Patricia Isabel Domingues dos SANTOS[1], Rui José Oliveira Nóbrega PESTANA[2], Carlos Manuel Borralho MACHADO FERREIRA[1,3], Fernando Pires MACIEL BARBOSA[4]

IPC/ISEC (1), REN – Rede Eléctrica Nacional (2), INESC Coimbra (3), FEUP and INESC Porto (4)

Identification of the Relevant Neighbouring Electric Power Systems using the Horizontal Network Methodology

***Abstract**. In this paper it is proposed a technique to identify the relevant neighbouring electric power systems using the Horizontal Network scheme. The developed methodology was applied to study the IEEE 118 test power network and the Iberian systems. All simulations were performed using the computational software package PSS®E developed by the Siemens/PTI. From the simulation results, some conclusions that provide a valuable contribution to the understanding of the impact of the cross-border interconnections between the countries will be pointed out.*

***Streszczenie.** W niniejszej pracy zaproponowano technikę w celu określenia sąsiadujących systemów elektroenergetycznych przy realizacji programu Network. Opracowana metodyka została zastosowana do testu IEEE 118 sieci energetycznej i systemów Iberyjskiego. Wszystkie symulacje zostały przeprowadzone przy użyciu pakietu oprogramowania obliczeniowego PSS®E opracowany przez Siemens/PTI. (**Identyfikacja sąsiadujących systemów energetycznych przy wykorzystaniu metodologii sieci horyzontalnych**)*

Keywords: Cross-borders Electricity Transits, Electric Power Systems, Horizontal Network.
Słowa kluczowe: systemy elektroenergetyczne, horyzontalne sieci.

Introduction

Nowadays, due to security reasons, reliability, power quality and guarantee of supply of the interconnections of the Electrical Power Systems (EPS) of different countries is mandatory. The establishment of a European Network of Transmission System Operators for Electricity, ENTSO E, increases the cooperation and coordination among transmission system operators (TSO) in strategic areas of their activity. Among these, there is the optimal management of the electricity transmission network, the coordination of system operation and the development of the European Network [1].

The electric power industry is currently ongoing an unprecedented restructuring process. The restructuring of the EPS has introduced new opportunities for competition to reduce the operating cost and cut the prices [2]. Moreover, in a competitive environment, economic and social constraints, force electric utilities to operate their power networks closer to their physical limits with an ever increasing risk of temporary supply interruption [3]. The main goal both for short-term and long-term operations is then to seek the best compromise between the requirements of security and economy.

The new paradigms associated with the restructuring of the electricity sector made it critical to develop new methodologies to study and analyze the security of the power networks. Furthermore, there has been a continuing effort to reinforce the interconnections between the networks so as to avoid congestion and improve safety [4]. With the construction of new cross-border tie-lines between different countries, it is essential to understand how the national transmission grid of each country will be affected.

The horizontal network of the neighbouring systems is one of the important issues that will have to be analyzed. The lines which are significantly affected by cross border trading constitute the so-called horizontal network [5]. It contains all those transmission system components that are significantly influenced by cross-border energy exchanges. For most countries, the horizontal network consists at least of the 400 kV interconnections, transmission lines and substations. This concept can be equally applied to existing or future transmission lines.

The interconnection capability between Portugal and Spain, as well as the rest of the ENTSO-E electric power network is of particular importance, since it allows international trade, either commercial or for mutual assistance among the systems. The interconnection between the two countries is currently under development with the objective of reaching 3000 MW in 2014 [6].

Electrical utilities are confronted daily with unforeseen events in their power networks that may reduce the security level. The Iberian cross-border transmission capacity might be subject to significant fluctuations in time, due to the variability of the generation level and unpredictable consumption patterns, as a result of accidental or planned outages of its components [7].

Commercial use of the interconnections requires that those participating in the energy market have information, in advance, about the available transmission capacity, to implement the import and export programs. Different scenarios of generation, consumption forecast and credible information on the prediction of system outages in each horizon are taken into account in order to evaluate the cross border capacity, avoid transmission congestion and market splitting [8]. Effective congestion management is one of the major tasks performed by the TSO and a fundamental factor for a reliable and efficient operation of an electricity market [9].

In this paper it is proposed a technique to identify the relevant neighbouring electric power systems using the horizontal network approach. The developed methodology was applied to the IEEE 118 test power network and the Iberian systems. The Portuguese and Spanish transmission networks were analysed using savecases that represent pictures of the real systems. All simulations were performed using the computational software package PSS®E, developed by the Siemens/PTI.

Identification of the Horizontal Network

The European Parliament, aiming to establish fair rules for trade in electricity, thereby increasing the competition in the internal electricity market, taking into account the specificities of national and regional markets, created the Regulation (EC) No. 1228/2003 [10]. This regulation will require the creation of a compensation mechanism for cross-border flows and the establishment of harmonized principles with regard to charges for cross-border transport and the allocation of available interconnection capacity between national transmission systems. This compensation scheme is called the Inter-TSO Compensation (ITC) and aims to support the development of the internal electricity market [11].

The ITC must provide a mechanism to offset the costs of hosting cross-border flows, including the provision of cross border access to the interconnected system [12]. On the other hand, the ENTSO-E has a background in order to compensate the operators of the transmission system to accommodate the cost of electricity flows across borders [13].

The TSO must identify the relevant network areas to international flows. Such identification results in the definition of the horizontal network, which includes all those network elements, that are significantly affected by cross border power flows [14]. The horizontal network corresponds to the part of the transmission system, which is used to transmit electricity across countries and inside the country.

Its determination is based on the variation of flows on lines and transformers when adding a transit, i.e., a flow entering on a set of tie-lines and exiting through another set. The electrical system of each country is studied independently and the tie-lines are modelled as the only external injections or extractions from the network of each country. It is impossible to simulate all possible transits through a network, as there are too many possible patterns and an infinite number of possible magnitudes. However, any transit through a country can be seen as a combination of several individual transits.

The horizontal network was defined using the transit flow of 100 MW between every combination of interconnection lines. Import flow of 100 MW on one interconnection line and export flow of 100 MW on the other interconnection line made a combination. During one simulation of transit – 100 MW import and export on two of interconnection lines – flows of other interconnection lines were set up to zero.

For the determination of the horizontal network it is used the DC model for load flow simulation on an empty network. In order to find the horizontal network in an unambiguous way, the transmission lines that belonging to a given nation must be clearly identified. This is accomplished by applying a standard 100 MW flow between each couple of nodes connecting the selected country with the others, all the national lines carrying a power greater than or equal to 1 MW are considered belonging to the horizontal network of the selected country, since it was the threshold value of the horizontal network for the ITC rate.

Formally the procedure is the following one [15]:

Criterion

(1) If $\underset{l,m}{Max}\left(\left|F_e(t_{lm})\right|\right) \geq 1\,\mathrm{MW}$

then *e* is part of the horizontal network

Notations: *e* – grid element (circuit or transformer), t_{lm} – the 100 MW individual transit normalised between lie-line *l* and tie-line *m*, $F_{e(tlm)}$ – flow in the grid element *e* due to the t_{lm} individual transit.

In Fig. 1 it is shown an example of the technique applied to identify the horizontal network between two countries. The main goal is to detect the transmission lines of country "B", that are significant for the cross-border transit of country "A" with three interconnection nodes. When there are *n* x (*n* - 1) transits for each individual part only *n* x (*n* - 1)/2 simulations are considered, since there are overlapping flows in the network (*n* – is the number of tie lines of the country with its neighbouring countries). In this example just three simulations were required to find the elements that belong to the horizontal network.

All transmission lines, which are usually operated, are connected in order to represent the transmission system in normal operation conditions. In the first simulation, a generator unit of 100 MW is placed in the sending end of a cross-border tie-line and a load of 100 MW is located in the receiving end of other interconnection tie-line between the two countries. It is run a power flow using the DC model and the lines influenced by the elementary transit are identified, i.e., the flows between any pair of nodes at the borders of the area.

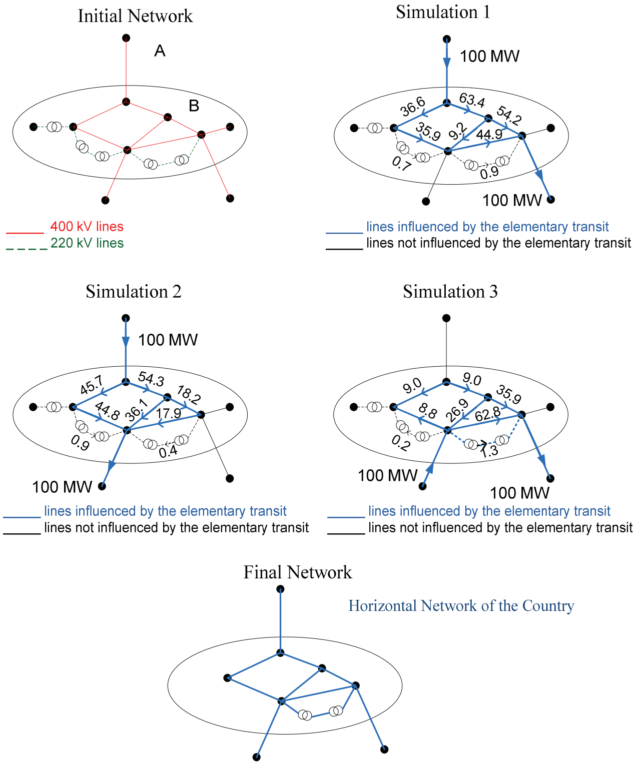

Fig. 1. Horizontal Network example

In simulations 2 and 3, it is performed the same procedure. In each simulation, the transmission lines belonging to the horizontal network are identified with the colour blue, since they have a transit of energy greater than 1 MW. As it is shown in Fig. 1, bringing together all the simulations, thus determines the relevant external network of country "A", represented as a "Final Network". The methodology of the horizontal network, in general, only applies to voltage levels equal to or greater than 220 kV.

For each grid element, the simulations give a list of flows for all the possible individual transits. Only the absolute value of transits is retained. According to the criterion specified in (1), an element is inserted in this list when the maximum value is equal or greater than 1 MW. If the maximum value is lower than 1 MW the element is not a part of the horizontal network, i.e., components with transit flows that are lower than the threshold value are not taken into account, since the line is not influenced by the elementary transit.

Application Example

The proposed methodology was applied to the IEEE 118 bus test power network [16]. This network comprises 118 bus, 194 transmission lines and transformers, 15 fixed shunts, 54 generators and 91 loads. The system was split into two areas labelled country "A" and country "B". The cross-border tie-lies as well as the boundary buses were properly identified and are shown in Table 1.

In order to identify the relevant external network of country "A", the generators, the fixed shunts and loads have been removed from the network, as well as buses and transmission lines, except those that have links with the country "B". All bus voltages were assumed equal to 1 pu.

Table 1. Boundary busbars of the two countries

Country A	Country B
19 – *Lincoln*	34 – *Rockhill*
24 – *Trenton*	70 – *Portsmth*
24 – *Trenton*	72 – *Hillsbro*
30 – *Sorenson*	38 – *Eastlima*
33 – *Haviland*	37 – *Eastlima*

Table 2. Interconnections between Portugal and Spain – Voltage levels

Portugal	Spain	Voltage
Alto Lindoso (SAL)	*Cartelle 1 (ECTL1)*	400 kV
Alto Lindoso (SAL)	*Cartelle 2 (ECTL2)*	400kV
Lagoaça (SLGC)	*Aldeadávila (CAAE)*	400 kV
Falagueira (SFR)	*Cedillo(CCIE)*	400 kV
Alqueva (SAV)	*Brovales (EBVL)*	400 kV
Pocinho (SPN)	*Aldeadávila 1 (CAAE1)*	220 kV
Pocinho (SPN)	*Aldeadávila 2 (CAAE2)*	220 kV
Pocinho (SPN)	*Saucelle (CSLE)*	220 kV

It was also studied the Iberian systems in order to identify the transmission lines of the Spanish grid that are relevant for the Portuguese power network. Presently, there are eight cross-border tie-lines in the Iberian network with voltage levels from 130 kV to 400 kV. With a new tie-line between Portugal and Spain, in 2011, in the Douro International area, it is essential to understand how the National Transmission Grid will be affected. It is expected that the reinforcement of electricity interconnections between the two countries improves the security and competitiveness of domestic energy supply. The network analyzed has eight interconnections between Portugal and Spain that include already the new interconnection between Lagoaça (Portugal) and Aldeadávila (Spain), with a voltage level of 400 kV. These interconnections are shown in Table 2.

Results

In the IEEE 118 bus test system five interconnection tie lines were identified, so there are 5 x (5 - 1) = 20 possible transits. Only 10 simulations were performed, since in a given grid element the variation of the flow produced by a transit in one way is equal, in absolute value, to the variation of the flow produced by a transit in the opposite direction.

The power flow study was carried out using the *DC Network Solution and Report* module of the PSS®E software package. The set of transmission lines of country "B" carrying a power greater than or equal to 1 MW was marked. This procedure was repeated until all possible cases were analyzed. It is important to notice that both generator and load are always connected in country "A" [17]. In the first simulation a generator of 100 MW was connected to busbar 19 and a load of 100 MW connected to busbar 24.

The relevant network is obtained based in all simulations. A total of 64 components were identified as part of the horizontal, where all rows with a power flow equal to or greater than 1 MW. In Fig. 2 it is presented the horizontal network of country "B" that is significant for country "A" for the IEEE 118 bus test power network. In this study it was necessary to perform 10 simulations in order to identify the relevant components of the neighbouring network [15]. The relevant network is obtained based in all simulations and contains the elements that have been marked, i.e., those with an elementary transit greater than the threshold value. A set of 13 lines or transformers located in the border area, have a power flow equal to or greater than 50 MW.

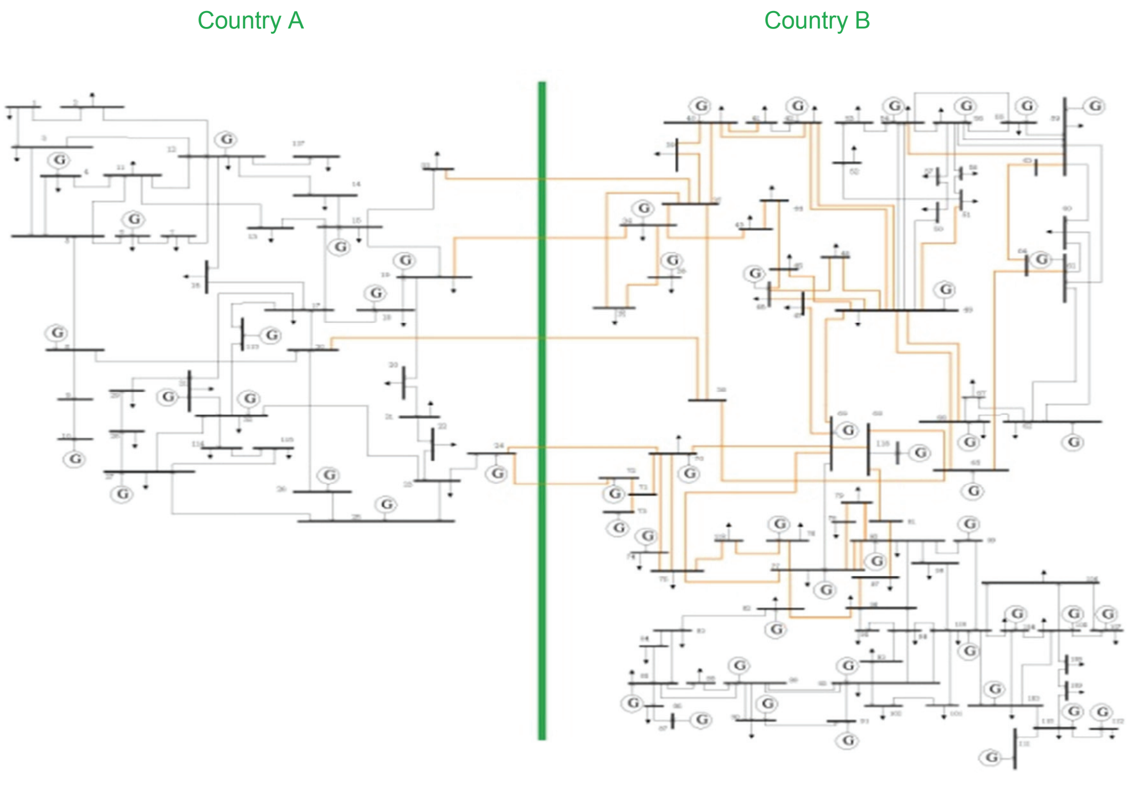

Fig. 2. Horizontal Network for the IEEE 118 busbars test system

In the study of the Iberian network eight interconnections were taken into account, including the new tie line between Portugal and Spain. In this case, there are 8 x (8 - 1) = 56 transits, although only 28 simulations were performed due to overlapping flows in the network.

The power flow study was also performed using the *DC Network Solution and Report* module of the PSS®E program. The results were analyzed and it was assumed that an element belongs to the horizontal network when the elementary transit was greater than or equal to 5 MW, otherwise it was removed, since this is a practical compromise threshold value in order identify the relevant external network [17].

In Table 3 are presented the elements of the horizontal network, which is composed of buses belonging to the Spanish power system. It was considered that only the voltage levels equal or greater than 220 kV were relevant to establish the horizontal network.

Table 3. Elements of the horizontal network

Bus	Voltage [kV]	Bus	Voltage [kV]
CAAE	220	EBVL	400
CAAE	400	EBVN	400
CAZE	400	ECAC	220
CCIE	400	ECHA	220
CORE	220	ECMP	400
CSLE	220	ECON	220
CVLE	220	ECST	220
CVLE	400	ECTL	400
EALM	220	EEAL	220
EALV	220	EFUE	400
EAPR	220	EGAL	400
EBAL	220	EGUI	220
EBAL	400	EGUI	400
EHER	400	ESSR	400
EJMO	400	ETOJ	220
ELLB	220	ETOR	220
ELLB	400	ETOR	400
ELOE	400	ETRI	220
ELRB	400	EVDC	400
EMER	220	EVLE	400
EMOR	400	EVLP	220
EMRL	400	EVPR	220
EMTA	220	EVVC	400
EMTA	400	EZAM	220
EMTS	400	SANE	400
EMUD	400	SGTE	400
EPBI	220	SHJE	400
EPGR	400	SMVE	400
ERIC	220	STVE	400

Fig 3. Relevant network in the area of Pocinho and Lagoaça

Fig 4. Relevant network in the interconnection Falagueira - Cedillo

The cross-border tie lines SAL - ECTL1 and SAL - ECTL2 have no power flow associated, since it is the same interconnection. The same happens in the interconnection SPN - CAAE1 and SPN - CAAE2. In Fig. 3 it is shown, as an example, the relevant network in the areas of Pocinho and Lagoaça, and the Fig. 4 illustrates the area Falagueira - Cedillo. The transmission lines with a voltage level of 220 kV are marked in green whereas the 400 kV lines are marked in red.

Conclusions

In this paper it was presented a methodology to identify the relevant electric power network of a neighbouring country or area, using the horizontal network approach. It was proved that the proposed technique is feasible when applied to a test system, as well as in a real world problem. The horizontal network is the part of a transmission system, which is used to transfer electricity between countries. It contains all those transmission system elements that are significantly influenced by cross-border exchanges. The use of the horizontal network methodology is relatively simple, easy to understand and implement, speeds up considerably the evaluation of the relevant neighbouring power systems for each scenario and enables an acceptable simulation time.

In the case of the IEEE 118 bus test power network, it was assumed a set of five interconnections between two areas, which were used to simulate the interconnection among two countries. The horizontal network of country "A" is composed of 45 nodes of country "B" and, as it was expected, most of the buses are in the border zone.

In the case of the Iberian systems the relevant external network of Portugal is composed by 59 elements of the Spanish grid. In the north, the horizontal network extends to Puentes de García Rodríguez, near La Coruna. In the east, the relevant network extends to Madrid and includes the following nodes: Galapagar, Morata, Moraleja Loeches, Villaviciosa and San Sebastian de los Reyes. To the south, the network reaches Guillena. Most of the network identified is located in northwest of Spain, with special relevance to the region of Galicia.

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***Authors**: Patrícia Isabel Domingues dos Santos, M.Sc., Instituto Politécnico de Coimbra, Instituto Superior de Engenharia de Coimbra, Rua Pedro Nunes, Quinta da Nora, 3030-199 Coimbra, Portugal, E-mail: pidsantos1@gmail.com; Rui José Oliveira Nóbrega Pestana, M.Sc., REN – Rede Eléctrica Nacional, Avenida Estados Unidos América 55, 1749-061 Lisboa, Portugal, E-mail: rui.pestana@ren.pt; Coordinator Professor Carlos Manuel Borralho Machado Ferreira, Ph.D., Politécnico de Coimbra, Instituto Superior de Engenharia de Coimbra, Rua Pedro Nunes, Quinta da Nora, 3030-199 Coimbra, Portugal, and INESC Coimbra, Portugal, E-mail: cmacfer@isec.pt; Full Professor. Fernando Pires Maciel Barbosa, Ph.D., Faculdade de Engenharia da Universidade do Porto and INESC Porto, Portugal, Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal, E-mail: fmb@fe.up.pt.*