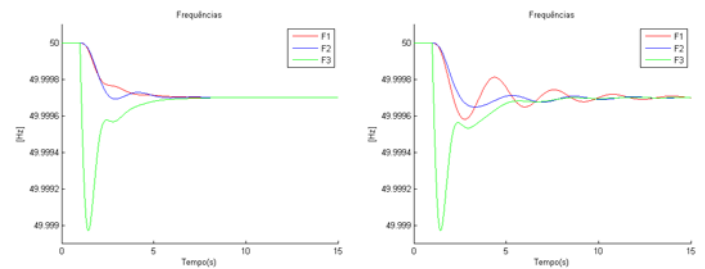


Fig. 9 - Result of frequencies with $T_1=0,3s$ (left) and $T_1=1,6s$ (right)

When observing the previous figures, it is verified that with the decrease in time constant, the oscillation suffered by the frequency also decrease. This is because the response time increases with decreasing time, then it will take longer to react to changing suffered.

B. Three Bus Interconnected and Two Generations with Frequency Controller

For this study it is considered that three buses are interconnected as shown in Fig. 10. Two of the buses are connected to generations, both having frequency controller.

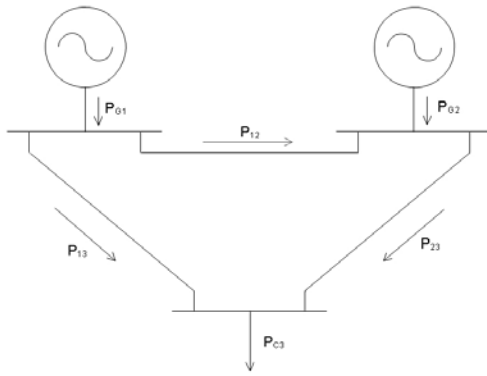


Fig. 10 - Network with 3 Buses

In contrast to what happened in the previous case, this does not use a simplified model to represent the interconnections.

In this case the interconnections network is described by algebraic equations that can be obtained by the “DC” power flow.

Thus the equations that describes of Fig. 10 are as follow:

$$P_{G1} = \frac{1}{X_{12}}(\delta_1 - \delta_2) + \frac{1}{X_{13}}(\delta_1 - \delta_3) \quad (15)$$

$$P_{G2} = -\frac{1}{X_{12}}(\delta_1 - \delta_2) + \frac{1}{X_{23}}(\delta_2 - \delta_3) \quad (16)$$

$$P_{C3} = \frac{1}{X_{13}}(\delta_1 - \delta_3) + \frac{1}{X_{23}}(\delta_2 - \delta_3) \quad (17)$$

These equations are considered the algebraic equations, since the variable that describe them can be changed instantly when is any change in loads. On the other hand the equations that represent the frequency controllers are considered differential equations, i.e. variables that describes them (also considered as state variables) can not be changed instantly when there is a change in load.

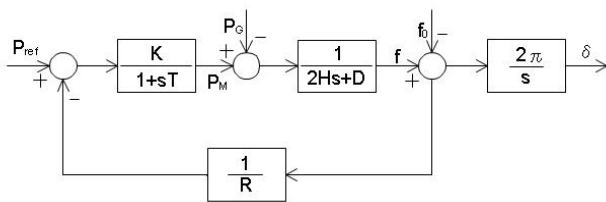


Fig. 11 - Block Diagram of Frequency Controller

The frequency control of each turbine is made according to the model represented in Fig. 11 as well, and once it is admitted that both generations are performed by steam turbine without reheating, the differential equations are:

$$\dot{f}_i = \frac{1}{2H_i} P_{m_i} - \frac{1}{2H_i} P_{G_i} - \frac{D}{2H_i} (f_i - f_0) \quad (18)$$

$$P_{m_i} = \frac{K_i}{T_i} P_{ref_i} - \frac{K_i}{R_i T_i} (f_i - f_0) - \frac{1}{T_i} P_{m_i} \quad (19)$$

$$\dot{\delta}_i = 2\pi(f_i - f_0) \quad (20)$$

The simulation of this network consisted to impose a change (increase of 0,1 p.u.) of load power at bus 3 (PC3)

when the network was in balance. The results are in the following figures:

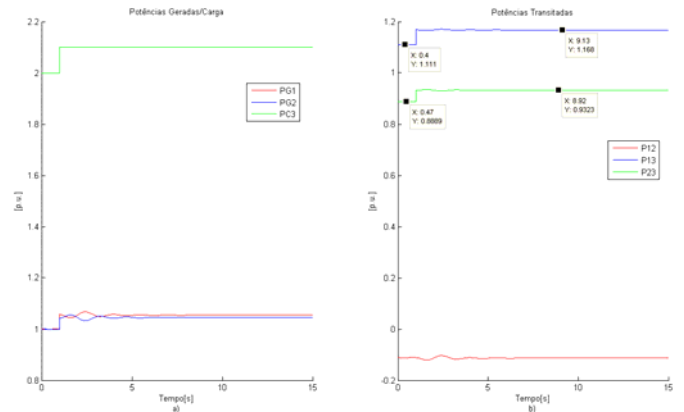


Fig. 12 - Results: a) Generation Power, b) Transited Power

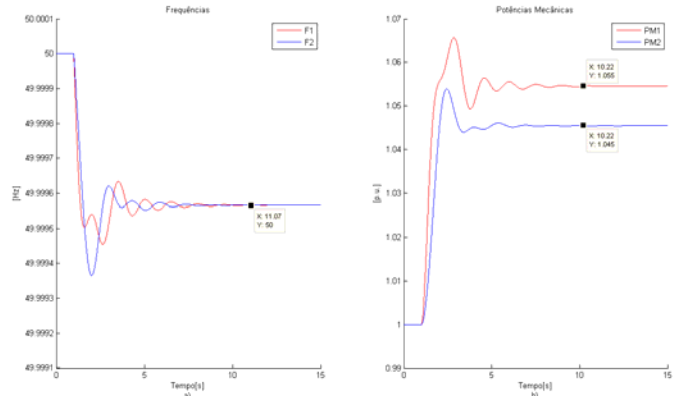


Fig. 13 - Results: a) Frequency, b) Mechanical Power

By analyzing Fig. 12 it is verified that with increasing load power of bus 3, also increases all the transmission powers connected with him, i.e. the power coming from the buses where there is generation. As a result of this increase, there is an increase of the generator power of the buses 1 and 2.

The frequency, Fig. 13 a), as expected, once there was an increased load, there was a decrease in frequency. Both have a dissimilar way because although they are two steam turbines without reheating, the time constants inherent in them are different.

In Fig. 13 b) it is verified that the mechanical power of each turbines in increased when the load increases. This increase is necessary to compensate the increase of generation power. The increased is carried out slowly since these powers depend on the reaction time of the turbines.

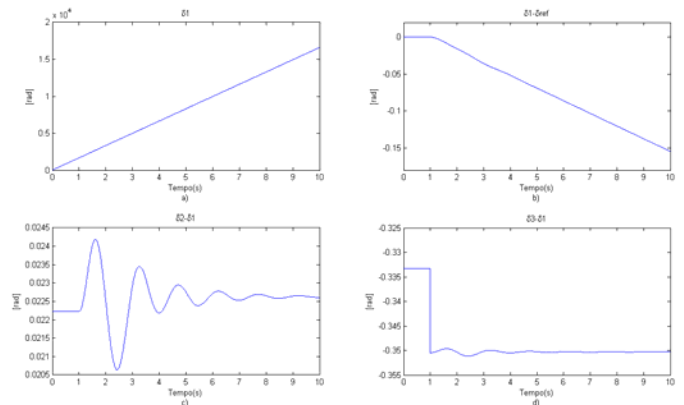


Fig. 14 - Results: a) Delta1, b) Delta1-Delta_ref, c) Delta3-Delta1, d) Delta3-Delta1

Relatively to deltas shown in Fig. 14, we observe that the deltas referring to generators (delta 1 and delta 2) are always increasing. This happens because the delta represents the rotor angle relatively to reference, and once the rotor is always in motion the angle is always increasing. The same happens with delta 3, although is not represented in the figure. The difference between delta 1 and δ_{ref} (present in Fig. 14 b)) indicates that there was a decrease in rotor speed of generator 1, i.e. with the increasing of the load, the generator has no longer a frequency of 50Hz (reference) passing to be a slightly lower, which cause the increase delta 1 unless δ_{ref} . The graph d) of Fig. 14 represents the difference between delta 3 and delta 1, and can be seen that when the load power change occur there is a decrease of this difference, i.e. there will be a delay of delta 3 to delta 1.

Sensitivity Analysis:

Making a change in load power in bus 3 (increase 0,1 p.u.), and by varying the time constant of the turbine 2, observe the following results:

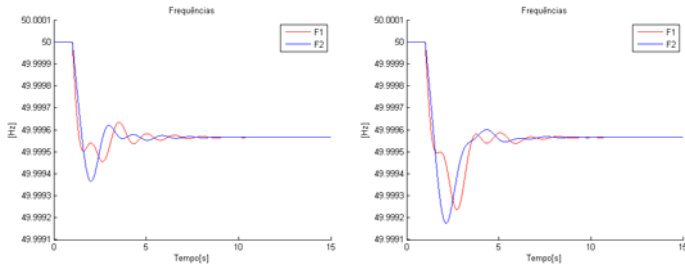


Fig. 15 - Results of Frequencies with $T_2=0,5s$ (left) e $T_2=2s$ (right)

Observing the results obtained we verify that with increasing time constant of turbine 2, the peak suffered by both frequencies and their oscillations also increase. This happens because the increased time constant makes the system more unstable.

C. Three Bus Interconnected and Two Generations with Frequency and Excitation Controller

For this study it is considered again the network shown in Fig. 10. However, in this case the generations have frequency controller and excitation controller.

In order to be able to implement the excitation controller is essential to know the value of voltage and current of each bus. So it is necessary to make an initial calculation of power flow by Newton-Raphson model to ascertain the initial value of voltage and current.

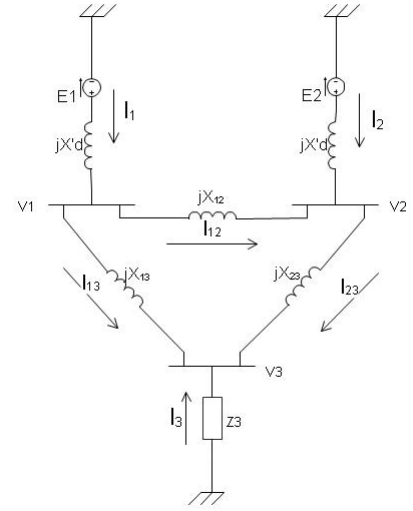


Fig. 16 - Equivalent Scheme of the Network with 3 Buses

The algebraic equations are obtained by analyzing the currents. Thus, using the equivalent network scheme (Fig. 16) we obtain the following equations:

$$\bar{E}_1 = \bar{V}_1 + jX'd \times \bar{I}_1 \quad (21)$$

$$\bar{E}_2 = \bar{V}_2 + jX'd \times \bar{I}_2 \quad (22)$$

$$\bar{V}_1 - \bar{V}_2 = jX_{12} \times \bar{I}_{12} \quad (23)$$

$$\bar{V}_1 - \bar{V}_3 = jX_{13} \times \bar{I}_{13} \quad (24)$$

$$\bar{V}_2 - \bar{V}_3 = jX_{23} \times \bar{I}_{23} \quad (25)$$

$$-\bar{V}_3 = \bar{Z}_3 \times \bar{I}_3 \quad (26)$$

Using the frequency controller of Fig. 11 and the excitation controller of Fig. 17, and considering the saturation value null ($S_E(E)=0$), we obtain the following differential equations:

$$\dot{f}_1 = \frac{1}{2H_1} P_{m1} - \frac{1}{2H_1} P_{G1} \quad (27)$$

$$P_{m1} = \frac{K_1}{T_1} P_{ref1} - \frac{K_1}{R_1 T_1} (f_1 - f_0) - \frac{1}{T_1} P_{m1} \quad (28)$$

$$\dot{\delta}_1 = 2\pi(f_1 - f_0) \quad (29)$$

$$\dot{E}_1 = \frac{K_{E1}}{T_{E1}} V_{ref} - \frac{K_{E1}}{T_{E1}} V_1 - \frac{1}{T_{E1}} E_1 \quad (30)$$

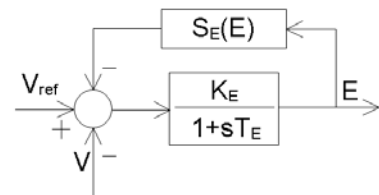


Fig. 17 - Block Diagram of Excitation Controller

When using an excitation controller is necessary to take into account that the value used to solve algebraic equations is the complex value of E, which does not happen when trying to solve the differential equations, it only uses the module E.

Thus, in each iteration step is necessary to calculate the complex E, and this is done through the equation (31)[7]:

$$\bar{E}^{(k+1)} = E^{(k+1)} \cos(\delta^{(k+1)}) + jE^{(k+1)} \sin(\delta^{(k+1)}) \quad (31)$$

The simulation will be done according to the diagram shown in Fig. 18.

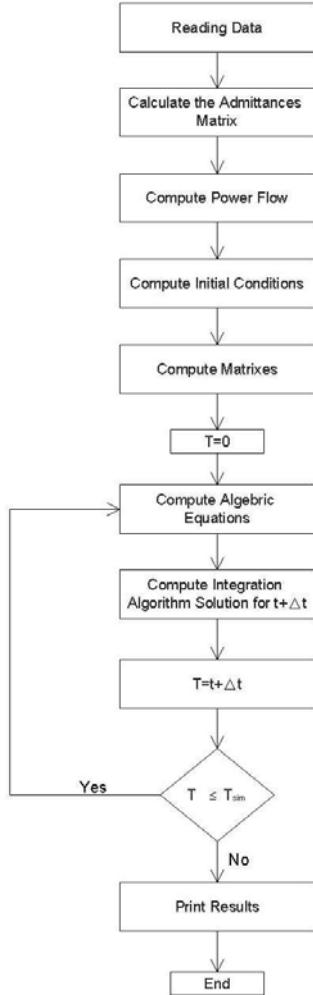


Fig. 18 - Simulation process diagram for a network with three buses and two generations interconnected with frequency and excitation controller

The simulation of this model consisted to impose a change (decrease 0,1 p.u.) at the load impedance (elasticity 2) present on bus 3, when the network was in balance. The results are in the following figures:

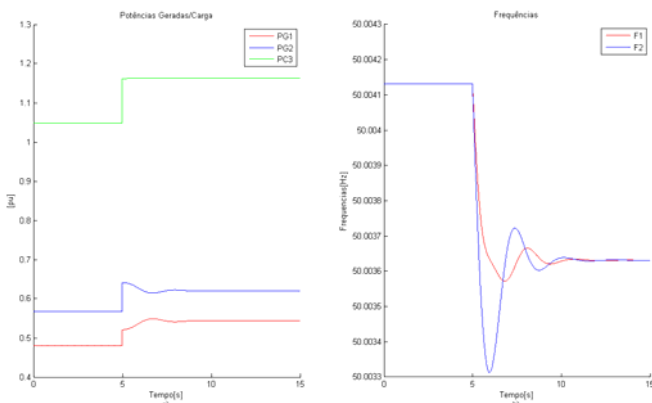


Fig. 19 - Results: a) Generation Power, b) Frequency

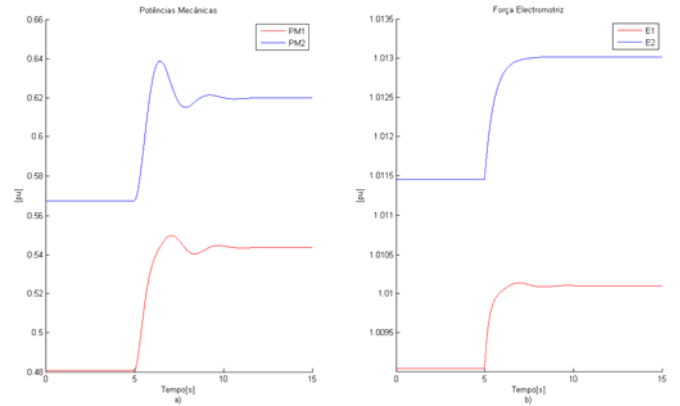


Fig. 20 - Results: a) Mechanical Power, b) Electromotive Force

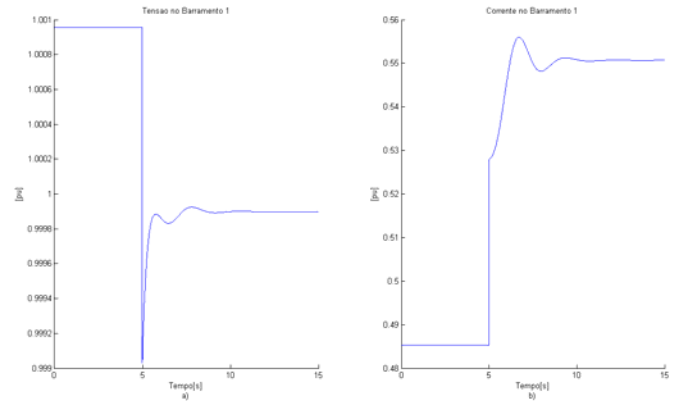


Fig. 21 - Results in Bus 1: Voltage (left), Current (right)

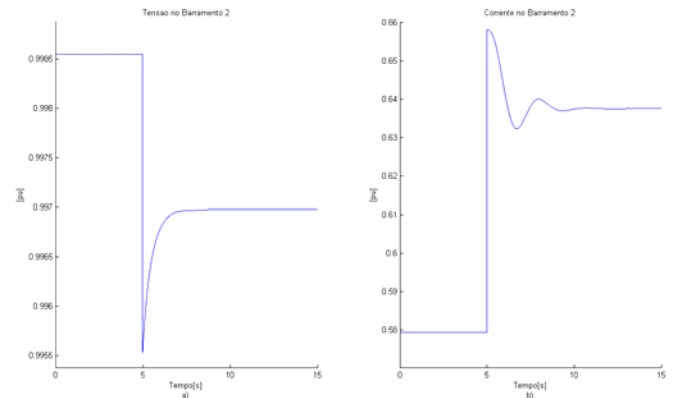


Fig. 22 - Results in Bus 2: Voltage (left), Current (right)

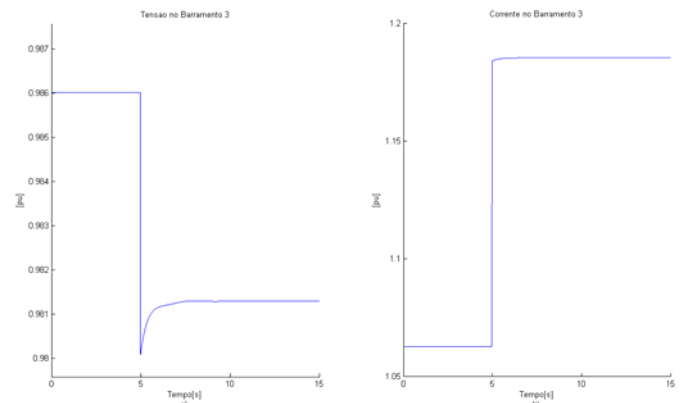


Fig. 23 - Results in Bus 3: Voltage (left), Current (right)

The decrease in the load impedance reflects in the reduction of voltage in buses and increasing of the generation power and load. This result is explained by these two equations:

$$V = ZI \quad (32)$$

$$P = \frac{V^2}{Z} \quad (33)$$

How can be check by equation (32), a decrease in the load impedance means that there is also a decrease in the voltage. Thus, and by equation (33), it is verified that the power is increased. In consequence of these results the current shows an increase in its value.

Once there was a reduction of voltage, this must be offset by an increase in electromotive force (e.m.f.).

Looking the Fig. 20 b) there is this increase in e.m.f. generated, and as a result of this increase, the voltage on both buses also suffer a slight increase.

Sensitivity Analysis:

For this model, the sensitivity analysis that will make is in relation to the excitation controller. The parameters that will be modified are the transient reactance (belonging to two generations).

Making a decrease of 0,1 p.u. in the impedance load and modifying the transient reactance are obtained the following results:

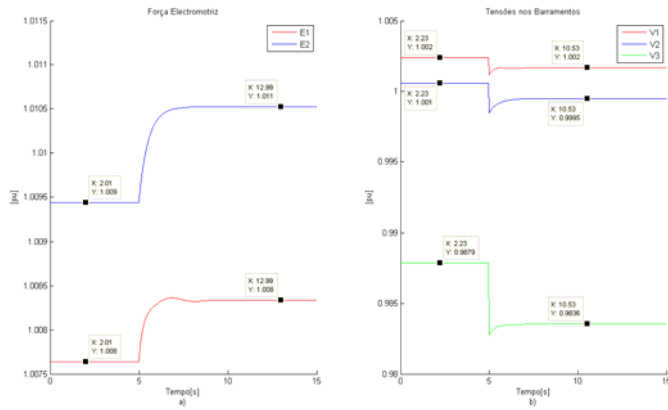


Fig. 24 - Results with $X'd=0,07$ p.u.:
a) Electromotive Force, b) Voltages in Buses

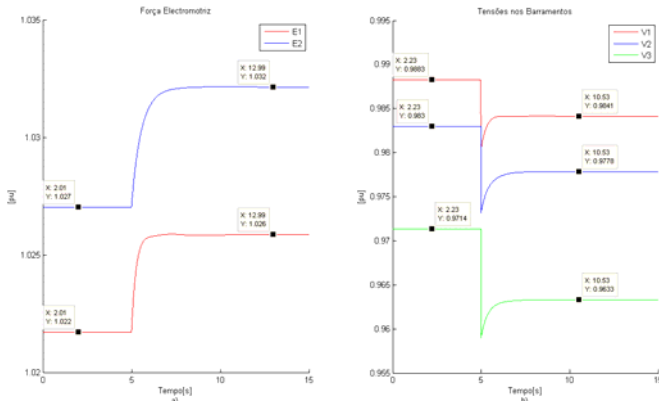


Fig. 25 - Results with $X'd=0,3$ p.u.:
a) Electromotive Force, b) Voltages in Buses

As shown by the figures represented above, the increase in transient reactance little influence the process of e.m.f.. However, this change is most visible in the curve of the voltage, especially in falls that suffer when the change occurs.

$$\bar{E}_1 = \bar{V}_1 + jX'd \times \bar{I}_1 \quad (34)$$

$$\bar{E}_2 = \bar{V}_2 + jX'd \times \bar{I}_2 \quad (35)$$

Analysis the equations above we can see that with an increase in the transient reactance the voltage is diminished. Although this decrease is noticeable, is not very significant, since the observed variations did not reach 1% of initial voltage.

Thus we can conclude that the transient reactance is not much interference in simulations

VI. COMPARING RESULTS

A. Interconnections of the Generations

Once has been used different methods for calculating the interconnected of generations, it is important to perform a comparative analysis of the results .

Comparing the results obtained in the Fig. 7 b) and the Fig. 13 b), it is clear that the final values are very similar. The mechanical power of turbine 1 and turbine 2 are increased by 0,055 and 0,045 p.u., respectively, and both frequencies decrease to the same value (Fig. 7 a) e Fig. 13 a)). However, the oscillations are quite different.

Observing the equations that characterize the frequency controller of the two models, it is verified that the equations (12) and (19) relating to the mechanical power are equal. Thus the inequality comes from equations (11) and (18) relating to the frequency.

When using the simplified model (with approximation to the interconnection between generations) the change is made in variable P_{Di} (demand power), so this directly affects the equations.

If on the other hand we are considering the interconnection by the power flow, the change occurs in the variable P_{Gi} but not directly. This variable results from the resolution of algebraic equations. And once it used the algebraic equations, we must take into account the reactance in the line, which were not used in the simplified model.

In previous results it was considered that the line reactance were small ($X_{12}=0,2$ p.u.; $X_{13}=0,3$ p.u.; $X_{23}=0,4$ p.u.), but considering that both reactance have a value of 1 p.u. the result obtained is in all identical to the results obtained with the simplified model.

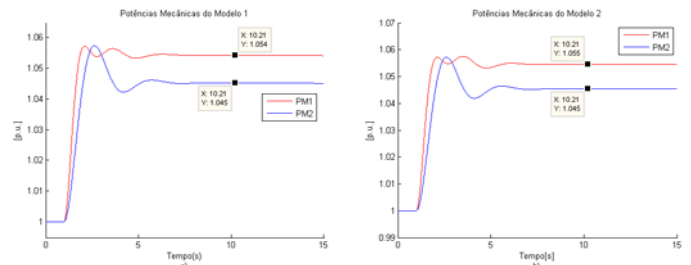


Fig. 26 - Results of Mechanical Power from increase of 0,1 p.u. in Load Power: a) with Simplified Model, b) with DC Power Flow

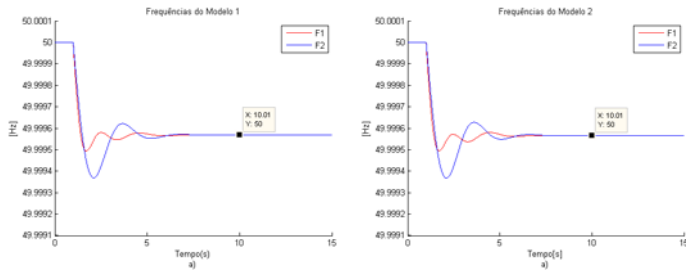


Fig. 27 - Results of Frequency from increase of 0,1 p.u. in Load Power:
a) with Simplified Model, b) with DC Power Flow

So comes to the conclusion that the results differ due to the values used in line reactance.

Also concludes that the approximation of the interconnection of generations and the approximation of the generation to a bus connected to an infinitive network, used in simplified model, constitutes a good approximation.

B. Excitation Controller with Saturation

For small load variations can be considered null value of $S_E(E)$. However, this simplification is no longer valid when you want to do a simulation closer to reality, once the increase in e.m.f. has a limit and can not increase infinitely.

In this study, simulations are held with excitation controllers with saturation and without saturation.

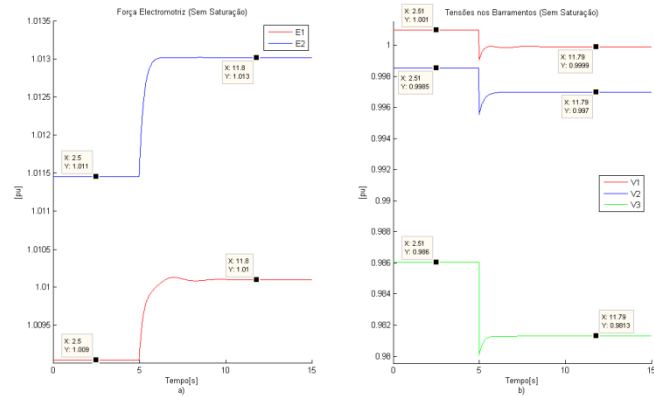


Fig. 28 - Results from decrease of 0,1 p.u. in load impedance:
a) Electromotive Force, b) Voltage (**Without Saturation**)

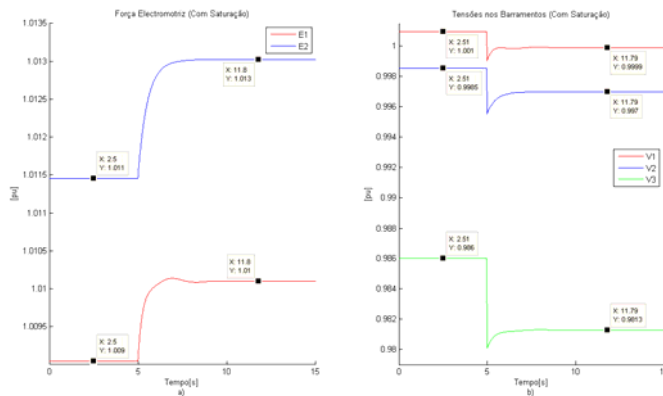


Fig. 29 - Results from decrease of 0,1 p.u. in load impedance:
a) Electromotive Force, b) Voltage (**With Saturation**)

Observing the figures represented above it is clear that with the decrease of 0.1 p.u. in the load impedance that both controllers reacts the same way, meaning that there is saturation. It begins to note a difference in value obtained when the decrease is more pronounced.

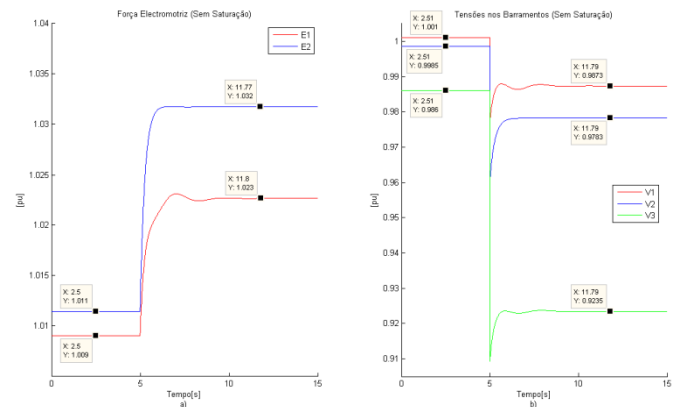


Fig. 30 - Results from decrease of 0,5 p.u. in load impedance:
a) Electromotive Force, b) Voltage (**Without Saturation**)

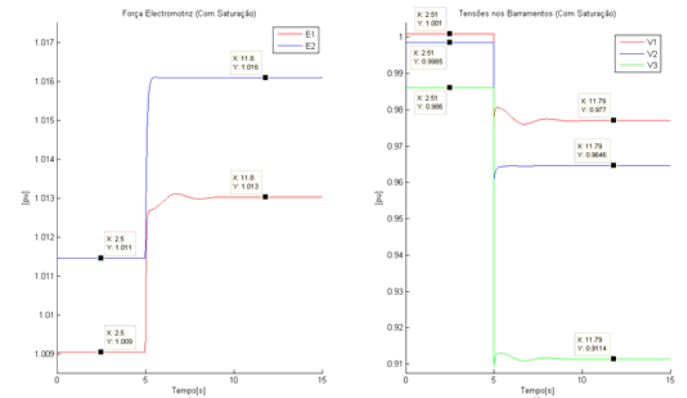


Fig. 31 - Results from decrease of 0,5 p.u. in load impedance:
a) Electromotive Force, b) Voltage (**With Saturation**)

Looking to Fig. 31 a) it is verified that the values of e.m.f. from generator 1 and the value of e.m.f. from generator 2 began reaching saturation. This means that the excitations controllers no longer provide e.m.f. that would be desired. This has implications on the voltage results, namely, the fact that they reach more pronounced falls in their values (Fig. 31 b)).

Making a comparison between the Fig. 30 and Fig. 31 can see that when neglects the factor of saturation, the voltage reach higher values, and the voltage on the buses suffer a less decrease.

VII. CONCLUSION

Through this study, was possible to understand the importance of the Control and Operation of Electrical Power Systems and how they can promote a satisfactory operation of the systems.

The interconnected synchronous networks with alternating current work with a common frequency, which must be regulated with a very narrow tolerance. For this reason is necessary to ensure, at each instant of time, the balance between generations and total consumption of active power. This balance is achieved by continually adjusting of mechanical power supplied by the machines drive from generators, controlling thereby the electrical power delivered to the network.

In interconnected networks it can be seen that the generators in service helps the offset the imbalance, since the interconnection lines has sufficient transmission capacity, and the system in difficulty should take the necessary measures to ensure the balance between generation and consumption.

VIII. REFERENCES

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