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# Line overload alleviation through corrective control in presence of wind energy

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ABSTRACT

With the growth of wind energy for power generation, several transmission system operators (TSOs) have increasing difficulties to forecast congestions due to the unpredictable nature of the energy source. This paper proposes to enhance congestion management using a real time supervisor. This supervisor performs automatic and dynamic re-dispatchings using both variable speed wind generators and conventional generators. In order to minimize production constraints, the real time congestion management system is based on an indicator of the efficiency of a re-dispatching on the power flowing in an overloaded line. This approach leads to reduced re-dispatching costs and increased network reliability. The simulation of the IEEE 14-bus test power system enhanced by the supervision system is done using the software "EUROSTAG". Grid integration of renewable generation is therefore increased through renewable production maximization while ensuring network security.


## 1. Introduction

For several years, global warming has become a world priority. One of the solutions proposed to solve this problem is to increase the use of renewable energy for power generation. However, the integration of such a production in the present grid is not always easy as this grid was not originally designed to accept this type of production. In many countries, the transmission system operators (TSOs) expect an increase of line congestion in rural areas due to the important increase of wind generation [1]. In order to maintain the state of the system within acceptable and secure operating conditions, operators must apply preventive or emergency/corrective actions. These can either be actions on the grid topology and/or on the generation outputs.

Actions on topology range from bus couplers switching and transformer tap changing to adjustment of phase shifter. However, in weak networks there are very limited available possibilities.

Actions on generation allow the modification of the power flow of an overloaded line as this power flow is affected by a modification of the nodal power injections. However, this modification must not affect the balance between generation and load. Therefore, re-dispatchings, which consist in reducing the injected power at one bus and increasing the generation of the same amount at another bus, are carried out.

A method classically used by TSOs is to manage congestions in planning (e.g. day-ahead) by reduction or disconnection of generation using technical and economical criteria [2]. The difficulty of the day-ahead method is to accurately predict the congestion magnitude and the moment congestion happens. Thus, the main drawback of this approach is a limitation of generation that can be more important than necessary, as precise day-ahead prediction of wind power is impossible. In the literature, other methods are dedicated to congestion management. Sensitivity-based optimum generation rescheduling and/or load shedding schemes are used in [3,4] to alleviate the overload of transmission lines. These methods, based on the computation of an optimal power flow (OPF), are precise approaches for congestion management as long as generation and transmission capacities are well known. Other methods are market-based [5–7] and are also very efficient for congestion elimination as long as two price areas, delimited by the congested elements, can be identified. Furthermore, market-based methods are affected by errors in load and generation prediction due to element outage or random generation such as wind generation.

In real time, congestion management becomes critical and the dispatcher needs to deal with it as quickly as possible using his experience and pre-established decision schemes. Nowadays, this approach is becoming increasingly difficult, due to the strong development of decentralized generation in areas where the network is poorly developed. To ensure a reliable power delivery in the presence of unpredictable generation, this paper proposes to automate corrective actions. In case of congestion, all type of local production will therefore be controlled. Therefore, these actions will indirectly contribute to the development of wind power of local network.

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This paper is divided as follows. Section 2 presents the principle of the automatic corrective control for congestion management. In Section 3, the controllers of the generators are described. A method is provided in Section 4 to set the control loop parameters and a stability analysis is performed. In Section 5, the IEEE 14-bus test power system is used to illustrate automatic corrective control and preventive congestion management. Simulation results using the software “EUROSTAG” [8] are shown to compare present and proposed congestion management in Section 6 and, finally, conclusions are drawn in the last section.

## 2. Principle of the automatic corrective control

The principle of automatic correction control is to use information gathered by the supervisory control and data acquisition system (SCADA) and perform local actions on the output active power of the generation units. Communication is therefore required but must be reduced to a minimum. To do so, the supervisor is divided in two parts as shown in Figs. 1 and 2, the centralized part located near the SCADA unit and the decentralized part located at the generator site.

The goal of the real time supervisor is to find the most effective generators to alleviate an overloaded line and then to mobilize these generators. Grid topology information is used to establish an order of efficiency which is introduced to choose the most effective couple of generators to use to avoid line congestion, while changing production plans as little as possible. In case of line congestion, actions are taken on the generators to reduce power flow in the congested line and to keep the total amount of power generation at the same level to avoid frequency deviation. The congestion management problem can therefore be stated as the selection of the two generators that will carry out the re-dispatching and the definition of the amount of active power to be re-dispatched. In order to perform these actions, an indicator (order of efficiency) which quantifies the effect of re-dispatchings on congestion is used.

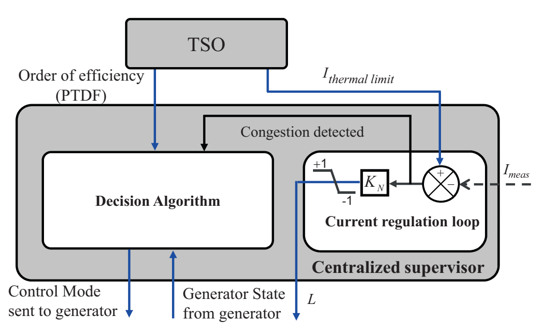


**Fig. 1.** Centralized supervisor structure.

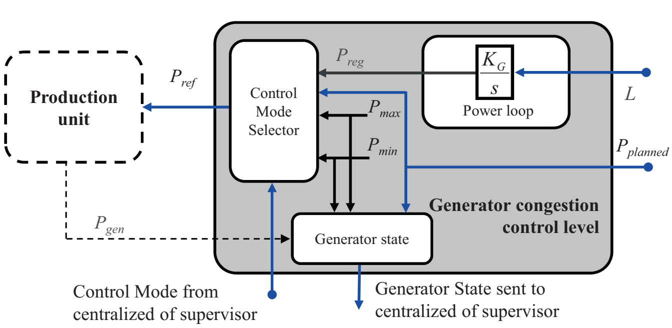


**Fig. 2.** Generator control for congestion management.

### 2.1. Order of efficiency

This indicator is related to the well known power transfer distribution factor (PTDF) [9,10]. As PTDF magnitudes depend on the topology, on the parameters of the power system and are weakly dependent on the working point [11], direct current (DC) load flow equations are used for the computation of the PTDF. From these equations, the power variation at all nodes, around a working point, is given by (1):

$$\Delta Pn = B\Delta\theta \quad \text{where} \quad B = A^T B' A$$
$$\text{with} \left\{ \begin{array}{ll} A^T = & [a_1, a_2, \cdots, a_L]^T \\ a_l^T = & [0\cdots0 \;\; \overset{i}{1} \;\; 0\cdots0 \;\; \overset{j}{-1} \;\; 0\cdots0]^T \end{array} \right\} \tag{1}$$

where the element $\Delta pn_i$ of the vector $\Delta Pn$ is the active power variation at node $i$, the element $\Delta\theta_i$ is the voltage angle variation at node $i$, $B'$ is the diagonal branch susceptance matrix and $A$ is the branch-to-node incidence matrix with $a_l$ as row $l$. Using a similar approach, the active power variation in all lines is given by (2):

$$\Delta Pl = B' A \Delta\theta \tag{2}$$

where the element $\Delta pl_l$ of the vector $\Delta Pl$ is the active power variation in line $l$. Using (1) and (2), (3) can be obtained:

$$\Delta Pl = B' A B^{-1} \Delta Pn = C\Delta Pn \tag{3}$$

where the element $c_{l,(i,SB)}$ of the matrix $C$ is the PTDF of line $l$ for an active power variation between node $i$ and the reference node $(SB)$ of the DC load flow [11]. Finally, the PTDF of line $l$ for an active power variation between node $i$ and node $j$ is given by (4):

$$\begin{aligned} F_{l,(i,j)} &= c_{l,(i,SB)} + c_{l,(SB,j)} \\ &= c_{l,(i,SB)} - c_{l,(j,SB)} = \frac{\Delta pl_{l,(i,SB)}}{\Delta pn_i} - \frac{\Delta pl_{l,(j,SB)}}{\Delta pn_j} \end{aligned} \tag{4}$$

where $\Delta pl_{l,(i,SB)}$ (resp. $\Delta pl_{l,(j,SB)}$) is the active power variation in line $l$ due to the active power variation at node $i$ (resp. node $j$) and the reference node $(SB)$. The re-dispatching power between nodes $i$ and $j$, called $\Delta P_{redispatch(i,j)}$, is then equal to $\Delta pn_i$ and $-\Delta pn_j$, so the PTDF in the context of our study can be summarized through Eq. (5).

$$PTDF_{l,(i,j)}(\%) = \frac{\Delta pl_l}{\Delta P_{redispatch(i,j)}} \tag{5}$$

Eq. (5) shows that the same quantity of re-dispatched power via two different couples of units does not have the same effect on the overloaded line. This depends on the location of the power units. The PTDF magnitude will be used to order re-dispatchings according to their effectiveness to alleviate overloaded lines. This defines the order of efficiency.

The re-dispatching which is number 1 in the order of efficiency, for an overloaded line $l$, is to be selected. This order of efficiency is used to define the structure of a decision algorithm.

### 2.2. Decision algorithm

The decision algorithm, that selects which generation is to be re-dispatched, is based on a particular type of Petri nets called STATEFLOW [12,13]. It is located in the centralized part of the supervisor shown in Fig. 1. Fig. 3 shows the principle of a STATEFLOW. For each state $(x)$ is associated a set of operating modes that represents the output of the algorithm. The transition variable $(t)$ allows the passage between two states.

The input events are the transitions which can either be a detection of congestion or a modification of generator availability for congestion management. This availability is called the generator state.