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# Congestion Management of Meshed System using Socio-Economic Congestion Cost (SCC)-Case Study

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## Abstract

*In practice, the nature of electrical network is of meshed interconnected type. An application of Price Area Congestion Management (PACM) in radial system is straightforward and simple due to the radial flow of power in the network. In this paper, an alternative methodology has been proposed for the congestion management (CM) in meshed network where, power flow calculations are included. Here, the main purpose of this paper is to present a simulation model which can be used to access alternative method for CM. The two new concepts, Flow-based Market Coupling (FMC) and Socio-economic Congestion Cost (SCC) have been introduced. A simple 4-bus meshed type system has been considered to validate the results with this new concept.*
*Keywords : PACM, FMC, SCC*



## 1. Introduction

In de-regulated environment, out of different issues, CM is one of them without which it affects on the system security1. One of CM technique i.e. PACM is mainly used in Nordic countries where the nature of electric utility is of open access, decentralized market type and where the operations are carried out in day-ahead manner. It is experienced that the application of PACM is very simple in case of radial systems where, the market splitting is very simple and straightforward2. This method has following advantages:

- The day-ahead prices in the total system are calculated simultaneously.
- The price differences between the predefined areas will adjust the power exchange to the available transfer capability (ATC) and reflect the consequences of congested corridors.
- Separate auctions of transfer capacity will not be needed.

However, the present model for calculating the Nordic day ahead prices have some vital limitations, Which should be considered before introduction of the model in the more meshed power system. The main limitations are:

- Lack of, or negative incentives, for investments in the grid because the area price differences will create an income to the Network Owners.
- Non Optimal utilization of the transfer capability in meshed networks because of limitations with regard to network representation in the presently used area price calculation methodology.

Point 1 is discussed in reference3, where the conclusion is that the income from congestions should be paid back to the market players by reduction in the grid tariff which is presently done in Norway and the Socio-economic Congestion Cost caused by lack of transmission capacity should be a real cost for the System Operator by introduction of a congestion penalty.

Point 2 is discussed where an alternative model for calculation of area prices based on optimal power flow calculations is proposed. In both cases minimization of the Socio-economic Congestion Cost is the main objective.

## 2. Market Splitting In Meshed Network

In the radial network it is simple and straightforward to create the price zones or to split the market across congested corridor due to radial topology. But, in case of meshed connected system it is not so obvious or straight that one can split the market by just getting the exhausted corridor3. The main and foremost reason for that is the presence of parallel flows in the meshed network. As shown in the Figure 1 it is clear that in non-radial or meshed connected bid areas it is hard to split the markets across the congested corridor. In figure, line with black dot is congested and market splitting could be done in two possible ways, because of the available parallel paths in the network. So in general strongly meshed connected network it is not possible to go with the market splitting method directly, as it require the sense of optimization in such a way that simultaneously satisfy the all transmission network constraints with maximum utilization of capacity available in the system, which would result in less price differential in the different zones in the system.

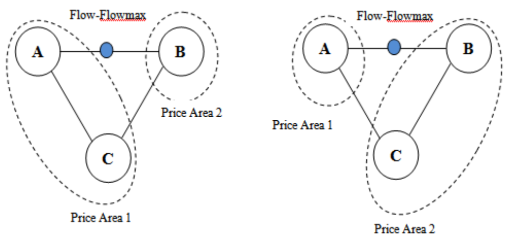


Figure 1: Market splitting in meshed network

In continental Europe there are a number of physical, structural and market obstacles to market splitting in its simple form:

- It is highly meshed network where both the location and capacity of the congested lines change considerably with demand and generation change.
- The net transmission capacities across neighbouring constraints are strongly interdependent and cannot be calculated independently.
- Market participants should be asked for their agreement on the impact of market splitting on the bilateral between congested areas.

## 3. Concept of Flow-Based Market Coupling Model

K. Uhlen et.al 3, proposed an alternative methodology for price area congestion management in the more meshed and complex power system where along with price area calculation load flow calculations are included. A similar concept named as Flow-based market coupling (FMC) was published as a joint ETSO and EuroPEX vision for cross border congestion management and integration of electricity markets across Europe.

This alternative price area congestion management methodology or similar flow based market coupling concept can be seen as compromise between the markets splitting model as used in Nordic market and a nodal pricing approach (DCOPF Based) involving detailed network representation. In this way reducing the system size and hence the cost and time involve in handling those huge size problems would be inevitable by appropriately modelling this mechanism. In the FMC model, similar to the zonal pricing each area is approximated by a node representing a particular bid area determined a priori. 'Market coupling' implies that the information about relation of price and net exchange or net injection in each area or market could be used to settle power exchange also between the markets. In this way several markets can co-exist in a hierarchical structure. Figure 2 and 3 shows the present and new FMC models 4,5.

In liberalized power markets several methods exist to determine the price(s) for electricity on the day-ahead markets for physical delivery (spot market). A main difference between these methods is related to the way, network constraints are taken into account.

An alternative method and a demo model were described4. In the proposed model each area is defined as one node and a network equivalent represents the transmission system. Figure 2 and 3 shows the main difference between the present market splitting model and the new model, which includes the real flow (F) between the areas instead of the net exchange (E).



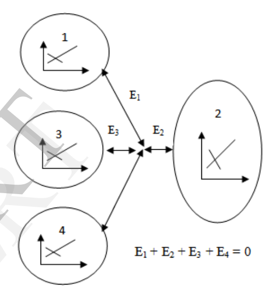


Figure 2: Present model

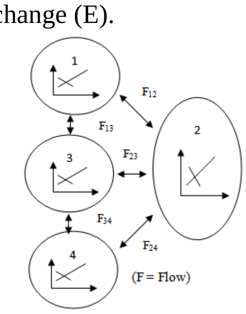


Figure 3: New FMC Model

## 4. Concept of Minimization of Socio-Economic Congestion Cost (SCC) (Dead Weight Loss)

The objective of the model is to find a solution (prices and exchanges or power injections) which minimizes the total operating cost while respecting the transmission limits. In the implemented method Area prices and power transfers or injections are computed using a DC optimal power flow method, where the socio-economic congestion cost is used as optimization criterion. This cost is defined as the cost of not having enough transmission capacity as required by the market, and is proportional to the area price difference and the lack of transmission capacity. The aim of the case studies is to demonstrate main features, e.g. how marginal differences in supply and demand bids in different areas influence congested corridors.

In4 it is shown how the socio-economic congestion cost for the area price model can be calculated as the reduction of producer and consumer surplus (profit) due to the congestion. Some of the market players will gain on congestion in the network and some will lose. The

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area prices should therefore be calculated in a way that provides the lowest congestion cost to society.

The Socio-economic Congestion Cost (SCC) is a function of the reduced transfer capacity (Ered) compared to market requirements and can be approximated with the area of the triangle in Figure 4, where the area prices in each area (Pa, Pb)as function of exchange capacity (E) defines the sides:

$$SCC \approx \frac{1}{2}(P_a - P_b).E_{red} \qquad (1)$$

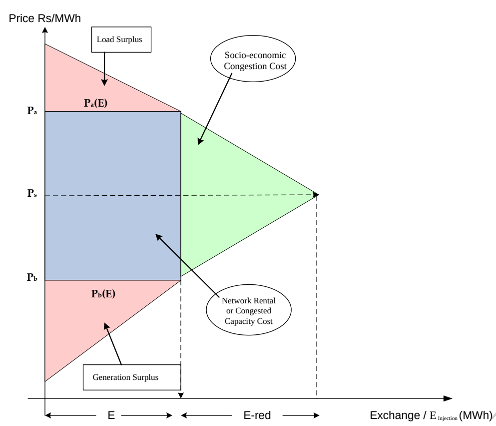


Figure 4: Costs due to congestion (model with 2 area)

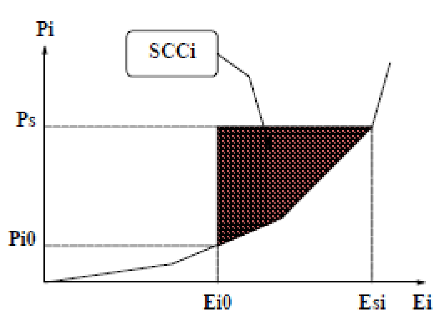


Figure 5: SCC area i. (general model)

The left square in Figure 4 is the Congested Capacity Cost or network rental paid by the market players. This cost creates an income to the network owner, which in the Norwegian case is paid back via grid tariff reduction6.

The graph in Figure 5 is showing the area-price pi in area i as a function of net exchanged power Ei from area i. The Socio economic Congestion Costs for area i is the area SCCi. In figure of Figure 6(a) area is generation surplus area, whereas in Figure 6(b) area is load surplus. As a first approach it can be assumed that the price functions can be approximated with linear functions(y = mx + c):

$$P_i(E_i) \approx \frac{P_s - P_{i0}}{E_{si} - E_{i0}} E_i + c \qquad (2)$$

It can then be shown that for an arbitrary Ei the total Socio-economic Congestion Cost for area i is:

$$SCC_i = \frac{1}{2}\frac{P_s - P_{i0}}{E_{si} - E_{i0}}(E_{si} - E_i)^2 = \frac{1}{2}\frac{\Delta P_i}{\Delta E_i}(E_{si} - E_i)^2 \qquad (3)$$

If, the assumption in Eq. 2 is done for all areas in an N-area model, the total cost function for the system is:

$$SCC_{total} = \frac{1}{2}\sum_{i=1}^{N}\frac{\Delta P_i}{\Delta E_i}(E_{si} - E_i)^2 \qquad (4)$$

$P_{sys}$ = Unconstraint System Price Psys

$E_{sys}(i)$ = Power injection of area i at system price E (i) sys Psys

$E(i)$ = Any arbitrary injection of area i E (i)

$P_0(i)$ = Price in area i at zero injection (MCP as individual) □ □ 0 P i

N = total no. of bid areas

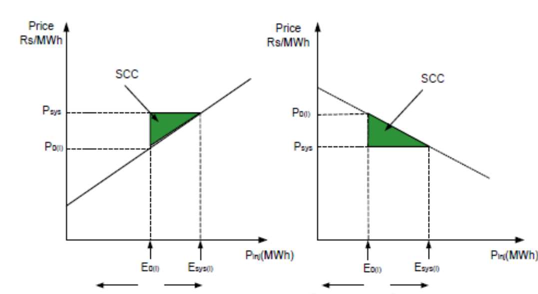


Figure 6: SCC (i) for Gen and Load surplus areas

## 5. Problem Formulation and Mathematical Model

### Methodology and Approach:

A demo version of the model is established. The model meets the following requirements:

- The model combines the area price principle and the nodal principle where each node represents a predefined “Price Area” or a “Bid Area” reflecting network constraints. A Price Area could be identical to a Bid Area or include two or more Bid Areas.

- The network equivalent represents the real power lines or corridors between the areas.
- The Bid Curves are estimated from real curves from Nord Pool
- The criterion of optimisation is minimization of the Socio-economic Congestion Cost.

Optimization Problem Formulation:

The objective function is given by,

$$\mathrm{Min.SCC} = \mathrm{Min}\left(\frac{1}{2}\sum_{i=1}^{N}\frac{P_s - P_{i0}}{E_{si} - E_{i0}}\,(E_{si} - E_i)^2\right)$$

$$= \mathrm{Min}\left(\frac{1}{2}\sum_{i=1}^{N}\frac{\Delta P_i}{\Delta E_i}\,(E_{si} - E_i)^2\right)$$

Subject to the line flows within the limits

## 6. Algorithm And Flowchart:

Following steps are involved in the complete algorithm for price area congestion management in meshed networks:

Step1: Collection of all bids and offers from each bid area and clear the market without any transmission constraint consideration.

Step2: Find out the generator and load dispatches and schedules for individual area with this unconstraint scenario and system MCP.

Step3: Find the injections based upon the selected generator bids and load offers (step2), and thus find out flows at each line.

Step4: Check for each line flow limit violation, if any line limit violates then proceed to next step otherwise stop.

Step5: SCC minimization is done considering all equality and inequality constraints. Find the optimal injections for all bid areas.

Step6: Based upon optimal injections, appropriately impose the virtual load And generation in positive and negative injection area respectively to get the final schedules and dispatches with the individual MCP of the each bid area

Flowchart: Following figure shows the flow chart for the procedure.

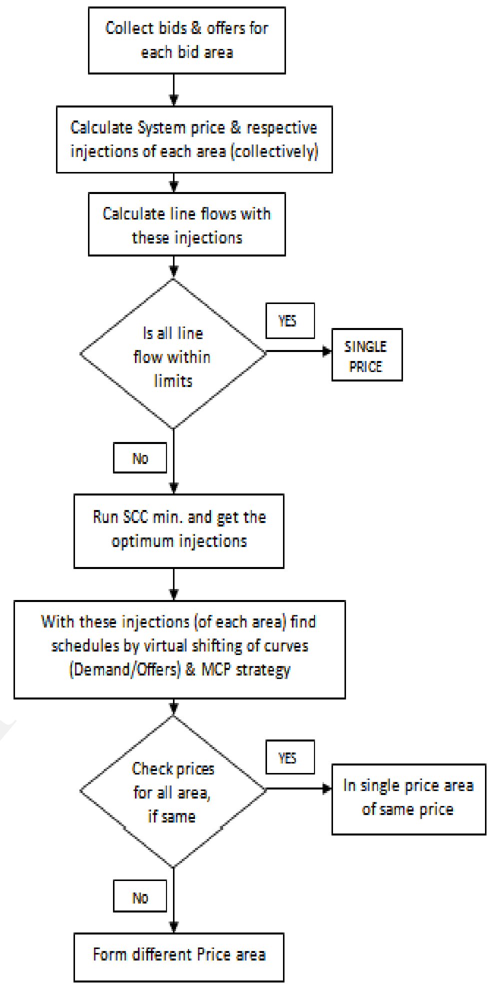


Figure 7: Flowchart of FMC based PACM



## 7. Simulated Results For A Case Study:

Discussed FMC model (for price area congestion management) is implemented in MATLAB using optimization tool. Since the main objective of this implementation was to realize an effective mechanism for meshed connected system, which can make out the market settlement in coupled scenario with respect to the network. Main aim in Price area congestion management is to obtain the schedules for various generators and loads in different area, thus the injections/exchanges in each area and the price. All these were found and validated for the simple 4-Area system with different case studies. A 4-bid area model has been used. In this system, all corridors are AC transmission lines and maximum capacities of each line is shown in the figure, which is taken higher with respect to the bids and offers submitted by the generators and loads respectively. The bids and offers submitted by participants are for an hour block, so 1MW

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power dispatch will be priced as per the 1MWh energy charge.

## 4-Bid Area System (Case Study -1)

In 4-bid area system as shown in Figure 8, there are 6, 5, 10 & 6 generators respectively in area-1 (A1-A6), area-2 (B1-B5), area-3 (C1-C10) and area-4 (D1-D6). Similarly 6 load offers in each area are there (a1-a6), (b1-b6), (c1-c6) & (d1-d6) respectively. Table 1, 2 and 3 are showing generator bids, load offers and line data respectively.

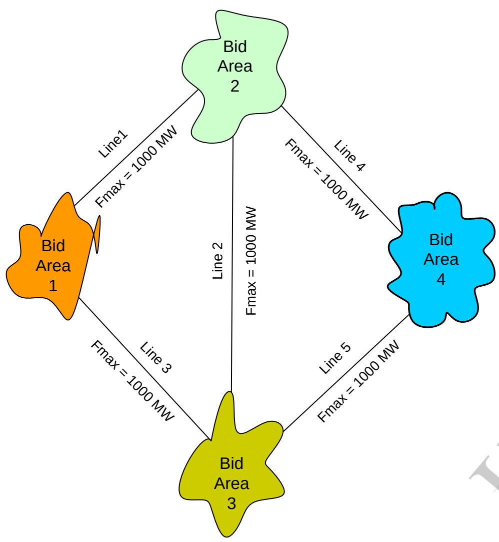


Figure 8: 4-bid area meshed system (case study-1)

Since in this case open limit for the transmission line is taken so no line gets congested. Thus no congestion and hence single price area in which MCP for all areas are same unconstraint market clearing schedules and dispatches results in the tie-line all are shown in Figure 9. Table 4 & 5 are showing selected generator bids and demand offers all other information is shown in the figure 9. Unconstrained MCP is `25/MWh.

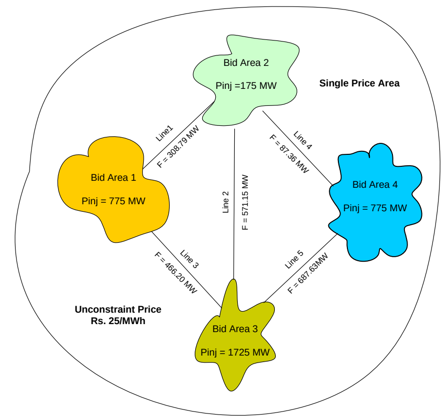


Figure 9: Output of 4-bus unconstrained meshed system

## Bid Area System (Case Study -3)

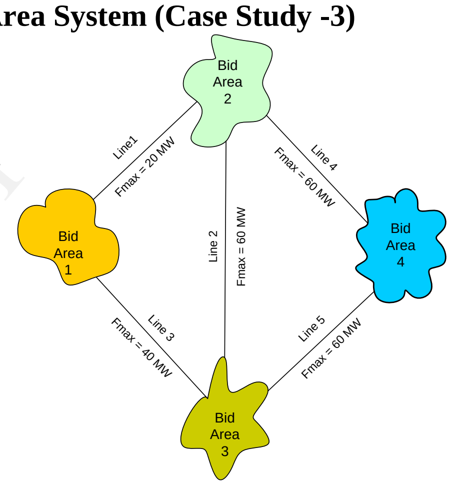


Figure 10: 4-bid area meshed system (case study-3)

Unconstrained MCP is Rs35.80/MWh in this case. And that unconstrained scenario leads to the system in congested situation. So SCC minimization is done which shows the scenario shown in the Fig. 4.11. 3 price areas are formed in which one comprises bid area-3 & 4while bid area-1 & 2 are separate price area. Table 4.10 & 4.11 are showing selected generator bids and demand offers. MCPs for price area formed are Rs34.44/MWh, Rs35.82/MWh and Rs36.28/MWh.

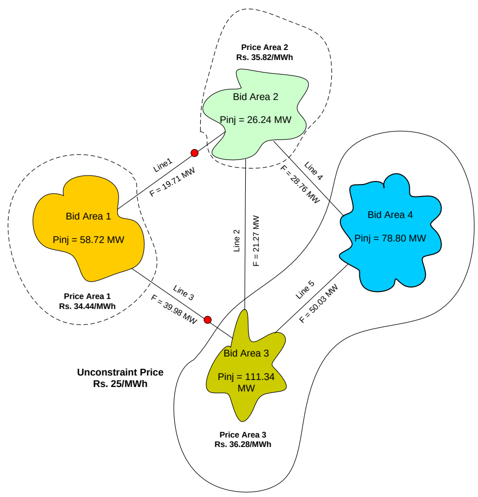


Figure 11: Output of 4-bid area meshed system (case study-3)

Table 1: Selected Generator Bids (Case Study-3)

| Area No. | Bid No. (Identifier) | Quantity (MW) |
|---|---|---|
| 1 | A1 | 2 |
| 1 | A2 | 77.7 |
| 1 | A3 | 51.8 |
| 1 | A4 | 30 |
| 1 | A5 | 16.4 |
| 1 | A6 | 100 |
| 2 | B1 | 2.2 |
| 2 | B2 | 51.9 |
| 2 | B3 | 30 |
| 2 | B4 | 16.5 |
| 2 | B5 | 77.9 |
| 3 | C1 | 30 |
| 3 | C2 | 7.8 |
| 3 | C3 | 13.6 |
| 3 | C4 | 10.7 |
| 3 | C5 | 16.6 |
| 3 | C6 | 5 |
| 3 | C7 | 2.2 |
| 3 | C8 | 0 |
| 3 | C9 | 0 |
| 3 | C10 | 30 |
| 4 | D1 | 2 |
| 4 | D2 | 77.7 |
| 4 | D3 | 51.8 |
| 4 | D4 | 30 |
| 4 | D5 | 16.4 |
| 4 | D6 | 100 |

Table 2: Selected Load Offers (Case Study-3)

| Area No. | Offer No. (Identifier) | Quantity (MW) |
|---|---|---|
| 1 | a1 | 75.1 |
| 1 | a2 | 30 |
| 1 | a3 | 30 |
| 1 | a4 | 30 |
| 1 | a5 | 20 |
| 1 | a6 | 20 |
| 2 | b1 | 75.1 |
| 2 | b2 | 30 |
| 2 | b3 | 30 |
| 2 | b4 | 30 |
| 2 | b5 | 20 |
| 2 | b6 | 20 |
| 3 | c1 | 75.1 |
| 3 | c2 | 30 |
| 3 | c3 | 30 |
| 3 | c4 | 30 |
| 3 | c5 | 20 |
| 3 | c6 | 20 |
| 4 | d1 | 75.1 |
| 4 | d2 | 30 |
| 4 | d3 | 30 |
| 4 | d4 | 30 |
| 4 | d5 | 20 |
| 4 | d6 | 20 |



In this case it has been observed that flows would not always from the cheaper area to high price area in meshed system. As flow is from price area-3 to price area-2 is there which is at lower price than previous one. So it depends upon the network topology as some other flows in the network could impose that to happen.

## 8. Discussion:

After completing all these case studies following very important inferences could be concluded:

- Even if there is a single congestion, but can lead to the formation of more than 2 price areas.
- The price areas will be formed with lower price in the sending end of congested corridor & higher price at the receiving end.
- It is not necessary that power would always flow from the area at lower price to area at higher price. This is on account of constraints put by other lines in an interconnected system.

## 9. Conclusion:

In price area congestion management, market splitting is very efficient for the radial systems, but for meshed networks Flow-based market coupling (FMC) method represents promising alternatives for congestion management in highly meshed decentralized electricity markets. Calculation of power flows are involved in the methodology. But it has got several important advantages over conventional OPF methodology used for nodal pricing. Simplicity, robustness and transparency of the scheme are the key factors. Although choice of power flow modelling, decides the complexity and accuracy of the model in practical scenario.

Flow base market coupling concept is implemented with the DC load flow model. FMC is implemented in MATLAB and different case studies have been done. Results of the case studies show various implications regarding the congestion management in meshed system with basic price area concept.

## 10. References

[1] Kumar, A., Srivastava, S. C. and Singh, S. N., "Congestion management in competitive power market: A bibliographical survey," *Electrical Power System Research Science Direct,* May 2005.

[2] R.D. Christie, B.F. Wollenberg, I. Wangstien, "Transmission management in the deregulated environment", *Proc. IEEE 88* (February (2)) (2000) 170–195

[3] Grande, O. S.; Uhlen, K.; Warland, L.; Solem, G.; Norheim, I., "Alternative model for area price determination in a deregulated power system," *IEEE Conference Paper*, May 2003

[4] Grande O.S., Wangensteen I., " Alternative models for congestion management and pricing". *Impact on network planning and physical operation Paper 37-203, CIGRE 2000, Paris,* August 2000.

[5] Grande, O. S.; Uhlen, K.; Warland, L., "*Model for area price determination and congestion management in joint power markets*," *IEEE Conference Paper*, Oct 2005.

[6] N. Flatabo, G. Doorman, O. S. Grande, H. Randen, I. Wangesteen, "Experience with the Nord Pool Design and Implementation," *IEEE Transaction on Power Systems.* Vol. 18, No. 2, May 2003.

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