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Bulk indices for transmission grids flexibility assessment in electricity market: A real application

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ABSTRACT

The present paper reviews the concept of flexibility for an application to power systems for operational planning of transmission grid in market environment. The background that makes useful the application of the flexibility notion to power systems is explained. Some general definitions concerning the concept of flexibility in more recent scientific literature are reported. A specific and unique definition of transmission system flexibility in respect of the generation changes is proposed. The mathematical model and the calculation methodology of some bulk system flexibility indices are presented. A dedicated tool in Matlab for their computation is briefly shown in its features. The tool is owned by the Italian Transmission System Operator (TERNA) and is in testing for the flexibility evaluation of parts of the Italian National Transmission Grid. An application of the procedure to a real case is presented and the main results are discussed with the aim of test the validity of the proposed indices.

1. Background

In the last twenty years, many important changes involved the electricity industry each of which has had a significant impact on the transmission system (TS) and generation system (GS) planning and operation.

First of all, the process of deregulation has introduced the electricity markets: a few large vertically integrated utilities operating the bulk system (generation and transmission) have been replaced by many individual profit-maximizing companies, that manage the generation power plants. The power generated is transmitted on a grid operated by an independent Transmission System Operator (TSO). Therefore in competitive markets, transmission and generation decisions are not made simultaneously by the same entity. This separation increases the uncertainty in transmission planning and operation.

Secondly, the increasing volume of international trade among the different electricity markets (e.g. in Europe) involved in a growth of transmission capacity since increases the power that has to be transported across each country. This process is still in progress and it has increased the set of uncertainties in transmission planning and operation due to the necessity to include prices and political developments in all the countries.

Finally, the warning about climate change has shown the way to enlarge the use of renewable sources for the electricity generation. On the other hand, the renewables power plants are more irregular and more scattered on the territory than the conventional ones.

All the three changes regarding the electricity industry are ongoing and will become more and more important in the next future years. Hence a different framework for transmission planning and operation has to be drawn.

In this context, the TS has a key role influencing the degree of competition of the electricity markets, as well as the overall system economy and reliability. Therefore, the role of a TSO becomes fundamental: it has to provide a non-discriminatory access to all the market participants, maintaining a right level of reliability. This aim is achievable only by a well-defined and more complex bulk system planning and management process. The TSO has to be able to manage the greater degree of uncertainty introduced by the recent changes within every time-horizon, for problems ranging from long-term power system and energy resources planning to short-term operational planning.

For these reasons, nowadays well-timed and efficient investments in the bulk system that can increase the ability to accurately manage different uncertainties (dealing with generation and load expansion, generation costs, facilities availability, wheeling transactions and market policies) are subject of significant research interest [1–5]. In particular in [1] a general framework to study

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Nomenclature

BuSFI	Bulk System Flexibility Index
DCLF	Direct Current Load Flow
GS	Generation system
MILP	Mixed Integer Linear Programming
INTS	Italian National Transmission System
RAMS	Reliability, Availability, Maintainability and Safety
TS	Transmission system
TSO	Transmission System Operator

transmission investments is proposed, in [2] a problem of multi-stage and coordinated planning of transmission planning is solved by means of a genetic algorithm, in [3] a decision-analysis approach for transmission planning based on net benefits is evaluated, in [4] transmission network expansion plans are evaluated minimizing a specific cost function and in [5] is analyzed the transmission planning in deregulated market considering operation cost, load curtailment cost and investment cost. In a worldwide context, regulatory authorities for electricity industry have drawn up some guidelines and rules as support to power system planning and operation, but these guidelines do not include information about specific models and related software tools [6,7]. In particular there is no general rule about:

– Definition of objective functions or attributes used to measure the goodness of each solution.
– Definition of maximum uncertainty level (particularly with respect to generation expansion and change) that has to be considered.
– Integration of investment analysis and financing decision.
– Review of Reliability, Availability, Maintainability and Safety (RAMS) criteria and their economic consequences.

The international literature proposes new market-based criteria, probabilistic tools and approaches, generally based on the resolution of optimization problems. Each optimal planning entails determining *ex-ante* the right type, location, capacity, and timing of measures in order to deliver maximal social welfare over the reference period, while maintaining adequate reliability levels.

In this framework, an attribute for the planning of electrical bulk systems in market environment on different time horizon (from the long to the operational) has been proposed in literature and became an important topic in power system studies. It is called "*flexibility*".

2. Flexibility definitions for power systems

The concept of flexibility was first proposed in industry design: flexibility in process systems refers to the ability of the system to reach a high level of performance also in presence of uncertain factors, for given design parameters. The optimization of the flexibility of an industrial process aims at reducing the negative effects on system efficiency caused by uncertain parameters [8]. Moreover, flexibility is a notion that must be related to, it can only be defined within specific problem formulation. A single and general-purpose measure of flexibility does not make sense.

Flexibility in power systems is wherever similar to flexibility in process systems: both of them deal with the ability of response and control parameter variations. However, relevant differences between them subsist: they are completely different for system structure, operation mechanism and management mode. For example, for safety and reliability standards in power systems, the uncertainty of operation parameters is much smaller than that in process systems.

Researches on flexibility analysis in power systems are not so widespread and they differ generally for a main aspect: the reference definition of flexibility.

Definitions of the power systems flexibility can be:

– Power system flexibility in reference to economic performance, defined as "*the ability to adapt to a wide range of possible demand conditions in the short run at little additional cost*" [9].
– Power system flexibility in reference to flexible plan, defined as "*one that enables the utility to quickly and inexpensively change the system configuration or operation in response to varying market and regulatory conditions*" [8–12].

In [9] a new metric is proposed to measure power system flexibility for use in long-term planning. It is derived from traditional generation adequacy metrics. In [10] the authors propose a stochastic two-stage modelling approach to capture the multistage nature of the electricity transmission planning problem and apply it to a stylised representation of the Great Britain (GB) transmission network. The paper [11] reviews the notion of flexibility and applies it to the problem of power system adequacy of supply and reserve computations in the face of a class of input uncertainties. In [12] an expansion planning approach aimed to increase flexibility by means of distributed generation is analyzed.

However the definitions of flexibility introduced are complementary concepts of adaptability (i.e. changing to accommodate new conditions) and robustness (i.e. satisfying all conditions in advance).

The most general definition of flexibility applied to the power systems that can be found in literature is: "the ability to adapt the planned development of the transmission system, quickly and at a reasonable cost, to any change, foreseen or not, in the conditions that were considered at the time it was planned" [13].

From this general standard definition, a more specific meaning of flexibility has to be extracted, since many parameters (such as generation capacity, system topology and load distribution) can affect the flexibility so defined. They can have different effects on the power systems operation in function of the time-horizon of the planning. Therefore it is necessary to define:

– The time-horizon of the power systems planning, that defines the type of the uncertainties that can occur into the power systems.
– Which of the uncertainties that are involved in the chosen time-horizon have to be considered for the evaluation of the power systems flexibility.

Both the choices depend on the task of the application.

In the present paper the authors propose a methodology able to evaluate the flexibility of the TS in respect of GS that can be an useful instrument for the operational planning of Highly Developed Power Systems (HDPS) operating in electricity market, such as the Italian National Transmission System (INTS).

In fact for HDPS, TSO needs to guarantee a certain level of flexibility that is affected by different issues: