

## Self-Regulation of the Project Great Inga for an Interconnected Electrical Network.

Lidinga Mobonda<sup>1</sup>, Alphonse Omboua<sup>2</sup>

*Phd In Engineering Sciences, Dept.Of Electricity, University Of Brazzaville-Congo<sup>1</sup>*

*Phd In Applied Sciences, From The University Of Liege. Prof At The University Of Brazzaville-Congo<sup>2</sup>*

---

**ABSTRACT:** In this article we present a mathematical approach which deals with the stability of power plants from which the synchronism should be lost; the regime on the interconnected network such as dynamic regime of linearization, the adjustment of the frequency and the regulation of power where we will take as the digital application, the case of the project great Inga (Inga is the great hydraulic power plant located in the Democratic Republic of Congo). The study of project great Inga planned for interconnecting several African countries.

**Keywords:** Inga, Alternator, Regulation, Automatic, Interconnected network.

---

### I. INTRODUCTION

The interconnection of power plants in the electrical networks requires the synchronism, the equality of the voltages and the succession order of the phases to the interconnection. A fault made up on one of power plants can create a disruption felt by the whole interconnected networks. The interconnection between power plants must be able to rely on the stability of the whole, otherwise it is not used at the time where it should be useful. During an abrupt modification of the load asked by the users or the power supplied by the producer(s), we chronologically observe according to the greatness of the order from the size of the in the first second, following phenomena:

- A spread of wave on the lines during the order of the one hundredth of a second.
- A change of the frequency in all the network corresponding to a change of the kinetic energy from the rotating groups.
- An intervention of the primary regulators (regulators to static instructions) corresponding to the frequency setting.

**The stability of the operation from power plants is a function of five levels of orientations in the progressive direction of their durations[1]:**

- Immediate Exploitation (of the order of second) bringing the primary regulation.
- Immediate scheduled Exploitation (of the order of a few second) bringing the second regulation.
- Short-term exploitation or economic dispatching (of the order of a few minutes) bringing the tertiary regulation.
- Medium-term exploitation or daily exploitation (day) said uncertain future.

### II. REGULATION OF SPEED OF A WATERTURBINE

Let first us of all remember by what mechanism the speed regulators assure the distribution of the load between the diverse machines of a network. The regulator of a group aims at settling the speed, it has for mission to establish between the speed of regime and the power, a relation called characteristic of statism $\omega(P)$ . Let us consider a speed of regime( $\omega_d$ ) imposed to the groups by the load from the network, we are going to notice that both generators develop, for the groups by the load of the network, we are going to notice that both groups develop, for this speed, a power  $P_{1d}$ , from and one group  $P_{2d}$ ; from another; then, the total power [2] of the network is  $P_d = P_{1d} + P_{2d}$  (1)

During an abrupt variation of the flow rate  $Q_0$ , the level  $N_0$  and the flowrate of the turbine is  $q_0 = Q_0$ . When the flowrate decreases abruptly and passes from  $Q_0$  to  $Q'$  as a result from a reduction of the load in an upstream factory, the level is going first to fall down to a speed such as :

$$\frac{dN}{dt} = \frac{Q_0 - Q_N}{\Omega} \quad (2)$$

$\Omega$  : Being the surface of the upstream groundwater (dam, feeder canal, chamber of water) ; this level reduction acts, though the ballcock and the regulator, on the debit  $q$  of the turbine. Very moment, the law of variation of the upstream level is given by:

$$\frac{dN}{dt} = \frac{Q' - q}{\Omega} \quad (3)$$

Let us take as the origin of the levels, the minimum level  $N_2$ , it and then we have:

$$q = Q_{max} \cdot \frac{N}{N_1} \quad (4)$$

and 
$$\frac{dN}{dt} = \frac{Q'}{\Omega} - \frac{Q_{max}}{\Omega} \cdot \frac{N}{N_1} \quad (5)$$

## II. PRIMARY REGULATION OF THE FREQUENCY

The primary regulation is operated by the action of the speed regulators from the groups of production which generally act on the organs of admission of the driving fluid from the turbine when the speed of the group (image of the frequency) is away from instruction speed as a result of an imbalance between the production and the consumption of the whole synchronous interconnected system. For each group  $j$  participating to the primary regulation frequency-power, the law of static regulation of the mechanical power resulting from the action of the speed regulator has to be in the form[3]:

$$P_j - P_{cj} = -K_j (f - f_0) \quad (6)$$

$P_j$ : real power supplied by the group  $j$  with almost still mode.

$P_{cj}$ : power of instruction of the group  $j$  with the reference  $f_0$ .

$f$ : frequency deducted from the measure of speed from the group  $j$ .

$f_0$ : frequency of instruction, generally equals to the reference frequency (50Hz).

$K_i$ : regulating energy of the group  $j$ .

The compensation of a gap from the balance sheet production-consumption  $\Delta P_{bil}$  by all the regulating groups is equal:

$$\Delta P_{bil} = -\sum_j (P_j - P_{cj}) \quad (7)$$

The resultant gap from frequency is then determined by the following equation:

$$f_1 - f_0 = \frac{\Delta P_{bil}}{\sum_j K_j} \quad (8)$$

$\sum_j K_j$ : total regulating energy of the synchronous system

## IV. SECONDARY REGULATION OF THE FREQUENCY AND THE POWER

The action of the primary regulation remains a gap of frequency with regard to the frequency of instruction  $f_0$ . It also causes gaps on the exchanges between the synchronous interconnected system and the generative groups[3]. Indeed, all the groups of the various synchronous interconnected systems, participating to the primary regulation, react to the variation of common frequency that the disturbance occurs on the electric system. The function of gap from regulation  $\Delta E$  used for the secondary regulation (as in France) is obtained by:

$$\Delta E = \Delta f + \frac{\Delta P_i}{\lambda} \quad (9)$$

$\Delta f$ : gap of frequency with regard to the frequency of reference;

$\Delta P_i$ : gap between the balance of powers measured on the interconnection lines of highways with the neighboring and  $\lambda$ : secondary regulating energy.

Let us consider that regulator frequency-power which is given up by the figure below. The powers exchanged on the interconnections are teletransmise distantly to the regulator which adds them and subtracts (it) the instruction of exchange to give the gap of exchange  $P_{AB}$ .

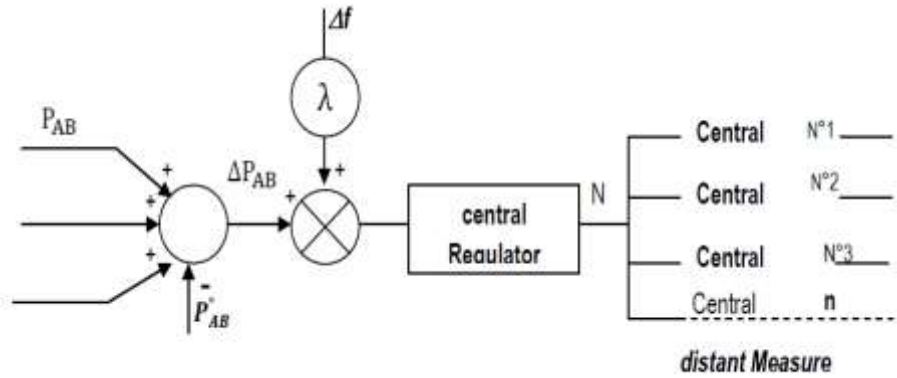


Figure 1. Interconnection of the groups with central regulator

The gap of the frequency ( $\Delta f$ ) is balanced by a coefficient ( $\lambda$ ) which must be amplified, and equal to ( $k_A$ ). As the latter is not known with big precision, it makes consider ( $\lambda/k_A$ ) to obtain the gap of regulation.  $\lambda$ : coefficient to increase the regulator  $\varepsilon = \Delta P_{AB} + \lambda \cdot \Delta f$  (10)

### III. SUBDIVISION OF THE REGULATION SYSTEM OF POWER

For an interconnected system with large number of generators, the modelling of the regulation of power for each generator, is very complex. We can use a technical aggregation to obtain an approximately simplified model. The precision of the pattern and its utility are acquired when the coherent limits of groups of generators coincide with the functioning or the utility. In this case, under a mere functioning, generators are frequently checked as an easy system. In such a case, the water is called (regulated domain). The model using the regulated domain is very useful when discovering the exchange between close powers[4]. Thus  $\Delta P_{12}$  is positive when  $\Delta P_{21}$  is negative, with the fall of the frequency,  $\Delta \omega$  are negative and  $ACE_2$  is the sum of two positive quantities with the tendency of cancellation. In accordance with the main basis of set operations, we want to increase  $PC_2$  while  $PC_1$  does not change.

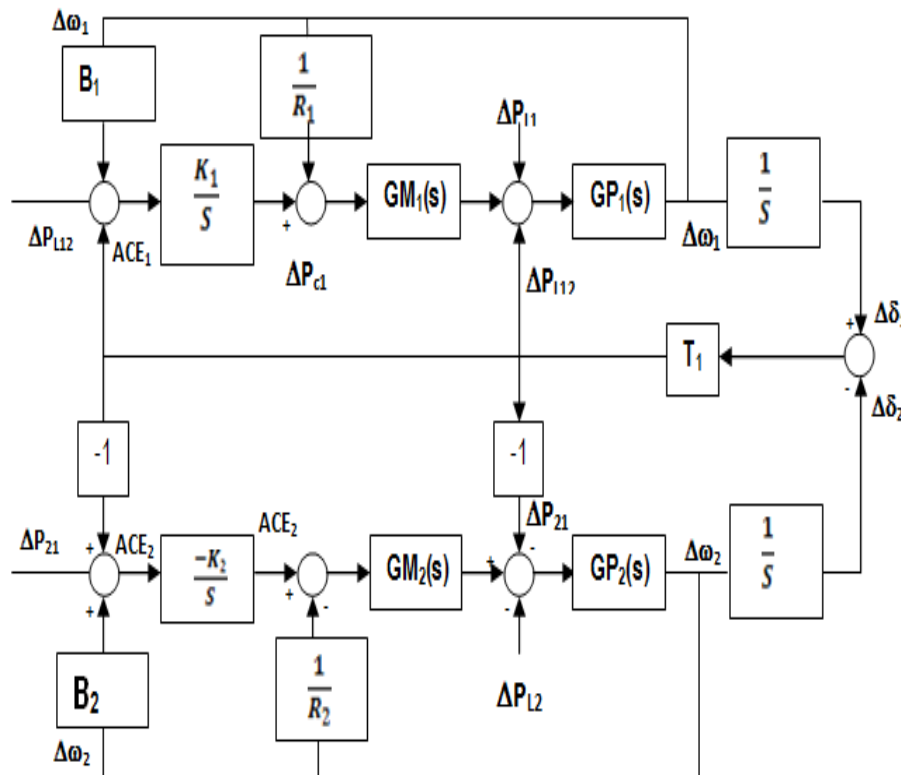


Figure 2. Representation of application of the controls in the cases of two domains of regulation

#### IV. REGULATION OF THE POWER, CASE OF SEVERAL GENERATORS

##### 4.1 Case of Three Generators

We are interested in the active power and suppose that we can use the model. All the voltages being fixed to their nominal values can be used as regulator of power in each generator. However we are going to consider that every connection is a connection of generators [6].

In every connection, we have inside the case of three generators:

$$P_{Gi} = P_{Di} + P$$

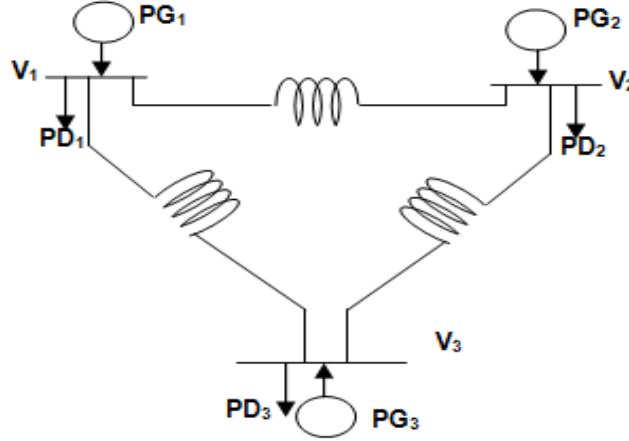


Figure 3. Power supplies by three generators

$P_i$  is the total active power for each connected generator in the system. Let us suppose a point of functioning such as :

$$P_{Gi}^0 = P_{Di}^0 + P_i^0 \quad (11)$$

$$\text{And with } P_{Gi} = P_{Gi}^0 + \Delta P_i \quad (12)$$

$$P_{Di} = P_{Di}^0 + \Delta P_{Di} \quad (13)$$

$$\text{And } P_i = P_i^0 + \Delta P_i \quad (14)$$

We shall have the following incremental relation:

$$\Delta P_{Gi} = \Delta P_{Di} + \Delta P_i \quad (15)$$

For each generator, we use the linearization and we have:

$$M_i \Delta \delta_i + \Delta_i \Delta \delta_i + \Delta P_{Gi} = \Delta P_{Mi} \quad (16)$$

$\delta_i$  is the internal angle of the terminal electricity of each generator. Then, we consider the behavior of  $P_{Di}$ . Generally  $P_{Di}$  depends on the amplitude of the voltage and the frequency. In our case, we consider that  $P_{Di}$  increases with the frequency. This supposition is in accordance with the observed behavior.

We can take into account the change of the outside load (disturbance) from the electrical network. So we can imagine an excessive increase of the load due to an interconnection from a network. In accordance with this description for small changes of the frequency. Let us suppose that:

$$P_{Di} = P_i + \frac{\partial P_{Di}(\omega^0)}{\partial \omega_i} \Delta \omega_i + \Delta P_{Li} \quad (17)$$

The first one from two terms describes the linearization. The frequency depends on the load and  $\Delta P_{Li}$  is the change of the load in the entrance during an interconnection. Let us note that the point of functioning of the frequency is  $\omega^0$ , which must be close, but not necessary with the nominal frequency [6]. When defining the frequency in the voltage for each connection, the immediate voltage will be:

$$V_i(t) = \sqrt{2} |V_i| \cos[\omega^0 t + \theta_i + \Delta \theta_i(t)] \quad (18)$$

The relationships which precede are shown in the block diagram of figure 5 below.

$K_{pi} = 1/D_i$  and  $T_{pi} = M_i/D_i$ . The figure below represents the system in block diagram, we have as an  $\Delta \omega_i$  exit and  $P_{Mi}$  as an entrance.

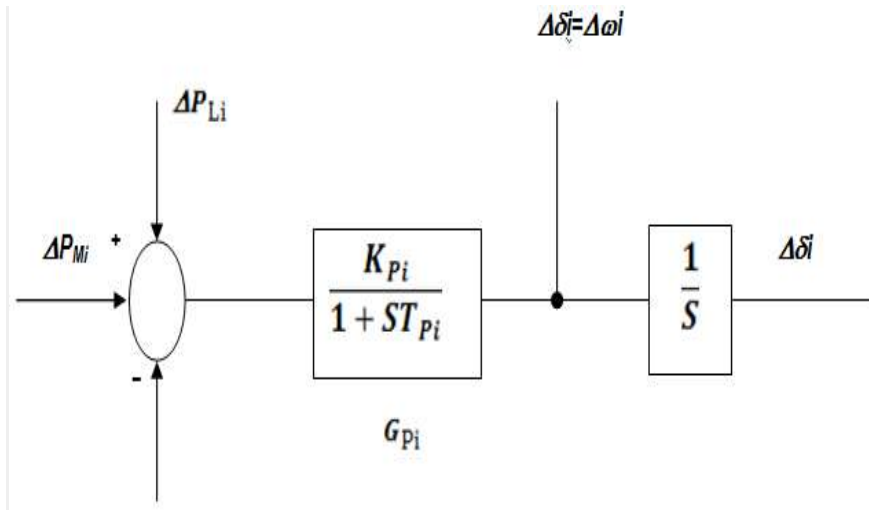


Figure 4. block diagram for the generator

#### 4.2. Case of two generators

In this case, we have two coefficients of the synchronous system to be considered [7]:

$$T_{12} = |V_1| |V_2| B_{12} \cos(\theta_1^0 - \theta_2^0) \quad (19)$$

$$T_{21} = |V_1| |V_2| B_{21} \cos(\theta_2^0 - \theta_1^0) \quad (20)$$

Then that  $T_{12}$  : synchronous of the turbine 1-2 and  $T_{21}$  : synchronous of the turbine 2-1

### V. APPLICATION TO THE GREAT INGA PROJECT IN THE INTERCONNECTED NETWORK

#### 5.1 Digital applications to the great Inga project.

We consider the same estimated data in the board below, for the functioning in isolated network. The behavior of the regulation of parameters from the alternator (frequency, voltage and power) with regard to the interconnected network to the various power plants.

(Board V.1 Estimated data of the isolated network to the project Big Inga)

Parameters	Symbol /Unit	Net <sub>1</sub>	Net <sub>2</sub>	Net <sub>3</sub>	Net <sub>4</sub>	Net <sub>5</sub>
Vacuuous speed	N <sub>o</sub> (tr/min)	375	375	375	375	375
Vacuuousfrequency	F <sub>o</sub> (Hz)	50	50	50	50	50
Engine torque	C <sub>m</sub> (MNm)	15,5	15,5	15,5	15,5	15,5
Vacuuous voltage	V <sub>o</sub> (kV)	16	16	16	16	16
Power of network	P <sub>r</sub> (MW)	250	500	750	1000	1250
Voltage of network	U <sub>r</sub> (kV)	500	500	500	500	500
Resistance of winding	R (MΩ)	0,25	0,25	0,25	0,25	0,25
Efficiency	H (%)	0,90	0,90	0,90	0,90	0,90

With Net: electrical network.

The data of the estimated power from power plants in interconnection with the project Great Inga are in the board below.

(Board V.2: illustration of powers from power plants in possible interconnection with the project Great Inga)

Power plants	P (MW)	Pr <sub>1</sub>	Pr <sub>2</sub>	Pr <sub>3</sub>	Pr <sub>4</sub>	Pr <sub>5</sub>
Power plant 1 (Imboulou)	120	250	500	750	1000	1250
Power plant 2	350	250	500	750	1000	1250
Power plant 3	500	250	500	750	1000	1250
Power plant 4	650	250	500	750	1000	1250

P is the power of the power plant in the interconnection and Pr : call power from the interconnected network.

#### 5.2. Obtained results

$$\alpha = \frac{P_{G1} - P_r}{\sum_{n=1}^n P_{che}} ; \gamma = U \cdot \cos\varphi \cdot \sqrt{3} \text{ et } \tau = \frac{\alpha}{\gamma}$$

(Board V.2 - Obtained results)

Parameter	Formula	Obtained results
Power supplied by the turbine	$P_{ft} = \alpha \cdot [(\tau)^2 \cdot R]$	167,25 MW
Efficiency of the generator	$\eta = \frac{\alpha}{\alpha + [(\tau)^2 \cdot R]}$	94 %
Angular speed	$\Omega = \frac{\alpha + [(\tau)^2 \cdot R]}{C_m}$	10,79 rad/s
Rotation speed of the generator	$N_r = \frac{30}{\pi} \left[ \frac{\alpha + (\tau)^2 \cdot R}{C_m} \right]$	103,04 tr/min
Frequency of these currents	$f_r = p \cdot \frac{30}{\pi} \cdot \left[ \frac{\alpha + (\tau)^2 \cdot R}{C_m} \right]$	13,73 Hz
Pulsation of these currents which deducts with the frequency	$\omega_r = p \cdot \frac{1}{\pi} \cdot \left[ \frac{\alpha + (\tau)^2 \cdot R}{C_m} \right]$	86,32 rad/s

### 5.3 Graphic simulation to the interconnected network

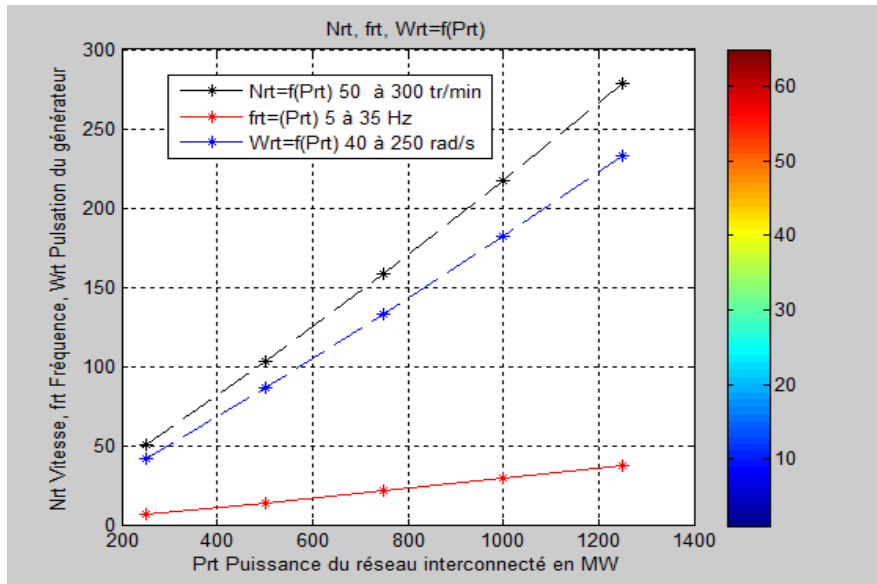


Figure 5. Graphic simulation of power plant to the interconnected network

### 5.4 Digital applications of the regulation the project Great Inga

In titular experiments, the stability of the network is linked to the frequency regulation through the value of instruction close to the nominal value. The data from experiments of the isolated electrical network are written in the board below.

(Board V.3: Data from the isolated network by imposition of the frequency)

Parameter	Symbol	Unit	Net <sub>1</sub>	Net <sub>2</sub>	Net <sub>3</sub>	Net <sub>4</sub>	Net <sub>5</sub>
Frequency in load	$F_r$	Hz	49.5	49.5	49.5	49.5	49.5
Vacuuous voltage	$V_o$	kV	16	16	16	16	16
Network voltage	$U_r$	kV	500	500	500	500	500
Network power	$P_r$	MW	250	500	750	1000	1250
Resistance of the winding	$R$	MΩ	0,25	0,25	0,25	0,25	0,25

When we impose the frequency in an energy system, the rotation speed, the angular speed and the pulsation, all these parameters stay constant in from of the variation of the electrodynamic parameters of the network. In this condition, the alternator produces on the network voltage and stable frequency, but the power supplied by the turbine will give a variable engine torque. Thus, in an important electrical network, the engine torque, the frequency and the power are bound by a following mathematical relationship:

$$C_{mr} = \frac{P_r + dP}{\omega_r} \cdot p \quad (21)$$

### 5.5 Resolutions of the regulation of the electrical network 2

$$\beta = \frac{f_r}{p} \quad (22)$$

(Board V.4 Results of the regulation of the electrical network 2 to the isolated network)

Parameter	Formula	Obtained results
Pulsation of these currents which deducts with the frequency	$\omega_r = 2\pi \cdot f_r$	311.0177 rad/s
Rotation speed of the generator	$N_r = 60 \cdot \beta$	371.25 tr/min
Angular speed	$\Omega_r = \beta \cdot 2\pi$	38,85 rad/s
Engine torque	$C_{mr} = \frac{P_{ft}}{\beta \cdot 2\pi}$	15.1804 rad/s

### 5.6 Graphic simulation power plants to the interconnected network

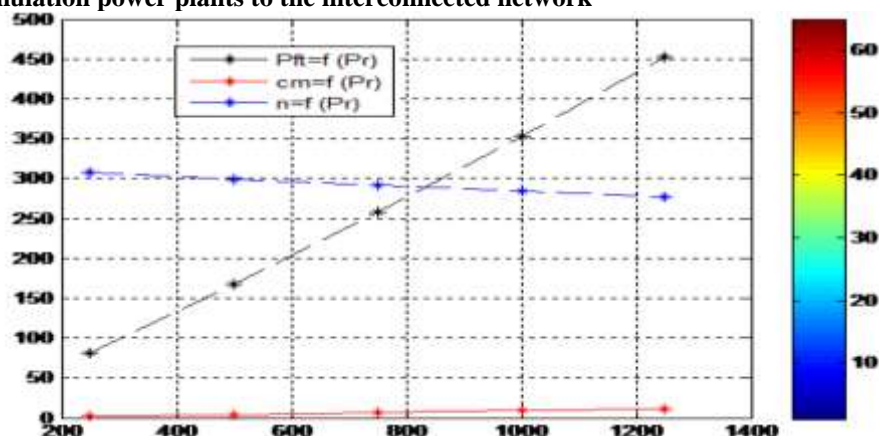


Figure 6. Graphic simulation power plants

## VI. CONCLUSION

The approach presented in this study deals with the survey of the self-regulation of the frequency and the module of the voltage from alternators in an interconnected network. This study enabled us to scrutinize on the following points:

- ✓ Regulation of speed from a water turbine;
- ✓ Primary Regulation of the frequency;
- ✓ Secondary Regulation of the frequency-power;
- ✓ power supplied by five power plants;
- ✓ Block diagram of the generator;
- ✓ Regulation of the power by a generator;
- ✓ Regulation of her (it) by several generators.

In addition, we developed equations linked to the static regime, before the disturbance, after the disturbance, the power difference, the incremental relation of power, the frequency for each connection, and the equation of the regulation of the frequency and power of each connection, and the equations of the regulation of the frequency and power of the alternator.

## REFERENCES

- [1]. <https://iiteeestudents.wordpress.com/2011/11/14/interconnected-grid-system>
- [2]. <http://www.sciencedirect.com/science/article/pii/S037877960700017X>
- [3]. J.F. Canard, " Impact of the generation of energy scattered in the distribution networks ", Doctoral thesis, National polytechnic institute of Grenoble, December 12th, 2000.
- [4]. B. Gotzig, " Research for an Optimal Diagram of Exploitation of an Electric Distribution network " , Doctoral thesis, National polytechnic institute of Grenoble, December, 1997.
- [5]. P. Petitclair, " Modelling and command of facts structures : application in the statcom " , Ph. D. essay, INP Grenoble, on 1997.
- [6]. <http://ieeexplore.ieee.org/document/6433832>
- [7]. <http://webfiles.portal.chalmers.se/et/Lic/GrauersAndersLic.pdf>