EFFECT OF SPEED-GOVERNOR DEADBAND ON AGC ANALYSIS FOR TWO AREAS THERMAL-THERMAL SYSTEM

Received 23/01/2002 – Accepted 31/12/2003

Abstract

A comprehensive mathematical model for the AGC of a two areas interconnected Thermal-Thermal system is present in this paper. The governor deadband nonlinearity is included in the analysis. The model by just changing the controllers can be used to study the response with and without governor deadband. It is shown that the governor deadband nonlinearity has a destabilizing effect on the transient response with deterministic load disturbance. It is found that the proportional integral controller reduces the over shoot and leaves the setting time unchanged with respect to case when using integral controller. It is found that the value of B has an important influence on the transient behavior of AGC.

***Keywords**: Automatic Generation Control, Governor Deadband effect, Integral and PI controllers.*

Résumé

Cet article présente un modèle mathématique complet pour l'AGC d'un système composé de deux aires thermique-thermique interconnectées. La non linéarité du régulateur de bande neutre qui contrôle le système est incluse dans cette étude. En variant uniquement les contrôleurs, le modèle peut être utilisé pour l'étude de la réponse du système avec ou sans régulation de la bande neutre. Il est montré que la non linéarité du régulateur de bande neutre a un effet destabilisateur sur la réponse transitoire selon une distribution déterministe des charges. Il a été également montré que le PIC réduit le changement brusque et laisse le temps de programmation inchangé lorsque c'est le contrôle intégral qui est utilisé. Il est aussi montré que la valeur de B a une influence importante sur le comportement transitoire du AGC.

***Mots clés**: Contrôle de génération automatique, effet de régulation par bande neutre, contrôleurs intégraux et PI.*

HUSSEIN A. KAZEM ALWAELI
Lecturer-Faculty of Engineering
Sohar University
PO Box 44, Sohar
PC311, Oman

ملخص

في هذه الورقة تم وضع نموذج رياضي لدراسة السيطرة الذاتية على التوليد AGC لمنظومة ثنائية حرارية-حرارية. وتم تضمين النموذج للتأثير اللاخطي للحزمة الميتة للمتحكم governor deadband. وبتغيير المسيطر تم دراسة استجابة المنظومة مع و بدون المتحكم. وقد لوحظ تأثير المتحكم حيث يسبب عدم استقرارية في الاستجابة في الحالة العابرة لحمل معين. ووجد ان المسيطر من نوع PIC (Proporational Integral) يقلل من التجاوز (over shoot) مع بقاء زمن الحالة العابرة بدون تغيير مقارنة مع المسيطر من نوع IC (Integral). ووجد ايضا ان تغير قيمة B (frequency bias setting) له تأثير مهم على السلوك العابر للسيطرة الذاتية للتوليد.

***الكلمات المفتاحية**: منظومة ثنائية حرارية-حرارية، الحزمة الميتة للمتحكم، التوليد AGC.*

The Automatic Generation Control (AGC) problem has been one of the major subjects of concern to power system engineers, and is becoming much more significant today in accordance with increasing size and complexity of interconnected power systems.

AGC realizes generation change in the system by sending signals to units under its control. The design and performance of an AGC system is dependent on how units respond to such signals. The type of generating unit affects unit response characteristics. AGC is very important for supplying sufficient and reliable electric power with good quality. In general, the requirements of AGC are: (1) minimizing the transient errors of frequency and tie line power and (2) ensuring zero steady-state errors of these two quantities.

The AGC problems are characterized by stochastic disturbances, variable and unpredictable inputs, nonlinearity, unknown parameters and changes in plant transfer function. Under these conditions, fixed controllers, such as Integral or Proportional Integral controllers, which are adequate under the designed condition, used to maintain the performance of the system at acceptable levels. One of the nonlinearity in the system is governor deadband. The limiting value of deadband is specified as (0.06). One of the effects of governor deadband is to increase the apparent steady state speed regulation R. The speed governor deadband has significant effect on the dynamic performance of AGC system.

This paper presents a computer simulation of the AGC problem in order to demonstrate the effect of the governor deadband in dealing with changes in different controllers. The simulation is performed on a

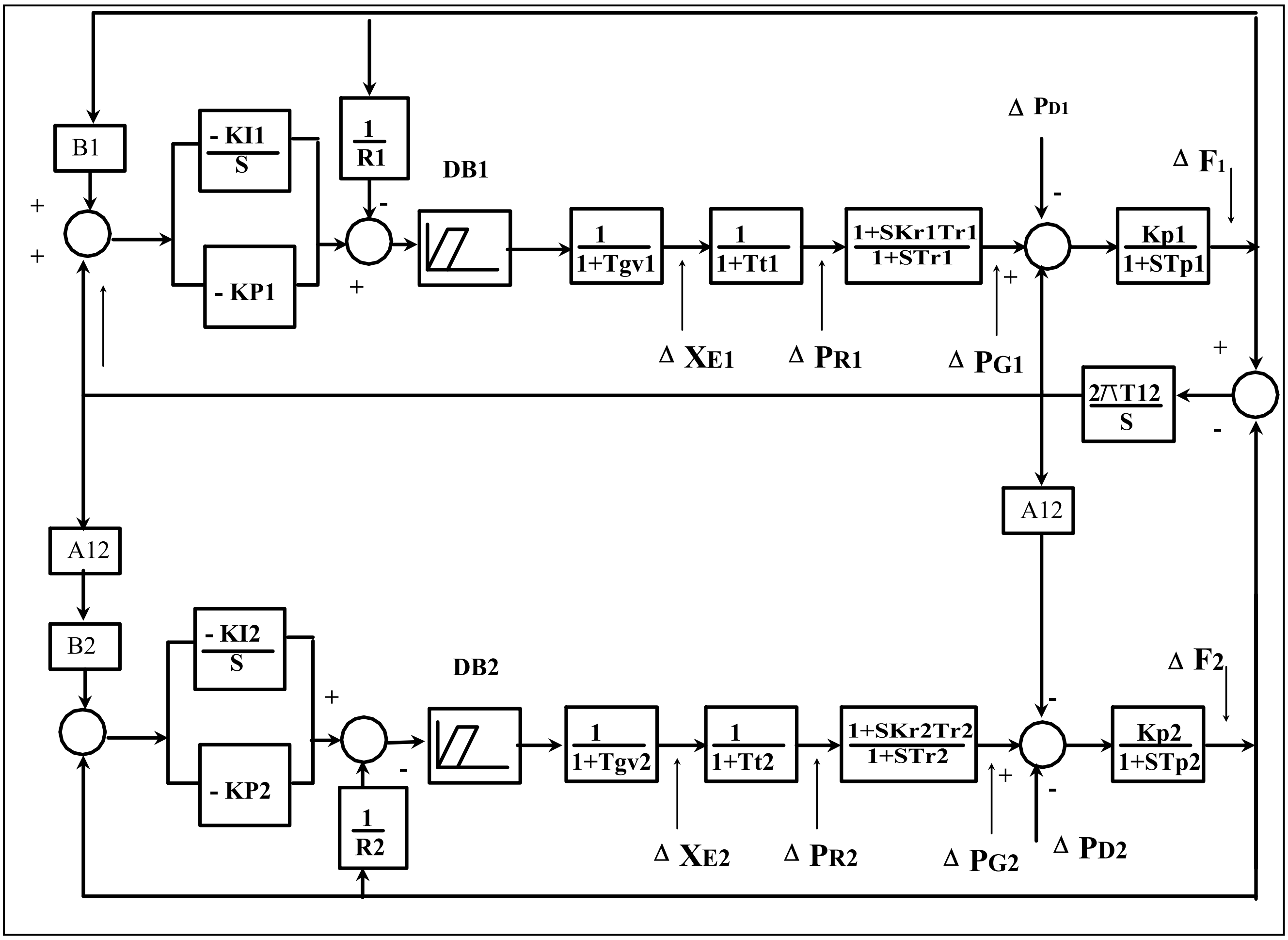

Figure 1: Block diagram for two area (Thermal-Thermal) power system.

mathematical model of the interconnection between two thermal power systems whose rated powers are equaled. Area 1 is connected to an area 2 through a tie line. Different controllers are used in area 1 to control the area control error of the interconnected systems.

GENERAL GOVERNOR OPERATION

Speed governors vary prime mover output (torque) automatically for changes in system speed (frequency). The speed-sensing device is usually a flyball assembly for mechanical-hydraulic governors and a frequency transducer for electro-hydraulic governors. The output of the speed sensor passes through signal conditioning and amplification (provided by a combination of mechanical-hydraulic elements, electronic circuits, and/or software) and operates a control mechanism to adjust the prime mover output (torque) until the system frequency change is arrested. The governor action arrests the drop in frequency, but does not return the frequency to the pre-upset value (approximately 60 Hz) on large interconnected systems.

Returning the frequency to 60 Hz is the job of the AGC (Automatic Generation Control) system. The rate and magnitude of the governor response to a speed change can be tuned for the characteristics of the generator that the governor controls and the power system to which it is connected.

POWER SYSTEM MODEL

An interconnected thermal power system consisting of two areas as shown in figure 1 is considered. The power stations are assumed to be steam plants. Each area is represented by transfer functions of the governor and turbine and the area transfer function.

In state variable form the controlling plant dynamics in an interconnected system takes the form:

$$\dot{X} = A\,X + B\,U + E\,\Delta P_D \tag{1}$$

where X, U and ΔP_D are state, input and disturbance vectors, where for area 1 the state vector is:

$$[X]^T = [\Delta F_1 \;\; \Delta P_{g1} \;\; \Delta P_{R1} \;\; \Delta X_{E1}\,] \tag{2}$$

And for area 2 the state vector is:

$$[X]^T = [\Delta F_2 \;\; \Delta P_{g2} \;\; \Delta P_{R2} \;\; \Delta X_{E2}\,] \tag{3}$$

The tie line equation is added to the system model as a state variable. In this case, nine state vectors define the state vector for a two Thermal-Thermal system namely

$$[X]^T = [\Delta P_{tie1} \;\; \Delta F_1 \;\; \Delta P_{g1} \;\; \Delta P_{R1} \;\; \Delta X_{E1} \;\; \Delta F_2 \;\; \Delta P_{g2} \;\; \Delta P_{R2} \;\; \Delta X_{E2}] \tag{4}$$

Each variable in the state vector given in equation (4) is expressed by first order differential equation. Control systems are widely applied in modern power systems. One of the most important problems faced during the design of these systems is the choice of control parameters that secure not only the stability of the system as a whole, but also an acceptable quality of control. This problem has not found an absolute solution especially when the number of control parameters, optimal of which are to be found is large. Modern optimization technique has been used to determine the optimum values of these parameters.

State space analysis has found a wide application in the solution of this problem. However, for achieving the basic objectives of AGC, i.e.zero steady state error in frequency and tie power, it is essential to have an integral or proportional integral of area control error (ACE) as a feedback signal. In order to design a classical controller for AGC, the state vector in equation (4) is augmented by two additional state variables X_{10} and X_{11}, defined as:

$$X_{10} = \int ACE1dt + ACE1 \text{ and } \quad X_{11} = \int ACE2dt + ACE2$$

In this case, the state vector of the system is defined by eleven state variables as:

$$[X]^T = [\Delta P_{tie1} \ \ \Delta F_1 \ \ \Delta P_{g1} \ \ \Delta P_{R1} \ \ \Delta X_{E1} \ \ \Delta F_2 \ \ \Delta P_{g2} \ \ \Delta X_{E2} \ \ \Delta P_{R2} \ \ \dot{X}_{10} \ \ \dot{X}_{11}] \quad (5)$$

GOVERNOR DEADBAND

There are two types of deadband in speed governing systems: inherent and intentional. Test results from many different types of governors including mechanical-flyball, analog electronic, and digital electronic indicate that inherent deadband is very small (less than .005 Hz) on most governors connected to the power system and can be neglected. Intentional deadband, conversely, may be used by some manufacturers and generation operators to reduce activity of controllers for normal power system frequency variations and may be large enough (about .05 Hz) to affect overall power system frequency control performance.

Describing function approach is used to incorporate the governor deadband nonlinearity. An adequate description of the hystrisis type of nonlinearities is expressed as:

$$y = F(x, \dot{x}) \quad (6)$$

It is necessary to make the basic assumption that the variable x is sufficiently close to a sinusoidal oscillation, that is

$$x = A \sin \omega_0 t \quad (7)$$

where the amplitude A and the frequency ω_0 of the oscillation are constant. Such an assumption is quite realistic as the nonlinear system may exhibit periodic oscillations arbitrarily close to pure sinusoidal. It has been found that the backlash nonlinearity tends to produce a contionuous sinusoidal oscillation with a natural period about 2 seconds. Then

$$2\pi f_0 = \pi, \text{ with } f_0 = 0.5 \text{ Hz.}$$

The nonlinear function, $F(x, \dot{x})$ can be developed in a furrier series as follows:

$$F(x, \dot{x}) = F^o + N_1.x + \frac{N_2}{\omega_o}.\dot{x} + \text{------} \quad (8)$$

A resonable approximation of this solution is to be consider the first three terms only. Since the backlash non-linearity is asymmetrical about the origin, the constant term F^o in furrier series equation (8) is zero.

$$F(x, \dot{x}) = N_1.x + \frac{N_2}{\omega_o}.\dot{x} = (N_1 + \frac{N_2}{\omega_o}.\frac{d}{dt}).x = DB.x \quad (9)$$

where DB is the deadband.

Refering to the discussion of [6], a backlash of approximately 0.05% is chosen for the analysis. As described in [5], the furrier coefficient are obtained as:

$$N_1 = 0.8 \text{ and } N_2 = -0.2$$

SYSTEM BEHAVIOR INCLUDING THE EFFECT GOVERNOR DEADBAND

In this paper the effects of governor deadband are studied in relation to the automatic generation control analysis. Transient responses are plotted with one percent step load change in area 1 of a-two equal area Thermal-Thermal power system without any controller, and it is shown that the governor deadband nonlinearity has a destabilizing effect on the transient response. Frequency deviation in the case of with and without deadband is shown in figure 2.

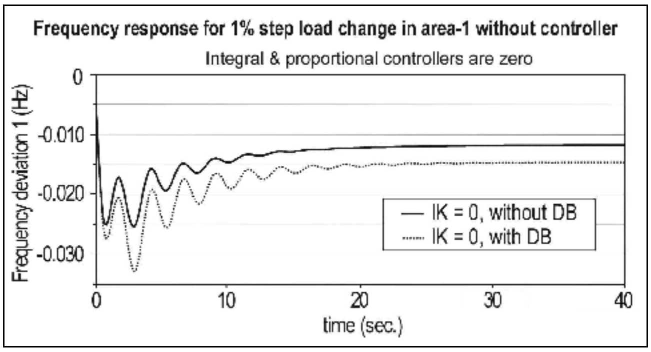

Figure 2: Double area thermal-thermal with and without governor deadband effect.

Transient responses for frequency deviation in area 1, tie-line power deviation out of area 1 with and without governor deadband effect are shown in figures 3 and 4 following 1% step load change in area 1. The dotted curves show the responses with deadband effect, whereas the solid curve shows the responses without deadband effect. It is seen that the deadband tends to produce continuous sinusoidal oscillation over approximately 40 seconds,

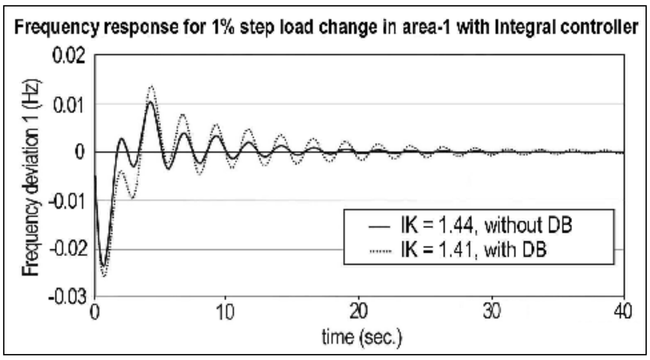

Figure 3: Double area thermal-thermal with and without governor deadband effect.

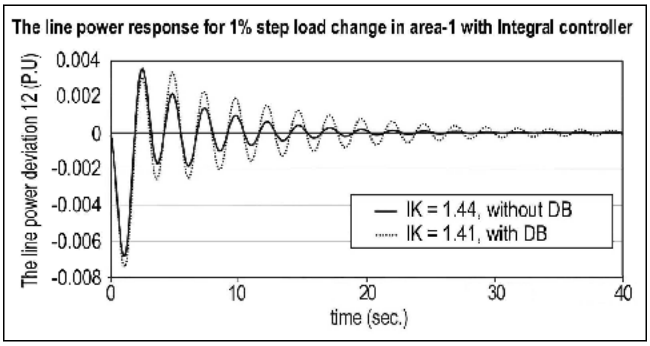

Figure 4: Double area thermal-thermal with and without governor deadband effect.

whereas without deadband the responses are more damped. It is clear from figures 3 and 4 that the optimum value of integral controller approximately constant (IK1=1.4). The overshoot increased in the case of with deadband.

Two loci for the cost function against IK (where IK1=IK2=IK) for constant value of B are shown in figure 5. Without deadband the cost function is less then that of with deadband and integral controller approximately do not changed. In other words IK is not affected by deadband and the cost function increased in the case of deadband then without deadband.

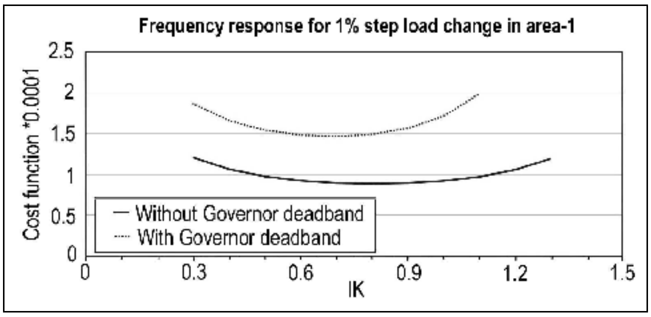

Figure 5: Integral controller vers Cost function with beta = 0.424 and A12 = -1.

An attempt is then made to stabilize the transient responses by giving proportional ACE feedback in addition to the usual feedback of integral ACE. However, it is found that the proportional feedback of ACE reduces the overshoot only and leaves setting time unchanged as seen in figure 6.

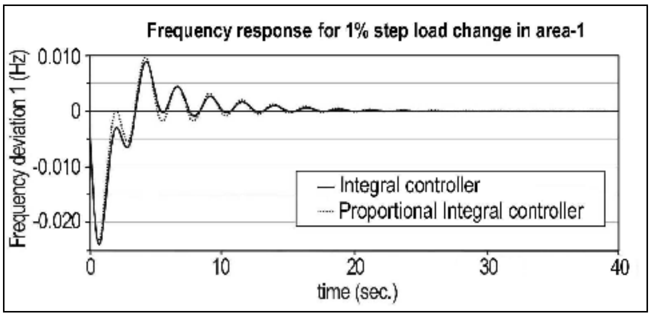

Figure 6: Double area thermal-thermal without governor deadband effect.

Optimization is specific to parameters easily tunable in AGC interface. The B value is not modified because it is judged preferable not to deviate from the recommended B=1%/0.1 Hz, on an annual peak load and spinning reserves basis. However, by adjusting PK1 and IK1, the optimization ends with the following parameters: IK1=0.484, PK1=1.484 for B=β=0.424 and IK1=0.498, PK1=1.998 for B= 2β=0.848 and IK1=0.998, PK1=1.998 for B= 3β=1.272. It is found that the value of B has an important influence on the transient behavior.

Multiplying B by 5.0 results in an oscillatory behavior of figure 7 and B cannot be raised too much. The combination of parameters has an important impact on performance.

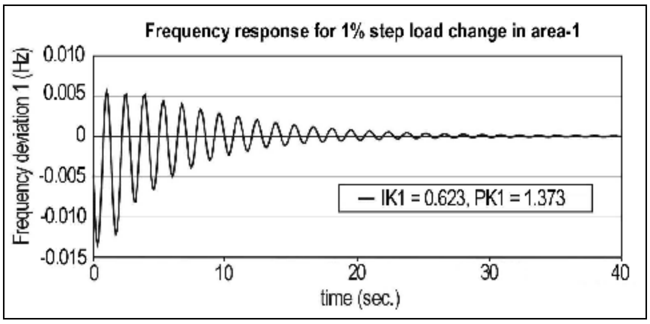

Figure 7: Double area thermal-thermal with governor deadband effect, B = 2.12.

CONCLUSIONS

It has been demonstrated that the governor deadband nonlinearity has a destabilizing effect on automatic generation control of power systems. The proportional ACE feedback reduces overshoot of the nonlinear system oscillation when used in conjunction with integral supplementary. It is found that the value of B has an important influence on the transient behavior of AGC. It is found that the overshoot is reduced in the case of PI controller with respect to integral controller.

APPENDIX (A)

Nominal parameters of the thermal-thermal system investigated:

Symbols	Area 1 Thermal	Area 2 Thermal	Units
F	60	60	Hz
R	2.4	2.4	Hz/p.uMW
δ	30	60	Degree
P_r	2000	2000	MW
D	0.00833	0.00833	p.uMW/Hz
P_r	1000	1000	MW
T_{gr}	0.08	-	Second
T_{ch}	0.3	-	Second
K_r	0.5	-	-
T_r	10	-	Second
σ	-	0.31	-
T_R	-	5	Second

$P_{tie,max}$ =200 MW ,T_{12}=0.544 , $\beta_1 = \beta_2$ = 0.4249

LIST OF PRINCIPAL SYMBOLS

i	subscript referring to area i (i = 1, n).
ΔP_{tie}	incremental change in tie line power.
ΔF_i	incremental change in frequency deviation of area i.
ΔX_{Ei}	incremental change in governor valve position of area i.
ΔP_{Ci}	incremental change in speed changer position of area i.
Δp_{Di}	incremental load change of area i.
K_{ri}	reheat coefficient of area I.
T_{ri}	reheat time constant of area I.
T_1, T_3	time constants of the steam governor.
R_i	seed regulation due to governor action of area i.
B_i	frequency bias setting of area I.
β_i	natural area frequency response characteristic of area i.
KI	integral gain.
t	time.

REFERENCES

[1]- Hussein A. Kazem, K.A. Sattar, Ali A. Hussein,"Sample Data Automatic Generation Control Analysis", 2-International Conference on Role of Engineering Towards Environment, (Sustainable Development), Alexandria, Egypt, 12-15 December (1998), pp.447-461.

[2]- Fukushima S., Sasaki T., Ihara S. and Leirbukt A.B., "Dynamic Anaysis of Power System Frequency Control", Cigre – 2000, System analysis and Techniques, Group 38-204, France (2000).

[3]- Vournas C.D., Dialynas E.N., Hatziargyiou N., Machias A.V., Souflis J.L. and Papadias B.C., "A Flexible AGC Algorithm for the Hellenic Interconnected system", IEEE Trans., Pas- 89, (1989), pp.61-68.

[4]- Kothari M.L., Satsangi P.S. and Nanda J., "Sampled data automatic generation control of interconnected reheat thermal systems considering generation rate constraints", IEEE Trans., VOL.PAS-100, N°5 (1981), pp.2334-2342.

[5]- Tripathy S.C., Balasubramanian R. and Chandramohanan Nair P.S., "Effect of Superconducting Magnetic Energy Storage on Automatic Generation Control Considering Governor Deadband and Boiler Dynamics", *IEEE Trans. on power systems*, Vol.7, N°3, August (1992), pp.1266-1272.

[6]- Hussein A. Kazem, K.A. Sattar, Ali A. Hussein, "Automatic Generation Control Using Continuous and Discrete Modes for Thermal-Hydro System Considering Governor Deadband Effect", 4th Regional Conference of Cigre Committees in Arab Countries, Tripoli, Great Jamahiriya, Vol.2, 19-21 feb. (2001), pp.259-270.

[7]- Malik0.P., Ashok Kumar and Hope G.S., "A Load Frequency Control Algorithm Based on a Generalized Approach", *IEEE Transaction on power Systems*, Vol.3, N°2, May (1988).

[8]- Das D., Nanda J., Kothari M.L. and Kothari D.P., "Automatic generation control of hydro thermal system with new area control error considering generation rate constraint", *Electric Machines and power systems*, Vol. 18, N°6, Nov-Dec. (1990), pp.461-471.

[9]- Tripathy S.C., Bhatti T.S., Jha C.S., Malik O.P. and Hope G.S., "Sampled data Automatic Generation Control Analysis with Reheat Steam Turbine and Governor Deadband Effects", *IEEE Power System Engineering Committee*, (1984), pp.1045-1051.

[10]- Lefebvre S. and Asber D., "Analysis and Improvement of Frequency Regulation", Cigre – 2000, System analysis and Techniques, Group 39-202, France (2000). ☐