STUDY OF PRIMARY AND SECONDARY CONTROL IN TURKISH SYSTEM FOR INTERCONNECTION WITH EUROPEAN SYSTEM

Ibrahim A. NASSAR
Department of Power and Electrical Machines, University of Al-Azhar
11787, Nasr City, Cairo, Egypt
Phone: 002-0100-5357-921, Fax: 002-02-2260-1706, Email: ibrahim1061877@yahoo.com

Abstract: *This paper presents the modelling and model validation of the primary and secondary control of the Turkish power system. With this model the simulations were performed to investigate the ability of the Turkish power system to become interconnected with the European ENTSO-E-CE System (European Network of Transmission System Operators for Electricity-Continental Europe). After constructing the simulation model using the data from the Turkish Electricity Transmission Company (TEIAS) and Electricity Generation Company (EUAS) the developed model was validated using measurements from performed power plant outage tests (Karakaya hydro power plant) in high load condition on 15 February 2010. With the validated model of the Turkish power system simulations were performed to investigate the expected volatility of the exchange power to the neighbors Bulgaria and Greece in normal system operation. For this investigation measured load variations of the Turkish power system were used. Also additional simulations were performed to investigate whether the Turkish power system can fulfil the ENTSO-E-CE requirements for primary and secondary control to be able to become interconnected. These tests were successful. All the models were created using MATLAB / SIMULINK software. On 18th September 2010 at 9h25 (CET) the Turkish power system was synchronized with the interconnected power systems of Continental Europe via three lines to Bulgaria and Greece.*

Key words: *model validation, primary control, secondary control, simulation, interconnected, exchange power, load variations.*

1. Introduction

Turkey is a natural bridge between the Middle East and Central Asia which are rich of energy resources on one hand, and the energy consuming European nations on the other hand (see Fig.1). It has been designated as one of the ten world's "Big Emerging Markets". Between 1980 and 2007, Turkish electric power demand grew at an average annual rate of 8,4%, among the highest such rates in the world. As of 2007, the government was planning to nearly double the country’s generating capacity by 2020 by adding more than 23,000MW in additional power [1].

Turkey's electricity demand tends to increase by a rapid average of 7,5%. Having been realized as 191,5 TWh in 2007, the electricity generation is expected by 2020 to reach 499 TWh with an annual increase of around 7,7% according to the higher demand scenario, or 406 TWh with an annual increase of 5,96% according to the lower demand scenario. As of 2008, the installed power is 41,987 MW, and the electricity consumption is 198,4 TWh [2].

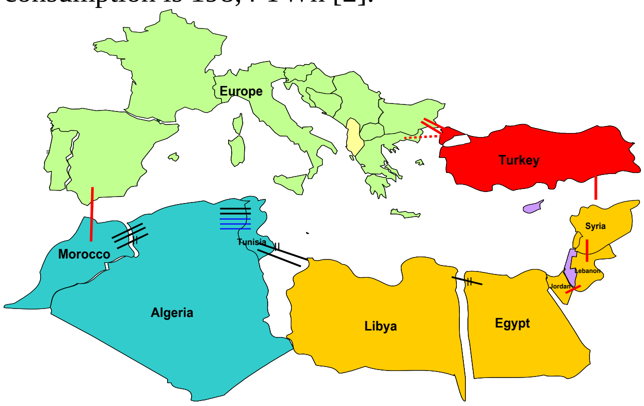

Fig. 1. Turkey’s location on the Europe-Asia-Africa Map

A study previously identified that unsuitable control structures and control parameter settings of hydraulic units are the main causes for the existing frequency control problem in the Turkish power system. The individual behaviour of generating units is usually optimized with respect to operational unit requirements and local grid requirements, but does not take into account all effects on the overall dynamic performance and stability of the entire power system [3]. The Wide Area Measurement System (WAMS) shows a systematic frequency control problem within the Turkish Power System in Island operation as shown in figure 2.

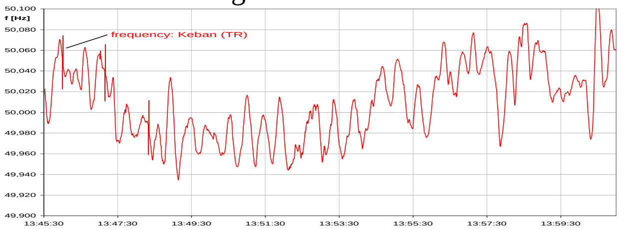

Fig. 2. Measured frequency in Keban received from WAMS (March 2006)

In large interconnected power systems like in the ENTSO-E-CE power system possible negative effects of single units or certain generation technologies (e.g. of hydraulic units) on the overall system performance are less observable and may therefore be tolerated. This approach is not admissible for the Turkish power system as the Turkish power system is significantly different in the following;

- Size (about 1/12 of installed capacity in comparison with ENTSO-E-CE)
- Structure of supply (about 1/3 of the total load is supplied by hydraulic units during peak hours, whereas the power supply within ENTSO-E-CE is dominated by thermal power plants)
- Longitudinal structure of the system in East-West direction with long transmission lines as shown in figure 3, the operation on themselves could be managed only by the help of permanent serial compensation

2. The Overall Objective of the Study

The overall objective was to fully integrate the Turkish Electricity Market to the EU Internal Electricity Market and Turkish Power System is prepared for parallel operation with ENTSO-E-CE regarding power and frequency control, steady state and transient stability [4].

The main scope of this work was to investigate the primary and secondary control of the Turkish power system for interconnection with the European power system.

This work concentrates on the specific problems related to the electromechanical systems of large size hydroelectric power plants regarding the primary and secondary control, which are prone to occur once the interconnected operation of the Turkish power system with the ENTSO-E-CE system is established.

3. Stability Criteria for Power and Frequency Control

The frequency performance (stability) of a power system results from the summary effect of its individual units, i.e. in the ideal case each individual unit should have a positive contribution to the frequency stability [5]. This leads to the following design philosophy:

- The controller dynamics have to ensure a stable operation in island conditions.
- The same controller dynamics utilized in parallel grid operation ensure a positive contribution to the overall frequency performance and stability. Thereby the adaptations related to the changeover between parallel grid operation and island operation does not affect these conditions provided that the decisive controller dynamics remain the same.

4. Isolated Turkish Power System

There are three different groups of plants in the Turkish power system based on the source of energy; Natural Gas Combined Cycle Power Plants (NGCCPPs), Thermal Power Plants (TPPs) and Hydro Power Plants (HPPs) as shown in figure 3. Their installed capacity ratio is almost equal (i.e. $\approx 30\%$). Currently, the installed generation capacity in Turkey is about 45 GW, with 14 GW generated in hydraulic units. The large hydro power plants are represented by blue blocks and mostly located in the East around Euphrates River [6].

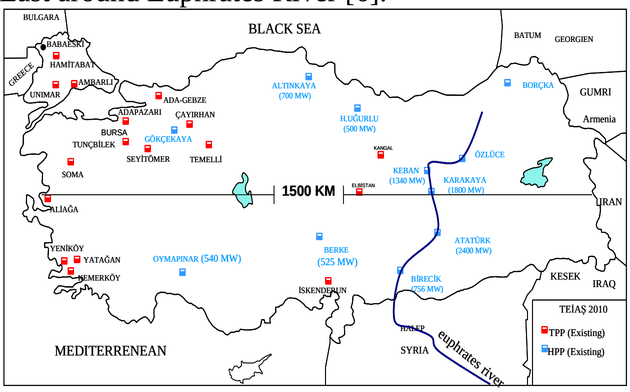

Fig. 3. Location of power plants in Turkey.

The hydro plant unit controller models are prepared in detail covering the dynamics and friction of penstock and detailed actual controller models which are determined by site visits and field tests. The control philosophy is resolved for each HPP in the priority list via manufacturer documentation. The documentations of major TPPs and NGCCPPs provided by TEIAS are utilized to model their unit controllers.

Also the secondary control model consists of the real controller as in operation in Ankara (see Fig. 7). Any model consists of separate models for power controller, governor and turbine regulator (see Fig. 4), where Yt and Yt_{ref} are the position and setpoint governor guide vane.

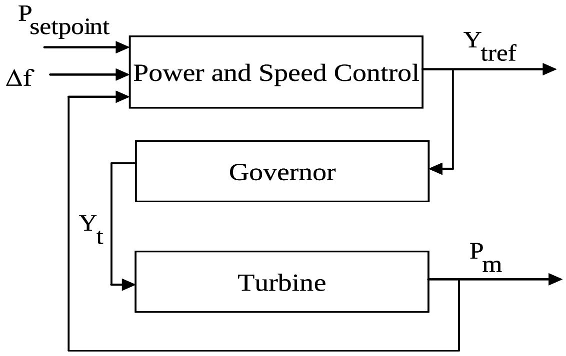

Fig. 4. General representaion of sub-models.

Figure 5 shows the dynamic model of the whole Turkish power system after connection of the sub models in one complete model. All power plants with primary controllers, loads and secondary control of Turkey are modelled completely in detail.

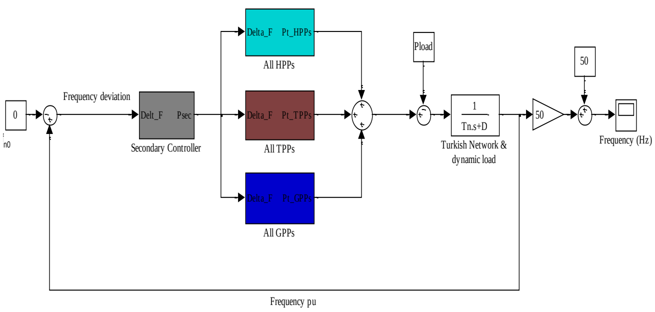

Fig. 5. The overall model of the whole Turkish power system with primary and secondary control.

The total network time constant T_n for the Turkish power system is calculated according to equation 1. Where T_{G_i} is the acceleration time constant of individual plants in seconds and P_{G_i} is the rated power for individual plants in MW.

$$T_n = \frac{\sum_{i=1}^{n} T_{G_i} * P_{G_i}}{\sum_{i=1}^{n} P_{G_i}} \quad (1)$$

4.1 Model Validation

Field Tests were carried out by TEIAS and EUAS. The incidence under consideration has happened in the Turkish power system during isolated operation with high load condition on 15 February 2010. In particular, it analyzed the consequences of an outage in the Turkish power system where 2 units of Karakaya hydro power plant has tripped with 600 MW generation loss in high load condition (25 GW)

4.1.1 Behaviour of Primary Control

The objective of primary control is to re-establish a balance between generation and demand within the synchronous area at a frequency different from the nominal value. The primary control action time is 0 to 30 seconds after disturbance of the balance between generation and demand [7, 8].The primary control reserve for Turkish system is 600 MW.

Figure 6 shows the frequency of overall performance in Hz and shows the comparison between simulation (solid line) and measured signal (dashed line). As a result the dynamic frequency deviation Δf_{dyn} will reach – 266 mHz and the steady state of frequency deviation Δf_{ss} is 150 mHz.

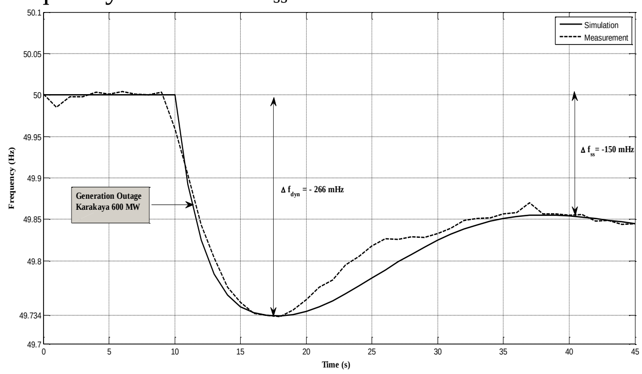

Fig. 6. The frequency behaviour with only primary control.

The steady-state frequency deviation depends on the speed-droop and self-regulation of the load and it is calculated by the following equation;

$$\Delta f_{ss} = -\Delta P_L / (\frac{1}{\sigma_{eq}} + D) \quad (2)$$

Where ΔP_L is the load change of the system, D is the dynamic load of Turkish system and σ_{eq} is the equivalent droop of Turkish system and it is calculated by the following equation;

$$\frac{1}{\sigma_{eq}} = \sum_{i=1}^{n} \frac{1}{\sigma_i} \frac{P_{G_i}}{P_N} \quad (3)$$

Where P_N is the rated power of the whole Turkish system in MW, P_{G_i} is the rated power of individual plants in MW and σ_i is the speed-droop of individual plants in percentage.

4.1.2 Behaviour of Secondary Control

Secondary control makes use of a central regulator, modifying the active power set points of generating sets subject to secondary control, in order to restore power interchanges with adjacent control areas to their programmed values and to restore the system frequency to its set-point value at the same time. Secondary control operates slower than primary control, in a timeframe of minutes. Its action becomes evident about 30 seconds after a disturbance/event, and ends within 15 minutes [9].

The basic equation of secondary control is the calculation of Area Control Error (ACE) [8, 10]:

$$ACE = \Delta P + K * \Delta f_{dyn} \quad (4)$$

Where ΔP is the deviation in tie-lies power flows (i.e. in island operation $\Delta P = 0$) and K is system factor, is a constant in MW/Hz set on the secondary controller.

The Area Control Signal is processed by a PI controller (see Fig. 7), where the correcting total desired generation (Psec), in most of the cases, is calculated as:

$$P_{sec} = -(G_A * ACE + \frac{G_A}{T_{CR}} \int ACE * dt) \quad (5)$$

Where G_A is the normal gain and T_{CR} is the integration time constant. The K-factor of Turkish system is 1480 MW/Hz and the parameters of integration time constant and the normal signal gain are 70 seconds and 0.5 respectively.

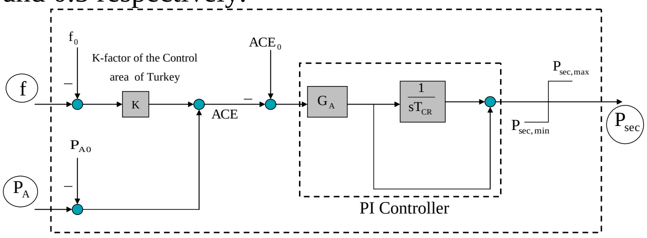

Fig. 7. Structure of secondary controller of Turkish system

According to SIEMENS the LFC function uses three classes of generating units when calling up secondary reserves as shown in figure 8. The first class should be fast units that are able to give a part of their operating range for secondary reserve. If the first class is exhausted then the units at the second class are used to reduce the ACE to zero along with all the secondary range of the first class units.

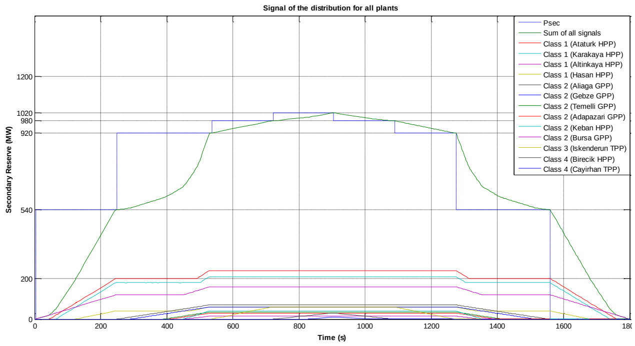

Fig. 8. Signal of the distribution unit for all classes.

Figure 8 shows the simulation (solid line) of the frequency response of Turkish system compared to the measured signal (dashed line). As a result the dynamic frequency deviation (Δf_{dyn}) will reach – 266 mhz and the frequency restored to the nominal value by secondary control reserve. Finally the overall model of the whole Turkish power system fits well with the measurements done in reality. Also this figure shows the trumpet curve characteristic which description of the quality assessment of frequency control (green lines) [11].

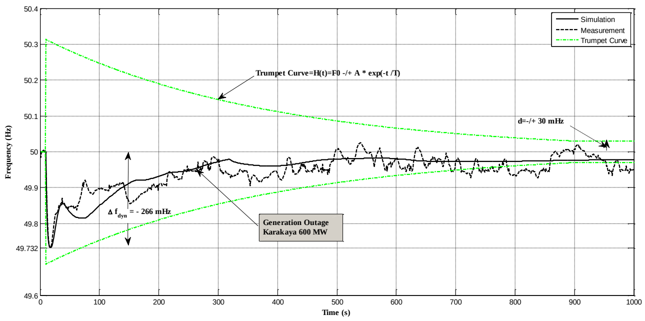

Fig. 9. The frequency behaviour in island operation with primary and secondary control.

Figure 9 shows the signal of secondary control reserve in MW and the area control error in MW of the Turkish power system is calculated at the maximum deviation according to equation (1) and equal to -390 MW.

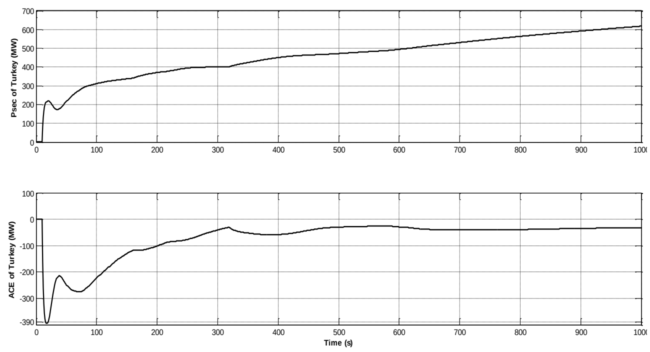

Fig. 10.Signal of secondary reserve and area control error.

5. Interconnected with European System

In order to fulfil ENTSO-E-CE requirements, the Turkish power system as control area has to provide approximately 300 MW primary control power within 30 seconds. This amount has to be allocated to thermal units (TPP and NGCCPP). The total amount of secondary control reserve has to be approximately 700 MW and must be activated within 15 minutes. Thereof, 300-400 MW must operate under automatic control. The remaining part can be activated manually within 15 minutes.

5.1 Simulation Results

The simulations are performed using a two area network consisting of the European system with a nominal power of Pn_EU = 300 GW and the Turkish system with a nominal power of Pn_Turk = 30 GW. Two areas can be represented by two single bus systems with a tie-line in between them. This is depicted in figure 11. Where P_{exc} is the exchange power on the tie line from area 1 to area 2, P_{set}, P_m, P_e and P_L are the power set point, mechanical, electrical power and the load in area 1 and area 2 respectively.

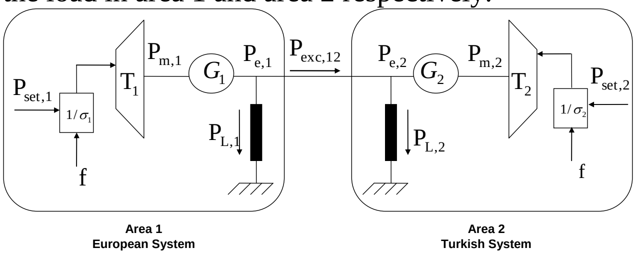

Fig. 11.Representation of a power system with two areas.

In the MATLAB model really used for the investigation of all power plants with their primary controllers and loads of Turkey are modelled completely in detail. Also the secondary control model consists of the real controller as in operation in Ankara; the block diagram is shown in figure 12.

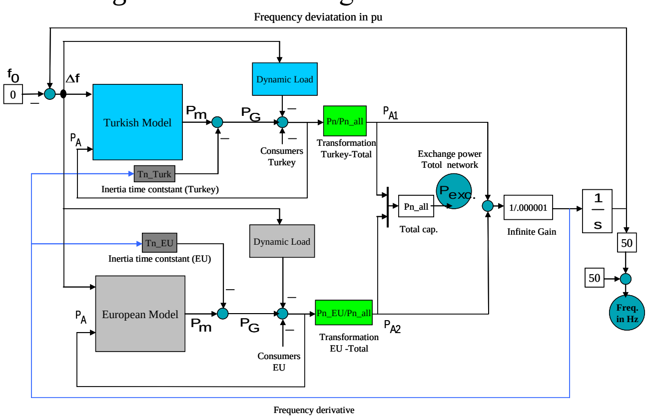

Fig. 12.Mid-term model of the Turkish and EU systems.

All power plants and all loads are collected together in one time constant of the total network Tn and calculated by equation 3. If the power plants are changed or removed always the total network time constant has also to be recalculated. To avoid this obstacle the model is changed to the model (infinite gain, T_n=0) as shown in figure 12, where all time constants are now directly located in the power plants and the loads.

5.1.1 700 MW Generation Loss in Turkish Power System

At time 5 seconds, 700 MW of generation is lost in Turkish power system with high load condition, secondary control reserve is 700 MW and primary control reserve is 300 MW (have contributed to TPP and NGCCPP).

Figure 15 shows the overall frequency performance in Hz and the exchange power in MW of the Turkish and ENTSO-E-CE systems.

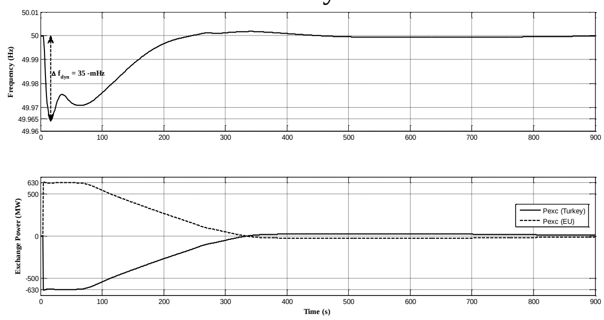

Fig. 13.The frequency and exchange power of the Turkish and ENTSO-E systems.

As a result the ENTSO-E-CE system will deliver nearly 630 MW to the Turkish power system and the dynamic frequency deviation is reached at - 35 mHz and then the system frequency restore to the set-point value with secondary control.

5.1.2 Existing Load Variation

The load variation was measured every 10 seconds on 17th of May 2010 and the working point with high load condition (25 GW). Figure 14 shows the load power in MW of the Turkish power system, overall frequency performance in Hz and the exchange power in MW of the Turkish and ENTSO-E-CE systems. As a result (according to the existing load variations) the simulated inadvertent exchange power is between 0-250 MW and the frequency deviation is between ± 0 - 20 mHz.

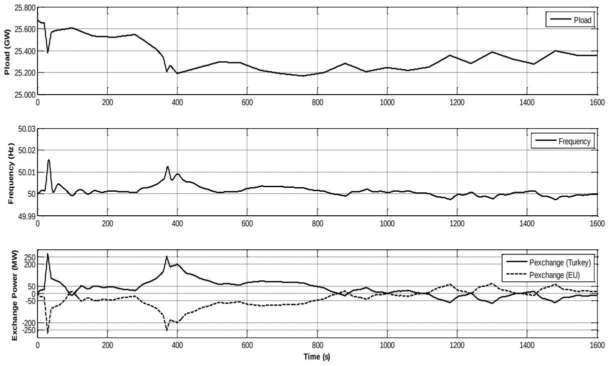

Fig. 14. The frequency and exchange power of the Turkish and ENTSO-E-CE systems.

5.2 Current Status after Interconnection with ENTSO-E-CE System

On 18 September 2010 the Turkish power system was synchronized to the interconnected power systems of Continental Europe, marking the start of the parallel trial interconnection as agreed between the Turkish system operator and ENTSO-E-CE. The parallel operation is achieved by two 400kV lines to the Bulgarian system and by one 400kV line to the Greek system. This trial parallel operation period is organized in three phases, the first two of which have been completed [12].

6. CONCLUSION

As a result in island operation, the simulation results compared with the measurement are approximately like the dynamic behaviour of the real system for primary and secondary control of the Turkish system in high load condition. Finally, the model of the Turkish power system is validated regarding the allocation of primary and secondary control and the tests were successful. For island operation of the Turkish power system with 700 MW generation loss in high load conditions the steady state frequency deviation is less than 200 mHz, the maximum frequency deviation is less than 800 mHz and overall frequency in the Turkish power system is stable.

After interconnection, with 700 MW generation loss in the Turkish power system the maximum frequency deviation is less than 200 mHz and stability of overall frequency. The exchange power according to the existing load variations is between 0-250 MW and the frequency deviation is between ± 0-20 mHz.

On 18th September 2012 the ENTSO-E-CE announces the extension of the third phase of the trial synchronous operation of the Turkish power system with Continental Europe by one year.

References

1. International Petroleum Monthly EIA, 2009. *http://www.eia.doe.gov*
2. Ministry of Energy and Natural Resources (ETKB). *http://www.enerji.gov.tr*
3. Final Report Stability Study: *Complementary technical studies for the synchronization of the Turkish power system with the UCTE Power System*. Ministry of Energy and Natural Resources, Turkey, 2007.
4. Nassar, I.A., Weber, H.: *Electrical Interconnection between Turkey and Europe - Problems and Solutions*. In: Proceedings of the 13th Middle East Power Systems Conference, MEPCON' 2009, Assuit University/Egypt, December 20–23, 2009.
5. Cebeci, M.E.: *The Effects of Hydro Power Plants governor Settings on the Turkish Power System Frequency*. Master Thesis, Middle East Technical University, Turkey, 2008.
6. Nassar, I.A., Weber, H.: *System Analysis of the Turkish Power System for Interconnection with Continental Europe*. In: Proceedings of the 8th International Conference on Power Plant & Power System Control PPPSC 2012, Toulouse-France, September 2-5, 2012,
7. UCTE Operation Handbook: *Policy 1: Load-Frequency Control.* Final Version, approved by Study Commettee on 19 March 2009.
8. Naji A. Al-Musabi et al.: *Variable Structure Load Frequency Controller: Optimal Design and Chattering Reduction using Particle Swarm Optimization Algorithm.* Journal of Electrical Engineering.
9. Boudiaf M. and Moudjahed M.: *Improvment of Transient Stability of Power System by IPFC, SSSC AND STATCOM.* Journal of Electrical Engineering: Volume 14 / 2014
10. UCTE Operation Handbook: *(Policy 1–Load-Frequency Control and Performance).* Preliminary v. 1.2, draft, 3.10.2002.
11. Nassar, I.A. , Al-Ali, S., Weber, H.: *The Overall Frequency Behaviour of the Turkish Power System in Island Operation to Interconnection with European System*. In: Proceedings of the 13th Symposium Maritime, Rostock, Germany, September 2010, pp.155-169,
12. European Network of Transmission System Operators for Electricity, (2012). *https://www.entsoe.eu/index.php?id=717*