Investigation of necessary Transmission Enforcements at the Balkan Region of ENTSO/E in the sense of Inter-area Oscillations after Interconnection of Turkey

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Abstract

This paper presents the investigation of 10-Year Network Development Plan (TYNDP) of ENTSO/E CESA countries for the planning period between 2010-2020, concentrating on transmission enforcement needs pointed for the Balkan region. The correlation between those transmission enforcements and the growing oscillations on the weak tie-lines of the Balkan countries particularly after the interconnection of Turkey with the ENTSO/E is discussed. The complaints of the Balkan countries due to growing power oscillations are also discussed considering the tie-line enforcement needs emphasized in the TYNDP report. The sufficiency of current tie-lines between Turkey and ENTSO/E is analyzed in the sense of inter-area oscillations based on computer simulations.

I. Introduction

One of the most serious concern after the interconnection of Turkish power system with the ENTSO/E CESA network (former UCTE), regarding the overall system stability, is the risk of poorly damped inter-area oscillations [1]-[3]. The expected frequency of the most poorly damped mode of the interconnected system can decrease up to ~0.15 Hz under weak system conditions, which may arise after outages of major elements of the system such as generating units or transmission lines [4]. In order to satisfy sufficient damping, many conventional and innovative measures have already been taken in Turkish power system including optimization of hydraulic power plant governor settings and tuning of power system stabilizer (PSS). Innovative measures include modification of the controllers of a STATCOM and SVCs that exist at different parts of the Turkish network, in order to provide damping when inter-area oscillations occur [1].

Although such measures have provided successful damping as verified by phase measurement units (PMU), the effect of enforcement of weak transmission corridors on the stability of the network has not discussed yet. In response, this paper presents the investigation of the 10-Year Network Development Plan (TYNDP) [5] of ENTSO/E countries for the planning period between 2010-2020, concentrating on transmission enforcement needs pointed for the Balkan region. The correlation between those transmission enforcements and the growing oscillations on the weak tie-lines of the Balkan countries, particularly after the interconnection of Turkey with the ENTSO/E, is discussed. The complaints of the Balkan countries due to growing power oscillations are also discussed considering the tie-line enforcement needs emphasized in the TYNDP report. Sufficiency of current tie-lines between Turkey and ENTSO/E is analysed in the sense of inter-area oscillations based on computer simulations.

The paper is organized as follows. The relevant sections of the TYNDP report are summarized and the important statements which emphasize the tie-line enforcement needs are underlined in Section 2. Then, the effect of Turkish power system interconnection to ENTSO/E system on the existing inter-area oscillations within the ENTSO/E is discussed in Section 3. In Section 4, the countermeasures taken by Turkey in order to improve damping inter area oscillations and the improvements on the damping of the oscillations since the synchronization are also discussed in this section. In Section 5, the complaints of the countries due to growing power oscillations are discussed considering the tie-line enforcement needs emphasized in the TYNDP report. Finally, in Section 6, sufficiency of current tie-lines between Turkey and ENTSO/E is analyzed in the sense of inter-area oscillations based on computer simulations. The paper ends with conclusive remarks.

II. Tie-Line Enforcement Needs of the Balkan Region

The following remarks and transmission investment needs are emphasized in the TYNDP report for the continental south east region (Balkan region):

- The transmission grid in the Continental South East European region is rather sparse compared to the relevant grid of the rest of the continent.
- Needs for new interconnectors (tie-lines) are identified in order to increase the import/export capabilities among the South East Europe countries and the Central Europe.

The main drivers for the enforcements include:

- Contribution to market integration in the Region (i.e. necessary network reinforcements to accommodate new conventional generation as well as to increase transfer capacities and consequently the volume of power exchanges).
- Accommodation of future RES production.
- Possible extension of the synchronous zone to the East.

As indicated in Figure 1 below, predominant power flows at the region show that:

- The block including Greece, FYR of Macedonia and Albania as well as Italy are usually importers.
- Imports of these countries from Bulgaria and Romania that have a surplus of generation and from countries on the North borders of the South East Europe Region are defining the principal power flow directions.

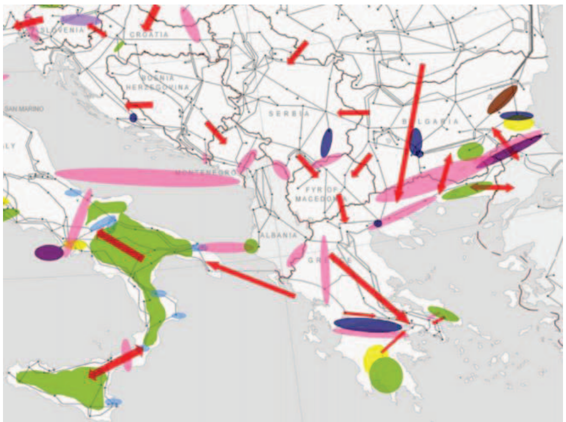

Fig. 1. Map of mid-term investment needs in the regional group continental south east [5].

A. *Driving Factors of Transmission Enforcements in the Mid-Term*

TYNDP report emphasizes the following driving factors for the transmission enforcement needs in the mid-term:

- New conventional generations foreseen arise in Bulgaria, Greece, Hungary and Croatia in order to increasing transfer capacities between South-East European countries.
- Renewable Electricity Sources (RES) generation appears mostly in Italy and Greece. In the long-run period the driver extends also to other countries and especially Bulgaria and Romania.

In response, completions of the followings transmission investment projects in the mid-term are important (see Figure 2):

- The 400 kV interconnection line between Stip (MK) and Nis (RS) is expected to be completed between 2011 and 2013. This line will strengthen considerably the South part of the South-East European grid and will increase transfer capacities towards the block of FYR of Macedonia, Albania and Greece.

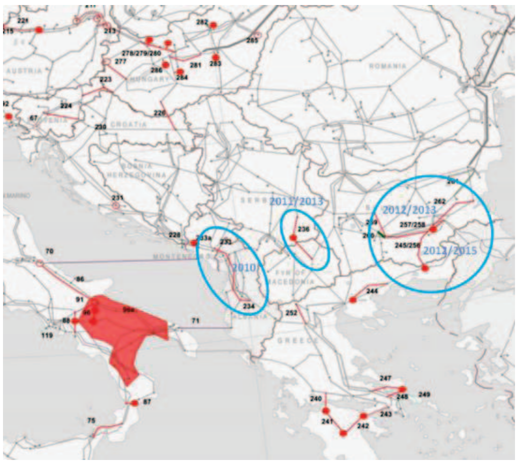

Fig. 2. Enforcement projects foreseen [5].

- The 400kV interconnection line Podgorica (ME) – Tirana (AL) is expected to be completed in 2010. This line is very important since it will establish a new 400 kV corridor from Greece to Italy along the Adriatic coast. All the described projects are crucial for the market integration in the region.

B. *Driving Factors of Transmission Enforcements in the Long-Term*

Long-term main transmission enforcement driving forces are:

- New conventional generations are extending to other South-East European countries including Bosnia& Herzegovina, Romania, Serbia and Albania.
- Increase of transfer capacities between South-East European countries and Italy continues to be an investment driver in this period also.
- Strengthening the Regional network in order to cope with the above investment needs, concerns both the construction of new tie-lines and the enhancement of internal networks.

As emphasized in the TYNDP report, it is important that the block including Greece, FYR of Macedonia, Albania, and Italy is usually importing electricity. Strengthening of the Regional network in the predominant power flow directions, in order to assist market integration, is a main driver that stimulates investment needs.

Concerning the foreseen extension of the synchronous zone to Turkey, a number of projects are included in the medium run period. These projects concern the extension of 400 kV network in North Greece as well as important grid reinforcements in the South part of the 400 kV Bulgarian network. These projects will assist also towards the safe accommodation of new RES and conventional integration in both countries. Project upon completion of all works becomes a “multi–task” project as it will contribute to:

- System extension to Turkey,
- Accommodation of new thermal power plants,
- Accommodation of wind generation in the area.

In addition, the planned interconnection of the Turkish power system created the need of expansion of the 400 kV network in Northern Greece and reinforcement of the 400 kV South-East Bulgarian network.

Long-term reinforcement projects in the South part of the 400 kV Bulgarian network include the construction of three new 400 kV lines: Maritsa East – Plovdiv, Maritsa East – Maritsa East 3, and Maritsa East – Burgas, as well as one double circuit 220 KV line: Aleko – Plovdiv (see Fig. 2). These four transmission line projects are also "multi-task" since they will contribute to accommodation of new thermal power plants and enhancement of the interconnections with Turkey and Greece. The new interconnection line between Greece and Bulgaria foreseen for 2012-2015 will further strengthen the network in the region.

III. Inter-area Oscillations after Interconnection of Turkey to ENTSO/E

Of particular importance for the damping of the low frequency oscillations is the direction of power exchange between the border regions and the centre of ENTSO/E network. Before interconnection of Turkey with the ENTSO/E network, graphical mode shape of the system was as given in Fig. 3. As seen in the figure, there were 2 coherent generator groups in the network that oscillate with ~0,22 Hz inter-area frequency [2]-[3]. That is, the inter-area oscillation was also observed before interconnection of Turkey.

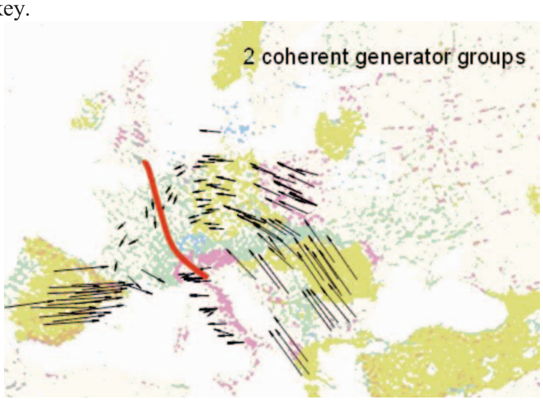

Fig. 3. Geographical mode shape of Global Mode former-U1 [2].

After interconnection of Turkey, however, the geographical mode shape mode has changed as presented in Figure 4 and 5. That is, after the interconnection of Turkey, 2 oscillation modes one of which is new due to Turkish interconnection (see Fig. 5) were expected based on computer simulations. Indeed, the new oscillation mode (Mode-T1: ~0,15 Hz) was also verified after the interconnection by measurements taken from PMUs [6]. Figure 6 illustrates a ~0,16 Hz inter-area oscillation that was observed to be the weakest damping during 23 April 2011.

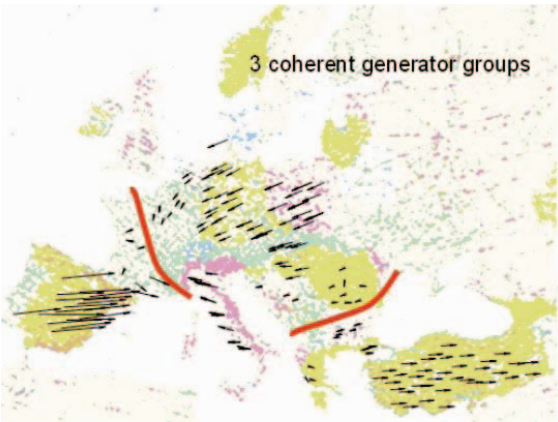

Fig. 4. Geographical mode shape of Global Mode new-U1 [2].

IV. Measures taken by Turkey against Mode-T1 & Results

The overview of the measures taken by Turkey for the damping of new global mode T1 (~0.15Hz) is given in Figure 7. Details of all the measures are out of scope of this paper and can be found in [1]. As a result of these measures, the damping of inter-area oscillations was considered to be satisfactory [7].

Fig. 5. Geographical mode shape of Global Mode T1 [2].

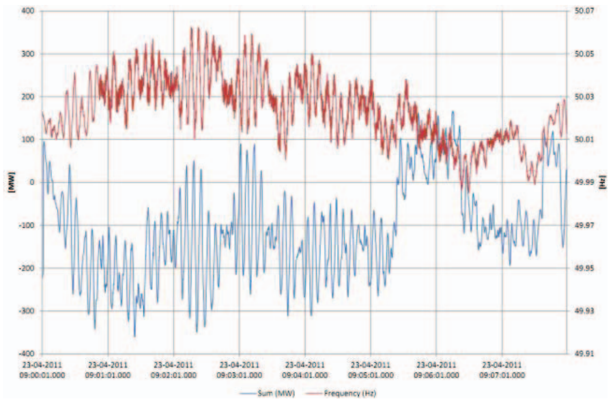

Fig. 6. Inter-area oscillations observed during 23 April 2011 (fundamental oscillation frequency is ~0,16 Hz) [6].

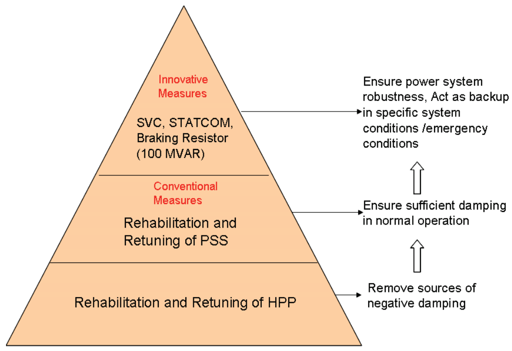

Fig. 7. Overview of the measures taken by TEİAŞ for the damping of global mode T1.

V. Complaints of the Balkan Countries

After interconnection of Turkey with ENTSO-E system, the discussions were focused on the performance indices and acceptable limits for these indices to consider Turkey as satisfactory. Finally, PG determined the expectations from Turkish system and TEİAŞ performed many studies in order to improve the "secondary control" performance and damping of inter-area oscillations. Although these expectations are satisfied, there are still complaints about the line flows in a particular line (400kV Sofia (Bulgaria) and Nis (Serbia) line). An example measurement from the line is given in Figure 8.

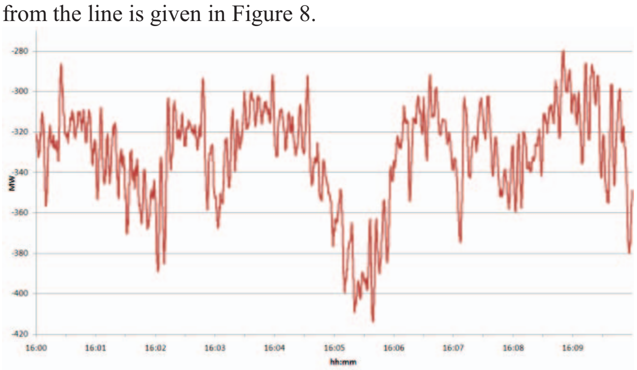

Fig. 8. 400kV Sofia-Nis line flow provided by Serbia TSO.

In order to determine the source of flow deviations on the line, the measurements are filtered to reveal the components of;

- Global Mode new-U1 (see Figure 9).
- Global Mode T1 (see Figure 10).
- Generation-Load imbalance to the East of the 400kV Sofia-Nis line (see Figure 11).

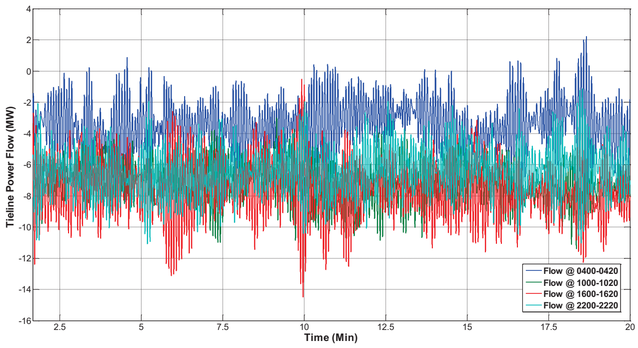

Fig. 9. The contribution of U1 to 400kV Sofia-Nis line flow deviations.

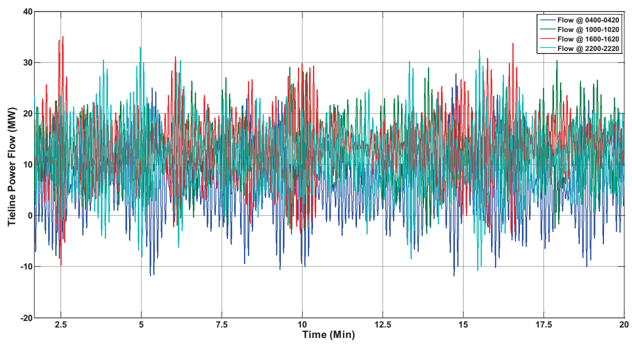

Figure 10. The contribution of T1 to 400kV Sofia-Nis line flow deviations.

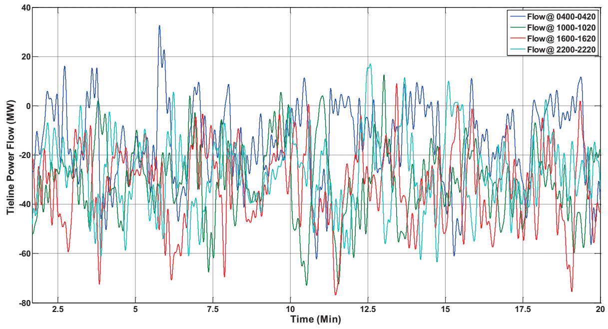

Figure 11. The contribution of generation-load imbalance to 400kV Sofia-Nis line flow deviations.

Followings summarize the observations from the above graphs:

- The contribution of global mode new-U1 to the 400kV Sofia-Nis line flow is around 5 to 10MW (see Fig 9). This contribution is due to all units that are coherent for new-U1. That is, all generators in Turkey as well as Greece and Bulgaria, as seen in Figure 4 above.
- The contribution of global mode T1 to the 400kV Sofia-Nis line flow is around 20-30MW (see Fig 10). This contribution is due to all units that are coherent for T1, including all generators in the Balkan area. The improvement on damping characteristic has already been reported and agreed that it is satisfactory.
- The contribution of the generation load imbalance of the network to the East of 400kV Sofia-Nis line to the 400kV Sofia-Nis line flow is around 60-80MW (see Fig 11).
- The following criteria for Turkish area Control Error (ACE) performance is satisfied [7]:
    - The absolute value of ACE is less than 175MW for 10% time, and
    - The absolute value of ACE should be less than 100MW for 33% time.

VI. Evaluation of the Sufficiency of Tie-Lines that Connect Turkey with ENTSO/E

As stated in [2], the existing three interconnection lines between Turkey and Bulgaria (2 lines) and Greece (1 line) is agreed to be sufficient for the interconnection. The triple (2xTR-BG and 1xTR-GR) interface guarantees a safe interconnection of the Turkish power system from the static security point of view. It is also adequate for significant power exchanges of the order of 1000 MW in both directions for all N -1 contingencies and it has been also verified for some critical double contingencies.

Moreover, given the stability concerns the power exchange between Turkey and UCTE has to be limited to 500 MW for the trial operation phase [3]. The stability investigations revealed the possibility of Wide Area Asynchronism. In order to reduce the probability of Wide Area Asynchronism, a special protection scheme that separates the systems, if necessary, has already installed by Turkey.

The synchronous interconnection of Turkey to UCTE is feasible provided that the frequency control problem is also resolved and the damping performance of the majority of the generation stations is improved by new Power System Stabilizers and/or optimized parameter settings of the existing controllers. Both measures are already taken as proved by measurements.

In order to prove the sufficiency of the tie-lines, the following study is performed in this paper. The effects of tie-line outage and enforcement on the inter-area oscillations are analyzed based on computer simulations with a verified dynamic model of Turkey and a representative model of ENTSO/E network. The scenario of Turkey exporting ~1000 MW to ENTSO/E is analyzed for the following cases and the damping characteristic of the system is compared.

- **Case 1 (Base case):** The current situation. That is 3 tie-lines 2 of which are between Turkey and Bulgaria, and one is between Turkey and Greece.
- **Case 2:** The most loaded line out of three is out of service (i.e., line between Hamitabat (Turkey) and Maritsa (Bulgaria).
- **Case 3:** The most loaded line out of three is doubled (i.e., enforcement of line between Hamitabat (Turkey) and Maritsa (Bulgaria).

Comparison of time domain simulation and frequency spectrum results are given in Figure 11 and 12, respectively. Relative effects of line outage (Case 2) and enforcement (Case 3) are illustrated in Table 1 and Figure 13 for better comparison.

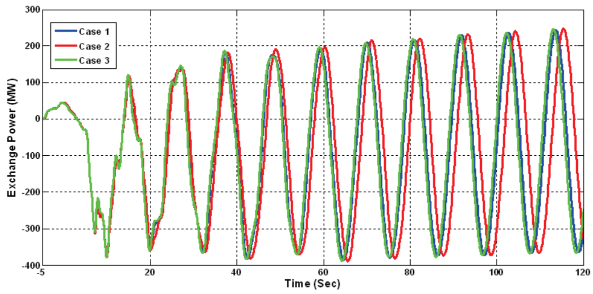

Fig. 11. Comparison of tie-lines effect on inter-area oscillations (time-domain simulations).

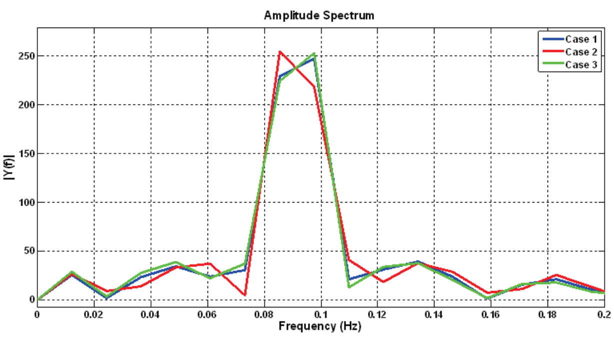

Fig. 12. Comparison of frequency spectrums.

Table 1. Comparison of eigen-value analysis results.

	Damped Freq. (Hz)	Damping (1/s)	Damping Ratio
Case 1	0,116	-0,251	-0,325
Case 2	0,115	-0,254	-0,332
Case 3	0,117	-0,250	-0,322

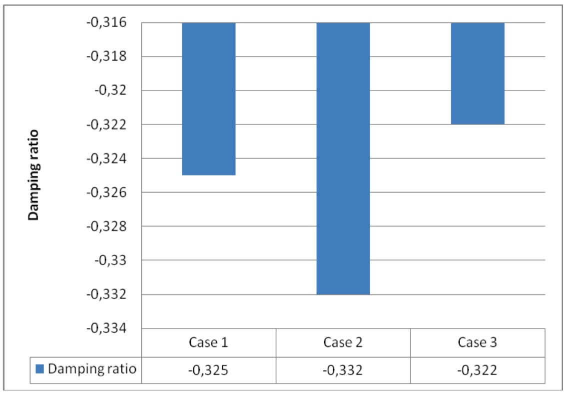

Fig. 13. Comparison of damping ratios.

When compared with the base case (i.e., Case 1), although the damping in Case 2 (i.e., outage of a line) is essentially minimum, the marginal gain in damping is not significant in Case 3. That is, the addition of a forth tie-line will not contribute to the damping significantly. In conclusion, the current 3 tie-lines are sufficient for damping against low frequency inter-area oscillations.

VII. Conclusions

Followings are the main conclusions of the paper:

- Needs for new interconnectors (tie-lines) that identified in TYNDP report of ENTSO/E will essentially contribute to unintentional power swings on weak inter-ties at the region.
- Indeed, the necessity for the enforcement of the existing interconnectors (tie-lines) at the region is independent from Turkish interconnection, as emphasized in TYNDP report of ENTSO/E.
- Unintentional power swings on the inter-ties at the region is not only due to swings of the generators in Turkey. The generators in Greece and Bulgaria, as being coherent with those of Turkish generators, also contribute to the power swings due to global mode new-U1.
- Turkey is suffering inter-area frequency oscillations most as being the border country. This motivated Turkey to make all possible efforts to improve damping inter-area oscillations. The results are satisfactory as reported by ENTSO/E.
- Safe interconnection of Turkey with ENTSO/E system is important given:
    - Safe accommodation of new RES in the region countries, as emphasized in TYNDP report of ENTSO/E.
    - Integration of the electricity markets

- Turkey, as suffering (and therefore concerning with) the inter-area oscillations most, is expecting that the new interconnectors (tie-lines) that identified in TYNDP report will be finalized without delay from the schedule.
- Current tie-lines between Turkey and ENTSO/E are sufficient in the sense of inter-area oscillations given marginal effect of line enforcement is insignificant.

VIII. References

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