Congestion Management:
The System Operators Challenge to Balance Transmission Transfer Capacity with an Acceptable Security Level

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1.0 Introduction

The JWG C2/C5-05 has its main working area within the changes the system operators (SO) face in the changing liberalised market environment [1]. System Operators must operate the system in a more "market compatible manner" without security risks. Two important tasks of the SOs are to provide transfer capacity to facilitate the market and to maintain an appropriate security level. After liberalisation the focus has very much been to get a well-functioning market and to increase flexibility by adding new functions to existing markets as well as to establish more global markets. This trend has caused a steadily increasing need for transfer capacity. However, the transmission system was designed under another organisation and was not dimensioned for the increased inter-area and cross-border transfer. The limited system expansions over the last decade have caused the power system to steadily operate closer to the limits. Recent blackouts in 2003 have shown the vulnerability of the system to wide-spread disturbances due to minor initiating incidents. The system security has again become a focused topic and will compete to a larger extent with the focus on market integration. These two focuses will in most cases be two conflicting aspects and a trade off has to be made.

The C2/C5-05 has earlier published papers related to cross-border congestion management [2]. This paper gave some examples and compared international practises. A paper has also been published on justification of operating standards [3]. These standards are an important item in the discussion of acceptable security levels and operating procedures.

2.0 Market actors versus System Operators needs

As mentioned two important task of the SOs are to provide transfer capacity to facilitate the market and to maintain the security of the system. Enough capacity available will increase competition and ensure effective use of the resources in the system as well as in neighbouring systems. Any active limitation will reduce market possibilities for market actors, reduce competition and possibly introduce opportunities for market power abuse in smaller regions.

The market actors perspective

From the market actors point of view, it is desirable to be able to trade with any other actor in any system and to rapidly react to changed market conditions. In cases with limited transmission capacity, knowledge about the actual transfer capacity and consequences for own decisions are required. Such information should be simple enough to be understood without too detailed knowledge about the dependence and interactions between the transmission corridors. From a competition point of view it is also desirable to give as little information as possible of trading strategies. Short time between scheduling decisions and implementation may be desirable.

The SOs perspective

The SOs define the available transfer capacity between regions before the market operators (MO) calculate the balance prices and exchange volumes. The given transfer capacities will therefore impact the output from the activities of the MO. The SOs are constantly under pressure to give as much transfer capacity as possible. Since the transfer limit calculations directly affects the market actors, the SOs are to a larger extent requested to justify any limits. Different flow conditions may cause different system phenomena to be limiting even on the same set of lines. The different transfer limits will vary and for an overall system optimisation the set of limits can not be calculated accurately in advance. With heavy power transfer between neighbouring control areas, the consequences of incidents are more wide-spread. System wide information is needed for transfer limit calculation and information exchange between SOs are very important for the quality of the results.

The market actors versus SO perspectives

In the restructured environment, there are increasing market actor demands for better power system security and quality. On the other hand, market actors also demand an increase in the power system limits and transfer capacities. These demands work in opposite directions. Market actors will ultimately be provided with the electric energy security and quality they can afford to pay. Moreover for all electric energy players, there has been a tendency to use the resources available to the maximum and operate closer to power system limits. This is why balancing market actors versus SO perspectives has become a major challenge involving regulators, market actors, system operators, generation/transmission/distribution companies, end consumers and also governments.

3.0 The power system security

Generally power system reliability consists of *adequacy* and *security*. This paper only considers the security aspect of the system operation. Power system security is a very complex topic involving dynamics of different time scales and phenomena. The increased utilisation of the inter-area connections has also made it necessary to analyse larger geographical areas since the impact of a disturbance may have widespread consequences. Large system models again calls for increased information flow from neighbouring systems and better tools for analysis and decision support.

In some cases the maximum exchange capacity must be published in advance in order to allow long-term contracts, and at the time of the publication of the capacities, it is very difficult to forecast the future flows. However, when the transfer capacity is given, it must also be maintained in the day ahead and the intra day markets.

3.1 Security levels

There has been a move from the use of conservative criteria, such as deterministic (N-2), to more balance the risk by increased utilization with possible expenses.

N-1 combined with lists of dependent contingencies has been viewed as minimum security margins. It is now common to at least filter these absolute criterions with the probability of occurrence. As also very unlikely cases show up occasionally, it will increase the overall risk in the system operation.

3.2 Correctively or preventively secure

Clear strategies and responsibilities in case of emergency situations will reduce the possibilities of wide-spread disturbances significantly. The benefits obtained due to increased trading capacity, may be very large by moving from a preventively secure to a correctable secure operation.

One way of relaxing the traditional deterministic criteria, is to carefully evaluate the consequences if the situation should occur in real time. Such evaluations will normally be to limit the overload to a level that gives the operator some time to intervene and to have prepared strategies of how to handle the case. For exchanges between markets it is very important to resolve these problems without a reduction of the allocated trade.

Alternatively, automatic remedies could be implemented that react on specified situations, like instantaneous demand management schemes combined with secondary control actions.

4.0 Congestion Management Principles and Methods

Congestion occurs when the demand for transmission capacity exceeds the available transmission network capabilities. Every power system will from time to time experience this situation. It is not economical to invest to a level where all constraints are eliminated.

The principles for congestion management in a country or a wider area are based on the legislation and regulation in place. An increased focus towards handling of congestions has developed over recent years. In Europe the EU Directive 2003/54/EC and the Regulation 1228/2003/EC draw up the basic principles for congestion management throughout Europe. Guidelines are being developed to detail the principles. Only market based methods for congestion management will be accepted in the future.

The chosen approach for congestion management will impact the possibility and incentive to utilize the transmission network. There are a few but important requirements to congestions management methods as: fair and non-discriminatory, economically efficient, transparent, feasible and compatible with different types of trades.

The currently used methods will to different extent fulfil these requirements, but it is important to realize that systems have different structure and by this technical challenges. From the feasibility point of view, the methods will be different. The market design will also be important for which kind of method that best suits a particular system.

From a competition point of view, the best principles are the ones that lump larger areas into a single one with simple rules of how to deal with constraints. Technical challenges may give preference to more network based methods where individual node prices can be used. It is not possible to state that one method is superior to the others. It is more a question of how it is necessary to prioritize between the general requirements of congestion management methods given specific systems. Giving priority to some specific features will often make it necessary to come up with countermeasures for the requirements not that well covered.

Congestion management methods can have different goals. Before the operating hour, it be hours, days, weeks or months, the goal may be to optimally allocate available capacity among market parties. In real time the goal may be to deal with congestions occurring during operation.

Congestion management methods can be divided into different sub-categories. It can be methods for handling congestions between areas (inter area) or it can handle congestions within an area (intra area). Market based or not market based is another subdivision. Finally it should be divided between methods used to allocate capacity up to the capacity limit (allocation methods) and methods used to alleviate the transmission network down to the capacity limit (alleviation methods).

Priority based rules, such as first come first served, and pro-rata rationing are allocation based and non market based methods.

Explicit and implicit auctions are the favoured methods by the European Union. They are market and allocation based methods. Market splitting and market coupling are special cases of implicit auctions. In an implicit auction energy and capacity are traded at the same time. In an explicit auction only transmission capacity is traded.

Locational Marginal Pricing (LMP) is similar to implicit auction since both methods consider both energy and capacity. But LMP is basically the backbone of a market organisation with central bid based dispatch.

Examples of alleviation methods are counter trading, re-dispatching, coordinated re-dispatching and transmission loading relief (TLR).

4.1 Market splitting

The market splitting is an implicit auction where the capacity is traded simultaneously with the energy. In cases with congestions, the markets are split into two or more price areas. Each price area is then balanced while fully utilizing the transfer capacities between the areas. As stated earlier, larger areas with uniform prices are important for the competition and the market splitting approach has therefore many advantages from this point of view.

Market splitting is applied in the Nordic market and some of the designs used there will be described and discussed for illustration purposes. The steps are:

- The whole market area is divided into smaller bidding areas, mainly defined along the structural bottlenecks.
- The TSOs calculate transfer capacities and all capacity for each hour is allocated to the power exchange for trade in the day-ahead market. Information on capacities are given to the market every morning.
- Market actors can then submit bids in a bidding area. Bids must be in balance in each area.
- Market clearing is performed for each hour by the latest 2 am the day ahead of operation. First an un-congested market clearing is performed for the whole market. Flows between areas are checked against available capacity. If there are any violations, the market is split in two areas and separate clearing is done in each area. This iteration process continues until all transfers are within capacity limits. All market actors will be compensated and charged according to the market prices in the area they are located.
- The market actors' obligations within each price area are then the basis for a detailed planning of the generation and loads. These detailed schedules are submitted to the

TSO and will be the basis for calculating deviations from the schedules and need for secondary control.

The market splitting method requires a centralised market operator that combines the bids in a market clearing procedure. As mentioned the market splitting enhances the competition due to relatively many market actors within the same price areas. The implicit auction principle also guarantees that the capacity is made available to the market participants in a non-discriminatory way since no single market actor can reserve the capacity for own use. In a case of congestion all the market actors can readily see the effect, since the energy price will rise in the deficit area. This gives the right incentive to market actors on both sides of the congestion. The price in an area also reflects the value of the electricity for the market actors. Congestion between the areas will generate a congestion rent to the TSOs. According to EU Directive the congestion rent can only be used for transmission investments, reduced tariffs or counter-trade.

In the market splitting method the central load dispatch has been replaced by market forces. This gives as result a system where generation and load are in balance in the planning phase. During the operating hour there is a decentralised dispatch where the generators follow their schedules. The System Operators will take care of the imbalances occurring after the planning by using the balancing market.

4.2 Locational marginal prices (LMP)

Other more physical network models, for example LMP, make it possible to some extent to operate closer to the limit. The LMP takes into account that inter area transactions may have different impact on the flow on congested transmission lines between those areas as well as on loop flows. This impact on the network flow is the reason for possible enhanced utilization of the transmission system. As long as the prices can be different on all nodes, it is in principle possible to find a power flow that gives the overall optimal solution and utilizes the transmission system as good as possible based on the bid curves. This requires however that all technical and economical details to run an optimal power flow are available when the SO is performing central dispatch.

There are different types of transactions where some are firm and may have transfer rights while others are more of opportunistic character. It is important to account for these differences when congestion management schemes are developed. In the follow description and discussion, the scheme developed by PJM and MISO will used as an example [4]. The purpose of the scheme (CM Process) was to balance system security with a market-sensitive usage of PJM's available transfer capability.

The cornerstone of *CM Process* is the delineation between energy flows associated with serving 'firm' load; and other energy flows associated with commercial activity. Firm flows are defined as those flows that would occur to serve only customer loads and those transactions that have Firm Transmission Rights (FTR). What is left over would be opportunistic transactions that do not have Firm transmission Rights. This approach allows those with firm FTRs to be secure that their respective transactions will flow; and those without FTRs can still make use of the system as subject to the requirement that there are no actual transfer problems. As long as the actual tie line flows are within the agreed transfer limit, then there is no reason to preclude additional transactions.

In an LMP-based system the bus prices will reflect which resources are more financially attractive and which resources are not. As long as the Market price shifts keep the flows within the transfer limits, the opportunistic transactions continue. When the normal market-prices are not sufficient to control the flows, then the opportunistic transactions would be curtailed. This approach allows SO to let transactions continue as long as the market players are willing to pay the energy costs caused by redispatching the system. The LMP will diverge until the flows are appropriately reduced.

Another benefit is that the transfers are based on real time flows and not on predicted flows. This approach increases both reliability (in the case where conditions adversely impact the transfer limits) and commerce (in the case where conditions support additional interchange.) The use of the simplified Interconnection Model provides a recognition that in a meshed interconnection transactions themselves are neither good nor bad, it is the effects of the transactions that help or hurt and those effects are a result of more than just the owner-area of the point of delivery and point of receipt of the respective transaction.

4.3 Flow-based market coupling

Flow-based market coupling is an implicit auction similar to market splitting but performed in opposite order. First each sub-market is cleared, and then these markets are coupled. In this section, particular emphasis will be given to the new method called Flow-based Market Coupling jointly proposed by ETSO (European Transmission System Operators) and Europex (European Power Exchanges). It is a mixture of a "flow based modelling" and a "Decentralised Market Coupling". A "flow based modelling" considers the physical flows that can be exchanged between different electric systems taking into account the mutual influence of the exchanges. A "Decentralised Market Coupling" is a method to execute a coordinated market among different markets, using their own market rules in each area. This method is still under development but is likely to become an important solution in Europe.

A simplification must be made, considering that a joint system can be operated as a number of single-price regions, connected with the other regions by notional transmission circuits. The real flow between different nodes is modelled by flow factors and the limits between nodes are calculated taking into account the influence of the bottleneck capacities on the cross-border inter-connectors. Market coupling is based on the assumption that a day-ahead market exists in each region.

Bottleneck capacities and flow factors are estimated and published in advance to inform users and updated before operation of the day-ahead market. This information is required by the day-ahead markets to describe the state of the simplified transmission model used for flow-based market coupling.

Users have the possibility to submit bids and offers to the regional day-ahead markets in order to purchase or sell energy in their region. In the same way they also have the option to submit price-difference bids in which they offer to transfer energy between two markets and pay or receive the inter-regional congestion rent. This method allows users to participate for cross-border trade through bilateral-contract or day-ahead access in a non discriminatory manner.

Every market will execute the matching process, firstly without exchanges, and will calculate an import/export curve for every hour, that represents the market price with different quantities of imported or exported energy. Every market executes the process with their own rules. A central module with all import/export curves, considering local prices, and price-different bids, optimises the flows between the regions, subject to the inter-regional transmission constraints represented by the simplified transmission model. Every market with the result (imported/exported energy) will execute its matching process considering imported/exported energy and calculates a new import/export curve, sending the new curves to the central module. Iteration is required between the different areas because of 'block' bids and offers. This sequence is repeated until it converges.

The described method can coexist with several forms of forward market arrangements. This will be needed for those users that want to hedge cross-border price risk (instead of facing the risk in the day-ahead market). It should be done independently from the FMC through forward transmission rights, explicit auctions or electricity financial markets.

Therefore it is not needed to have a single market in a whole area, as it is needed in the market splitting method. The corridors will always be full of energy from the cheapest market to the most expensive one. The only problem that must be resolved is that a production shift in an area is a meshed network to some extent influence the flow on all connections. Therefore, it will be necessary to establish a base case fairly close to the final schedules for the calculated maximum transfer capacities between market areas to be valid.

Market Splitting as well as Market Coupling or FMC of ETSO-Europex proposal, offer more security to the producers since the implicit auction mechanism will ensure congested lines to be fully utilized. On the other hand, explicit auctions of "options" of international exchange flows do not offer the same security to SOs, since the owner of the "options" can decide at the last moment not to use it.

5.0 Conclusions and future outlook

The trend in market development is to have larger areas integrated. Regional markets are established even though the individual sub markets may have differences in rules and regulations. These regional differences should not impede the future evolution and development of larger market areas with harmonized congestion management methods.

Ensuring network security is the responsibility of TSOs. Market operators should be designed in such a way that the TSOs can enable these operations in compliance with network security operation.

Moves to closer regional and wider co-operation raise some legal issues regarding institutional arrangements. Some level of regulatory control is necessary for all key activities affecting congestion management, for example: Capacity calculation, bidding into explicit and implicit auctions, capacity allocation, obligation to provide information and transparency. Transparency is a necessary condition for a well functioning electricity market. It is needed for establishing a level playing field, especially for new entrants, and for market actors for their planning and decisions.

In Europe EU Directive, Regulation and Guidelines state that only market based congestion management methods will be accepted in the future. Present methods are de facto becoming a combination of explicit auctions and implicit auctions. Zonal pricing is also a fundamental choice in the European electricity markets.

Explicit auctions are the minimum requirement for congested interconnections in Europe. The main challenge with the current explicit auctions is a better co-ordination, starting from multilateral co-ordination between the TSOs and developing to a full regional co-ordination.

Implicit auctions target especially the day-ahead and intra-day markets and congested interconnections where price differences change direction. They also have potentially a big positive influence on the liquidity of spot-markets in power exchanges. Finally implicit auctions are expected to enhance the competition in electricity markets because of their efficiency in terms of maximising the use of capacity and mitigating market power.

Flow based market coupling proposes implicit auctions between price areas using power exchanges in a decentralised manner. Implementation of the model requires a high level of coordination. Market coupling also requires a reasonable liquid day-ahead spot-market in all price zones to be coupled. Solving the market price in a complex multi-zone environment is also a computational challenge. Introduction of market coupling needs also institutional arrangements between market actors, work on methods for market settlement and perhaps also changes in regional legislation and regulation.

The LMP requires a central dispatch and may in congested cases give significant differences in the marginal node prices. This is a result of an optimal utilization of the overall market opportunities and the transmission system. The node prices reflect that generation shifts on individual nodes have different impact on the active system constraints. The detailed technical and economical information needed to do a central dispatch will introduce further challenges when expanding markets.

7.0 References

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SUMMARY

The paper discusses the challenges and possible solutions to balance the increasing need of transfer capacity with an acceptable security level. The liberalised market system calls for flexibility in power exchanges to enhance the competition at the same time as there is an increasing need for someone to supervise the overall system operation. Operating the power system closer to technical limits makes it necessary to have efficient methods to deal with cases with insufficient transfer capacity. Major techniques discussed in this paper to handle this are the *Market splitting*, *Locational marginal pricing* and the recently proposed *Flow-based market coupling*. Basic principles, possibilities and limitations of these techniques as well as suitable instruments to mitigate the limitations are addressed. A discussion of which market models these techniques are suitable for, is included. The paper further discusses the aspects related to defining appropriate transfer levels under different security criteria and the possibility to make corrective actions during emergencies. Moving from a preventively secure system operation to a correctable secure operation will significantly increase the transfer capacities and give the market some of the requested capacity, but at some risk for disconnection of loads and components.