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Power Flow Based Indices for the Coordination of Transmission and Generation System Planning

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***Abstract* -- This paper deals with one of the issues consequent on the recent restructuring of the electricity industry: the lack of coordination between generation and transmission system development. Indeed, in this new environment the planning of these two systems is driven by different objectives, resulting in a possible conflict between economics and security. The nodal index called Weighted Transmission Loading Relief (WTLR), recently proposed in literature, seems to be able to supply clear information about the impact of generation and transmission system investments on network security. Therefore, the authors of this paper have developed an automatic procedure to calculate and represent graphically these indices. The procedure has been applied to a detailed model of the Italian EHV network with reference to a summer peak load condition at the projection horizon of the year 2013, in order to highlight the various kinds of information which the above mentioned indices can supply.**

***Index Terms* -- Contingency analysis, Injection Shift Distribution Factor, Weighted Transmission Loading Relief, transmission and generation planning.**

I. Nomenclature

P_{hk}	real power flow on branch *hk* in the pre-contingency condition
$P_{hk,rs}$	real power flow on branch *hk* following the outage of branch *rs*
b_{hk}	susceptance of branch *hk*
x_{rr}^0, x_{rs}^0	elements of the matrix $X^0 = -\left(B^0\right)^{-1}$, where B^0 is the susceptance matrix in the pre-contingency condition
$ISDF_{hk}^i$	Injection Shift Distribution Factor in pre-contingency condition
$ISDF_{hk,rs}^i$	Injection Shift Distribution Factor in post-contingency condition (following the outage of line *rs*)
A_i	real power injection at bus *i*
ρ_j	participation factor of generation unit *j*
N_{ds}	number of distributed slack buses
$P_{\max j}$	rated power of generation unit *j*
$Overload_{SYS}$	total system overload
N_{viol}	total number of overloads
$Overload_{hk}$	overload of branch *hk* in N security condition
$Overload_{hk,rs}$	overload of branch *hk* following the outage of line *rs*

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II. Introduction

THE evolution of the electricity industry from the past vertically integrated utilities to the nowadays deregulated and unbundled structures has introduced deep changes in electric energy system operation and planning. In particular, in this new environment the coordination of transmission and generation planning is no more assured as it was in the previous vertically integrated structures, where both the transmission network and generation plants belonged to only one entity. The electricity market liberalization has opened the generation supply to competition, so GENeration COmpanies (GENCOs) define their investment plans in order to maximize their expected profits. Instead, the transmission provider is often a single regulated entity. So in those countries where the electricity market liberalization has already been completed, the generation system development is driven by different GENCOs, while the task of operating the transmission network in a secure and reliable way pertains to the Transmission System Operator (TSO), TERNA in Italy [1]. This new situation has substantially modified the transmission system planning, above all introducing some new uncertainties, for example the size and location of new power plants. Indeed, GENCOs are not interested in the various problems which the TSO has to face in order to guarantee a secure, reliable and uninterrupted electricity supply. This situation may undermine the electricity market efficiency, since it may lead to a bad location of the cheapest generation plants, whose production may be substituted by that of more expensive units, because of the occurrence of network congestions consequent on a not adequate transmission capacity.

Such generation system development, which is not necessarily correlated to the network planning, may reduce or even undermine the expected effectiveness of a grid reinforcement. If the TSO had some easy and simple methods to send direct and intuitive signals to the GENCOs pertinent to the areas where the transmission capacity is adequate to support the power injection of new plants, a more coherent integration between generation and transmission expansion would be achieved. Therefore, a better exploitation of both existing and planned network facilities will be attained.

Recent bibliography [2]-[4] pertinent to the problem of transmission system security has proposed and applied the nodal index called Weighted Transmission Loading Relief (WTLR), which is able to capture how a nodal real power injection impacts on network security. In restructured electricity markets, the generation planning based on profit maximization may undermine the transmission system security and reliability: installing new generation plants may have positive or negative impact on network security, depending on where the new capacity will be installed and on the amount of that capacity. From this point of view, the WTLR factors supply some important information: they show the grid areas where new generation capacity will contribute to congestion alleviation (negative WTLR) or vice versa where the transmission capacity is not adequate to support an additional power injection (positive WTLR).

On the basis of that, the authors of this paper have developed an automatic procedure, coded in MATLAB, which calculates and represents graphically the above mentioned indices. The procedure is very fast and can be applied to very large systems. Its results, easy to be understood, can be used:

- to assess the impact of the generation system expansion on network security and to identify the grid buses which are adequate to host new power plants coherently with the planned network development;
- to identify the weakest grid areas, where new transmission facilities are to be realized;
- to assess the effectiveness of grid reinforcements planned by the TSO in terms of security enhancement and so to rank them in order to prioritize transmission planning;
- to determine some new alternative network reinforcements, in case some externalities obstacle the realization of the priority ones.

The procedure was successfully applied to a small test system and also to a detailed model of the Italian EHV network with reference to a winter 2007 scenario [5].

The paper will present some modifications made in the procedure and the results obtained by its application to the Italian EHV network with reference to a summer peak load condition at the projection horizon of the year 2013.

III. Generation and Transmission Planning After the Electricity Industry Liberalization

In the recent past, both the operation and the planning of the electric energy system were in the hands of centralized entities characterized by a vertically integrated structure. In particular, the planning process was integrated and its aim was that of minimizing investment and operational costs, while meeting both demand growth and reliability criteria. The unbundling and the liberalization have produced new challenges which the restructured electricity industry has to face, above all because of the presence of lots of new players (power producers, brokers, etc.), so resulting in a decentralized decision making. In particular, the generation supply has been opened to competition and so GENCOs individually make their investment plans in order to maximize their expected profits over the planning horizon.

One critical consequence is the increasing number of commercial transactions, which causes the more and more frequent stressing of the transmission network: in fact, the grid is the interface where buyers and sellers interact with each other.

Unlike in the past vertically integrated structures, in the competitive electricity market, as demand grows and new power plants are installed, increasing transmission capacity is likely to be necessary also to improve market competition and to mitigate the exercise of local market power. Any form of transmission constraints or bottlenecks will prevent the fulfilment of a perfectly competitive market. In particular, network congestions may prevent the exploitation of lower-priced generators, resulting in higher electricity prices and market inefficiencies. The occurrence of network congestions may encourage the exercise of market power by some power producers to increase their profits. So in restructured electricity markets, transmission expansion generally has distributional impact [6]: a transmission investment may affect the economic outcomes of market participants, creating “winners” and “losers”, even if such investment is socially-efficient. In other words, the maximization of social welfare may not assure Pareto efficiency, that is to say making all participants better off or neutral.

Therefore, an effective transmission development is fundamental because poor transmission planning may lead to network congestions, market inefficiency and opportunities for the exercise of market power. The TSO has to define strong and flexible transmission expansion plans in order to face the various uncertainties that characterize the planning phase, such as the generation system development. The analysis of current and forecast scenarios of the electric energy system allows the TSO to evaluate where, when and what type of grid reinforcements are to be realized to avoid future inefficiencies.

Even though in the competitive electricity markets the planning of generation and transmission development pertains to different entities with different goals, there is still a strong interrelationship between these two systems. On the one hand, network constraints may affect power producers’ operational and planning decisions according to where the generators are or will be located relative to the transmission limits; on the other, generation capacity expansion may worsen existing network congestions and even compromise the effectiveness of a planned grid reinforcement.

If adequately chosen, generation and transmission investments may have the same positive impact on social welfare and consequently on electricity market efficiency. On the one hand, increasing transmission capacity may cause a substitution (in production) of some expensive power by cheaper one (substitution effect) and mitigate the opportunity to exercise local market power (competitive effect), so improving the market efficiency [7]. On the other, generation capacity expansion can enhance the productive efficiency by reducing total generation costs and the allocative efficiency so encouraging the competition among power producers.

IV. Description of the MATLAB Procedure

The MATLAB coded procedure, which calculates and represents graphically the Weighted Transmission Loading Relief factors, operates in the following steps:

1. Contingency analysis (N and N-1 security assessment) to find possible branch overloads.
   In [5] this step was time-consuming because performed by means of an AC load flow, repeated for each examined contingency.
   Instead, in this case, in order to reduce the total computational time, the procedure carries out an AC load flow to evaluate the real power flows in intact system condition, while the real power flows following a line outage $P_{hk,rs}$ are determined by means of the distribution coefficients $\gamma_{hk,rs}$ given by a DC approximation:

$$P_{hk,rs} = P_{hk} + \gamma_{hk,rs} \cdot P_{rs} \tag{1}$$

$$\gamma_{hk,rs} = \frac{b_{hk}}{b_{rs}} \cdot \frac{(x_{rh}^0 - x_{sh}^0) - (x_{rk}^0 - x_{sk}^0)}{\frac{1}{b_{rs}} - (x_{rr}^0 + x_{ss}^0 - 2x_{rs}^0)} \tag{2}$$

2. Calculation of Injection Shift Distribution Factors (ISDFs) in both pre-contingency and post-contingency conditions [8]:

$$ISDF_{hk}^i = \frac{\partial P_{hk}}{\partial A_i} \tag{3}$$

$$ISDF_{hk,rs}^i = \frac{\partial P_{hk,rs}}{\partial A_i} \tag{4}$$

   In [5] the calculation of ISDFs has been carried out supposing that there is only one slack bus (concentrated slack). So the ISDFs in pre-contingency condition were calculated using the following expression (DC formulation):

$$ISDF_{hk}^i = -b_{hk} \cdot \left(x_{hi}^0 - x_{ki}^0\right) \tag{5}$$

   In this case, in order to avoid the dependence of the distribution factors on the choice of the slack bus, the concentrated burden of the phase reference bus has been removed by introducing an appropriate vector of participation factors ρ_j (> 0) to balance the additional unit injection at bus i by means of an assigned set of N_{ds} distributed slack buses [9]. The phases of the distributed slack buses are still dependent variables, except that of the last one (the phase reference bus of DC load flow), which is fixed to zero. According to this assumption, the new formulation of the distribution factors (DSISDF - Distributed Slack Injection Shift Distribution Factor) becomes:

$$DSISDF_{hk}^i = -b_{hk} \cdot \left(x_{hi}^0 - x_{ki}^0\right) + b_{hk} \cdot \sum_{j=1}^{N_{ds}-1} \rho_j \cdot \left(x_{hj}^0 - x_{kj}^0\right) \tag{6}$$

   with:

$$\sum_{j=1}^{N_{ds}-1} \rho_j + \rho_{N_{ds}} = 1 \tag{7}$$

   ρ_j can be obtained by the participation factor of the generation unit j to the economic dispatch or defined as proportional to the rated power (MW) of generator j:

$$\rho_j = \frac{P_{\max j}}{\sum_{j=1}^{N_{ds}} P_{\max j}} \tag{8}$$

   For the calculation of DSISDFs in post-contingency condition, it is necessary to determine the inverse of the new susceptance matrix, because of the grid topological changes as a result of the line *rs* outage; to do this, the procedure applies the Woodbury Matrix Identity (also called the matrix inversion lemma) [10].
3. Computation of the total system overload $Overload_{SYS}$ as the sum of all overloads found at step 1.
4. Calculation of Weighted Transmission Loading Relief (WTLR) factors by using the following mathematical expression:

$$WTLR_i = \frac{N_{viol}}{Overload_{SYS}} \cdot \Big(\sum_{hk} DSISDF_{hk}^i \cdot Overload_{hk} + \\ + \sum_{hk} \sum_{rs} DSISDF_{hk(rs)}^i \cdot Overload_{hk(rs)}\Big) \tag{9}$$

   This index provides a sensitivity (metric) of how much the system overload can be improved or worsened by a 1 MW injection at bus i, balanced by the withdrawal of ρ_j MW at each of the N_{ds} distributed slack buses.
5. WTLR graphical representation:
   it defines qualitatively the areas adequate to the installation of new power plants and those requiring network reinforcements.

V. Tests and Results

The procedure has been applied to a detailed model of the Italian EHV network (380 and 220 kV) with reference to a summer peak load condition at the projection horizon of the year 2013. The simulations aim at highlighting the various kinds of information which the calculation and the graphical representation of WTLR factors can supply. The hypotheses assumed for all the case studies analyzed are the following:

- the power productions of the thermoelectric plants refer to an unconstrained clearing market point; in other words, the schedule is the result of a λ-dispatching procedure that takes into account the economic merit order, while ignoring transmission system constraints. As result of the unconstrained market, the Italian transmission system may be harmfully stressed in peak load conditions, since the main power plants are not always located near the load areas;
- the N-1 security assessment is carried out including the outages of all 380 kV lines in the contingency set and increasing the power flow limits of all branches by 20% of their rating;
- a set of five slack buses belonging to the five macro-areas of the Italian EHV system (North, Central-North, Central-South, South, Sicily) has been chosen for the calculation of the DISDFs. The participation factors ρ_j are calculated by using (8).

A. First case study (load and generation updated to 2013 and existing transmission network)

In the first case study, the total load, the generation park and the power import of the Italian electric system are those forecast by the TSO [1] for the projection horizon of the year 2013, while the transmission network presents the existing structure.

The most significant results of the contingency analysis are summarized in Table I. They highlight the weakest elements of the Italian 380 kV network.

TABLE I
CONTINGENCY ANALYSIS RESULTS (FIRST CASE)

Tripped line	Overloaded branch	Overload [MW]
Rondissone-Turbigo	Rondissone 380-Rondissone 220	75.6 (40%)
S. Rocco al P.-Parma Vigh.	S. Rocco al P.-Caorso	127.0 (30%)
Pieve Albignola-Baggio	Rondissone-Turbigo	119.6 (28%)
Gissi-Villanova	Foggia-Benevento	735.2 (88%)
Gissi-Larino	Foggia-Benevento	263.2 (44%)
Foggia-Benevento	Gissi-Villanova	298.3 (43%)
Matera-S. Sofia	Foggia-Benevento	43.9 (24%)

As shown in Fig. 1 (Northern Italy) and in Fig. 2 (Southern Italy), these grid sections are already critical and their operation will get worse and worse in consequence of the foreseen demand growth and generation system expansion. In particular, the new generation capacity will be located mainly in the northwest and in the south, in other words in areas already exposed to the risk of network congestions.

The WTLR graphical representation is shown in Fig. 3. The highest values (red coloured region) correspond to the buses in Southern Italy, particularly on the Adriatic coast (for instance, Larino WTLR = + 14.9; Bari WTLR = + 11.8), because of the high power transfers from Apulia region towards Central Italy, which cause the congestion of the 380 kV Gissi - Villanova line. Obviously, the WTLR of the buses belonging to the receiving region (Marche) are negative (for example, Teramo WTLR = - 0.50). Although positive, the nodal indices in Piedmont are lower (for instance, Chivasso WTLR = + 0.68; Casanova WTLR = + 0.51). An additional power injection in the areas with positive WTLR factors will make the system security and the operation condition worse.

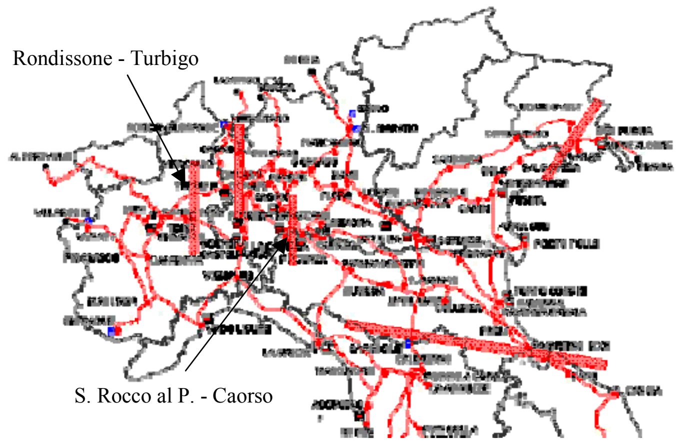

Fig. 1. Critical grid sections in Northern Italy [1]

Fig. 2. Critical grid sections in Southern Italy [1]

Furthermore, it should be noted that changes from negative (green coloured regions) to positive WTLR values (red coloured regions) reveal the presence of congested grid elements or sections. This information can be used to identify some possible grid reinforcements. For this case study, the WTLR representation confirms the need to realize some of the new network facilities planned by the Italian TSO for the projection horizon of the year 2013 [1], namely: the increase of the transmission capacity of the 380 kV Foggia - Benevento line; the doubling of the 380 kV Adriatic backbone between the electrical stations of Villanova and Foggia; the realization of the new 380 kV double circuit lines La Casella - Caorso and Trino - Lacchiarella.

The analysis of the results obtained in the first case study has demonstrated that the proposed procedure is useful to identify the grid buses which are adequate to host new power plants coherently with the existing transmission system, and also to identify the most critical grid sections, which present structural limitations and therefore are to be reinforced.

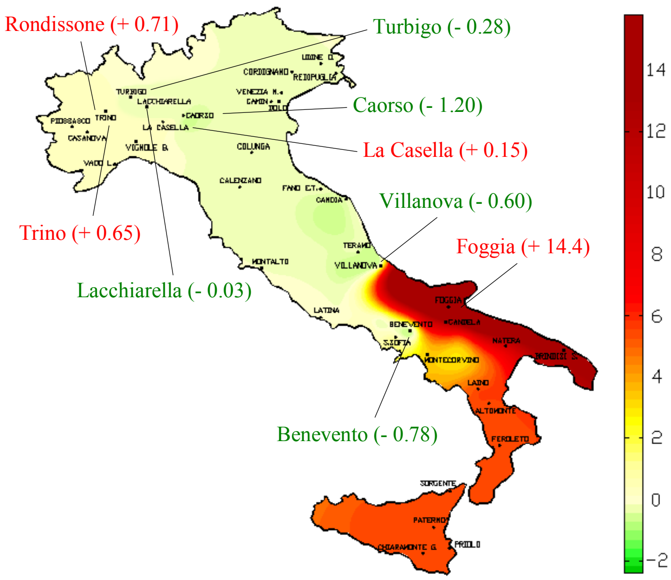

Fig. 3. WTLR graphical representation - first case study

The following paragraphs will describe some other tests carried out on the Italian EHV network in order to:

- verify if the transmission expansion plans will be able to support the generation system development;
- evaluate the effectiveness of a single grid reinforcement, already planned by the TSO, in terms of congestion alleviation and security enhancement;
- assess the impact of new generation capacity on network security.

B. Second case study (year 2013)

The MATLAB procedure has been applied to a second case study, which presents the same hypotheses as the previous one for what concerns the total load, the generation park and the power import of the Italian electric system; also the transmission network structure has been upgraded according to the planning of the Italian TSO for the projection horizon of the year 2013. Table II summarizes the main 380 kV network reinforcements planned by 2013 [1].

TABLE II
MAIN 380 KV NETWORK REINFORCEMENTS

Double circuit line La Casella-Caorso
Double circuit line Trino-Lacchiarella
Double circuit line Dolo-Camin
Line Cordignano-Venezia Nord
Increase of the transmission capacity of line Benevento-Foggia
Doubling of the existing Adriatic backbone Foggia-Villanova
Line Fano-Abbadia-Teramo
Double circuit line Sorgente-Rizziconi
Double circuit line Montecorvino-Benevento

The new WTLR graphical representation (Fig. 4) clearly shows that these reinforcements will improve the system security operation. In fact, the contingency analysis has found no violations of the power flow limits in Southern Italy, as reflected by the WTLR values which are all equal to zero. As regards Northern Italy, despite the upgrades of the transmission network, such as the realization of the new 380 kV double circuit lines La Casella - Caorso and Trino - Lacchiarella, there are still some problems on 220 kV grid of Milan area due to its structural limitations. However, on the whole the transmission expansion plans will solve all the most critical situations, so improving network security and effectively supporting the generation system development.

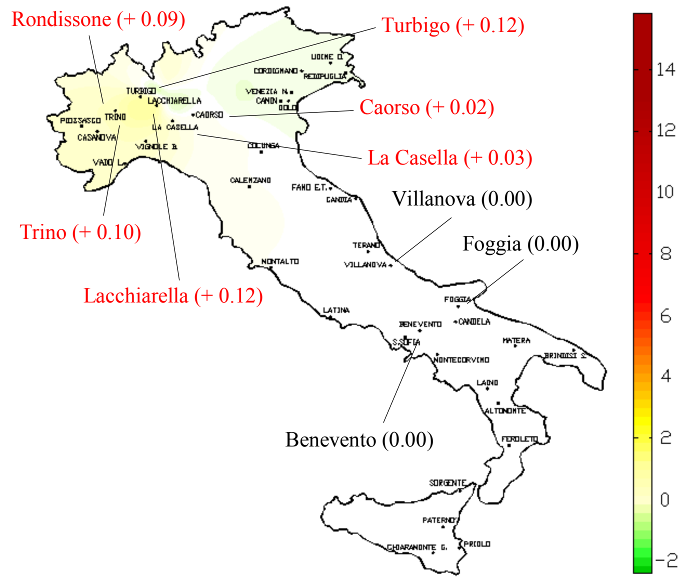

Fig. 4. WTLR graphical representation - second case study

C. Third case study (doubling of the existing 380 kV Adriatic backbone between Villanova and Foggia)

The third simulation aims at demonstrating the usefulness of the proposed procedure to assess the effectiveness of a single network reinforcement, already planned by the TSO, in terms of congestion alleviation and security enhancement. The case study has been defined by assuming the same hypotheses of the first one for what concerns load, generation and import, which have been updated to 2013. On the contrary, the existing network structure has been upgraded thanks to the doubling of the 380 kV Adriatic backbone between the electrical stations of Villanova and Foggia. In the first case study, the WTLR values of these two buses are - 0.60 and + 14.4 respectively, so suggesting the reinforcement of this grid section. Therefore, it is right to expect notable congestion alleviation and security enhancement.

Obviously, the situation in Northern Italy is unchanged and in fact the contingency analysis has found the same violations of the power flow limits as the first case study.

Besides avoiding the congestion of the 380 kV Adriatic backbone, the main benefit of the examined network reinforcement regards the security operation of the existing 380 kV Foggia - Benevento line, as there is a new way to evacuate the power production of the generation units belonging to the "limited production poles" of Brindisi and Foggia towards Central Italy. The overall situation in Central-South and South macro-areas is substantially improved; the security assessment has revealed only some problems on 220 kV grid in Campania due to its structural limitations.

The general security enhancement in the above mentioned areas affects the WTLR factors, whose absolute values decrease considerably, as shown by their graphical representation in Fig. 5.

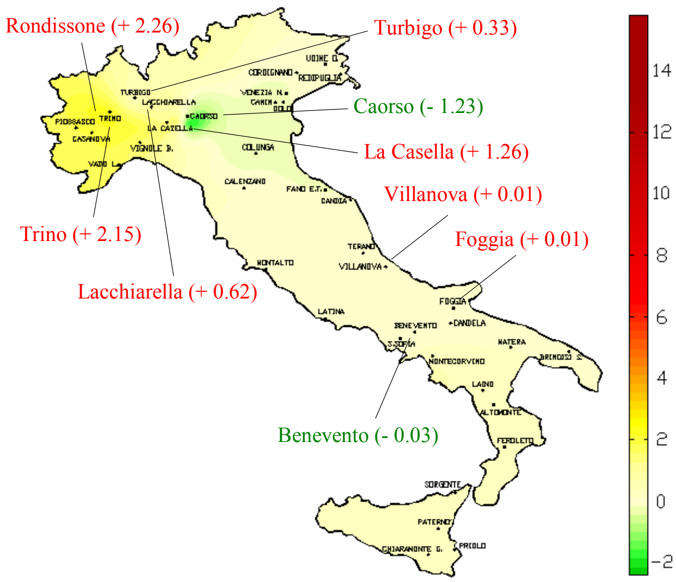

Fig. 5. WTLR graphical representation - third case study

Also the nodal indices of Northern Italy change: the highest WTLR factors correspond to the buses of Rondissone (+ 2.26), Chivasso (+ 2.19), Trino (+ 2.15) and Leyni (+ 2.15), while the smallest ones are those of the buses of Caorso (- 1.23) and Cremona (- 0.91). In particular, the WTLR values in Piedmont increase, since the most severe contingencies occur on the grid sections between Piedmont and Lombardy (the 380 kV Rondissone - Turbigo line) and between Lombardy and Emilia Romagna (the 380 kV S. Rocco al Porto - Caorso line).

The WTLR graphical representation highlights exactly the necessity of reinforcing these two network sections.

D. Fourth case study (new power plants at Villanova and Benevento buses)

The fourth simulation wants to show how the procedure can be helpful to assess how the real power injection of a new plant may impact on network security.

The case study has been defined by assuming the same hypotheses of the first one, except for the addition of two new CCGT generators with a rated power of 700 MW each, connected to the 380 kV buses of Villanova and Benevento. The choice of the sites has been driven by the WTLR factors obtained in the first case study. In fact, the regions with negative values are at the receiving end of at least one congested grid element, while locations with a positive index are at the sending end. Therefore, real power injections at a negative-value bus will produce counter-flows which will contribute to congestion alleviation. In the first case study, the nodal indices corresponding to the above mentioned buses are equal to - 0.60 and - 0.78 respectively, so suggesting that they will be adequate locations for the installation of new power plants.

The new generators are dispatched at their rating, while the power production of Apulia and Abruzzi regions, where a CCGT generation capacity of about 3800 MW should be available for the projection horizon of the year 2013, is reduced by the same amount.

The security assessment results are alike to those obtained in the previous simulation (third case study). The most significant ones are summarized in Table III, which shows that the situation in Northern Italy is not influenced by the addition of the new power plants, as however it is not affected by the doubling of the 380 kV Adriatic backbone.

TABLE III
CONTINGENCY ANALYSIS RESULTS (FOURTH CASE)

Tripped line	Overloaded branch	Overload [MW]
Rondissone-Turbigo	Rondissone 380-Rondissone 220	75.3 (40%)
S. Rocco al P.-Parma Vigh.	S. Rocco al P.-Caorso	125.5 (30%)
Pieve Albignola-Baggio	Rondissone-Turbigo	116.8 (28%)

The remarks made about the situation of Central and Southern Italy in the preceding case study are valid also in this one. In particular, only some problems on 220 kV grid in Campania persist, even if the overloads are little lower thanks to the addition of the new plant at Benevento bus, whose power production contributes to alleviate them.

In Table IV the WTLR values of some 380 kV buses of Southern Italy are indicated with reference to the first, third and fourth simulations.

TABLE IV
WTLR VALUES OF SOUTHERN ITALY BUSES IN FIRST, THIRD AND FOURTH CASE STUDIES

Bus	Before (first case study)	After (third case study)	After (fourth case study)
Rosara	- 0.45	+ 0.01	+ 0.01
Teramo	- 0.50	+ 0.01	+ 0.01
Villanova	- 0.60	+ 0.01	+ 0.01
Gissi	+ 12.4	+ 0.01	+ 0.01
Larino	+ 14.9	+ 0.01	+ 0.01
Foggia	+ 14.4	+ 0.01	0.00
Benevento	- 0.78	- 0.03	- 0.01
Presenzano	- 0.01	- 0.03	- 0.01
Bari	+ 11.8	+ 0.02	+ 0.01
Brindisi	+ 9.6	+ 0.03	+ 0.01
Matera	+ 7.8	+ 0.07	+ 0.01
Montecorvino	+ 2.4	+ 0.15	+ 0.02
Laino	+ 3.5	+ 0.13	+ 0.01

The comparison between the first column and the last one shows that the installation of new generation capacity at Villanova and Benevento buses will significantly improve the network security operation. The two last columns confirm the results of the contingency analysis carried out in the third and forth case studies. In fact, the WTLR factors are nearly the same, as the security assessment results are alike. The only difference regards the indices of the buses in Southern Italy. In the fourth case study their absolute values are slightly smaller because, as previously said, the overloads on 220 kV grid in Campania are little lower.

The comparison between the two last columns of Table IV proves that, if appropriately located, the real power injection of a new generation unit may have the same effect of a certain grid reinforcement in terms of network security enhancement.

VI. Conclusions

In restructured electricity markets the planning of generation and transmission expansion pertains to different entities with different objectives. In fact, in this new environment the generation system development is not necessarily correlated to the network planning. A such discrepancy may lead to an inhomogeneous development of the whole electric system and make the transmission network weak, reducing or even undermining the expected effectiveness of a planned grid reinforcement.

From this point of view, the nodal index, recently proposed in literature and called Weighted Transmission Loading Relief (WTLR), could be of great help to the TSO, since it supplies evident information about the effect of transmission and generation system plans on network security.

The authors of this paper have developed a MATLAB coded procedure to calculate and represent graphically the above mentioned indices. In particular, this paper have proposed some modifications made in the procedure. The calculation of the real power flows following a line outage, determined by means of the distribution coefficients given by a DC approximation, allows the total computational time to be reduced significantly. Moreover, the distributed slack is introduced in the calculation of Injection Shift Distribution Factors and consequently of Weighted Transmission Loading Relief, in order to avoid their dependence on the choice of the slack bus.

The simulations, carried out on the Italian EHV network with reference to a summer peak load condition for the projection horizon of the year 2013, have demonstrated the usefulness of the proposed procedure. Above all, they have highlighted the different kinds of information that the nodal indices WTLR can supply: the most adequate buses to host new power plants coherently with the existing and planned transmission system; the most critical grid elements and sections; the effectiveness of a single network reinforcement in terms of security enhancement; the impact of new generation capacity on network security.

Finally, it has been shown how the real power injections of new plants, appropriately located, may have the same positive effect of a grid reinforcement, planned by the TSO, in terms of network security enhancement. Therefore, it has been demonstrated that the WTLR indices could be useful to achieve a more coordination between generation and transmission expansion.

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VIII. Biographies

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