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Determining LBMP through Optimal Power Flow in the Electric Power Business

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Abstract

The energy crisis has got the serious attention of experts since the middle19th century. Many efforts with significant progresses has been yielded to obtain its solution, such as technology development and diversification of primary energy sources, but the threat of the energy crisis has not been able to be avoided. Early tahun 1990, attention of experts are focused on energy savings, operating efficiencies and transparency. As a result, they have recommended changing the electric power business of the monopoly system to the market system, competition. In a competitive system, the problems will be more complex, especially in the energy price through optimization. One of the popular energy pricing methods today is LBMP, Locational Based Marginal Price, which has been successfully applied by New York, US. Generally, it is determined through ED, Economic Dispatch, calculations. In this case, Operator must do the complicated adjustments, especially for congestion conditions, so that thier results can be applied to the network. The simulation results, both heavy and light loads, showed that the OPF with step reduction can work well. Comparing with ED has to done some adjustments because a few contraints were out of their limits.

Keywords: *competition, energy price, optimization, step reduction*

1. Introduction

The energy crisis is a serious problem that must be solved, either now and in the future. Technological efforts to improve plant efficiency has been started since the 19th century and reached its culmination after a combined - cycle plant with high efficiency has been found. But the threat of energy shortages persist today, which is caused by the reserves of fossil energy more and more sharply diminishing while demand growth rose sharply in line with population growth and industrial. As a result, the price of energy (fossil) in the future is very difficult to estimate although energy from renewable energy sources has been attempted in the past three decades. Beginning in 1990, experts have focused attention on energy savings, operating efficiencies and transparency, and they suggest a change in the business of electric power from monopoly system to a market system (competition), [1, 2]. Until now many countries that have been successfully running the competition, such as the USA, UK, Australia, etc.

In competition, electric energy pricing is a big issue. In spite of a few methods in determining the energy prices have been widely publicized, such as the method of spot pricing and nodal pricing. Until now, a popular method is LBMP method, [3]; and this method has been tested in practice in the United States; it is used in the electric power business in New York. Under this method, the price of energy depends on the characteristics of the location. However, the determination of LBMP until now, as used by NYISO, still based on EDM. In this method, the loss system is a problem that will be solved separately at a later stage. The other weakness is necessary adjustments again if the results can not be applied to the system because possible occur violations of the constraints, such as a few lines are over flow. Settlement through the adjustment can be ascertained that the results will not fall to the optimal price. This condition will make the situation of unfair competition.

Economic dispatch method used in the determination of LBMP not necessarily be able to work quickly because need the adjustments that can take longer if the results can not be

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applied to the grid. If violations of constraints occur from EDM results, the ISO will make adjustments to the results until they can be received by grid. The other weakness is that problem of losses must be completed separately at a later stage. If the grid is robust (or unlimited), EDM application is better because it is simpler and faster work [4].

In the operation of the power system must meet the conditions of system constraints, bus voltage limit, current limit each line and power limit of each generator. Another thing is losses is a problem that can not be ignored in the electric power business because there is always as naturally, where the amount is about 5%.

The method that can overcome the weaknesses EDM is OPF method. Conventionally, the method is very slow, so it is difficult to implement to market system. But experts have developed this method in order to work more quickly, such as the OPF with step reduction developed by [5] that can work faster (Table 1). This table shows the running time comparison between OPF with step treduction and conventional OPF. Then, this method will be used to determine LBMP to market mechanism as in Figure 1.

Table 1. Running time of OPF

Parameter	Electric Power System				Remarks
Bus Number.	4	15	19	225	
Run Time (scond)	0.01	0.22	0.46	474.29	Step reduction
Run Time (scond)	0.02	0.45	0.88	1153.68	Conventional

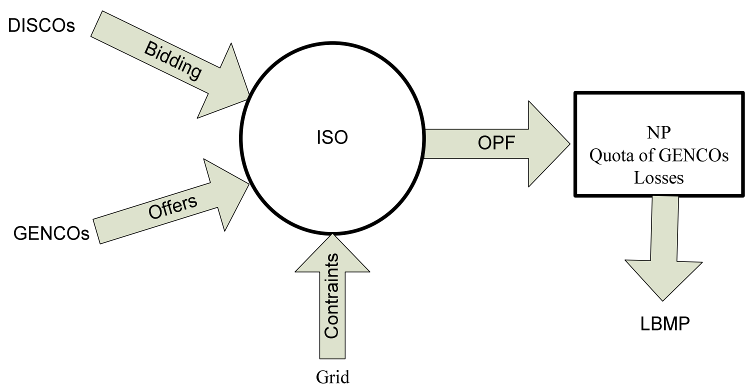

Figure 1. Mekanisme LBMP with OPF

In this mechanism, independent service operator (ISO) runs OPF program after data of energy demands by DISCO, energy-offers by GENCO and grid constraints have been obtained. In this case, the program OPF yields nodal prices (NPs), the quota of generators and losses. Where these results can be ascertained to be applied directly on the system, it is caused by all constraints had met.

To realize this idea, this paper presents a numerical simulation calculation for electric power system that contained in the Figure 2. In this simulation creates two different loads, namely a heavy and a light load. Whereas bidding of each generator deliberately different from one another, either in one location or between locations.

2. Research Method

In the electric power business is not fully follow conventional economic problems because there are something that should be considered, such as losses naturally that can not be ignored and the system is limited (like every Genco is not free to enter the power grid). Due to these problems, we need a method that can resolve completely the problems. This paper proposes a model of determination LBMP that can accommodate demand-supply, losses and limited system. Furthermore, the market mechanism proposed in the Figure 1, which in this paper is used to determine LBMP.

In the Figure 1, every DISCO does energy demand to ISO in the form of power capacity and its energy price. While every GENCO does energy offer to ISO in the form of power capacity and its energy price. Then ISO runs the OPF program to produce NP, Losses of system and generator capacities that are connected to the system. After the OPF results obtained then ditermine LBMP at each location with the following conditions.

a) For the normal case, LBMP is the same at every location and is equal to the highest NP system, that is:

$$\text{LBMP} = \text{NP}_{\text{max system}} \tag{1}$$

b) For the congestion case, LBMP is determined by the value of the highest NP in each location, that is:

$$\text{LBMP} = \text{NP}_{\text{max locatoni}} \tag{2}$$

c) If the location is only composed of DISCO alone or without NP in that location, then LBMP determined by exported power to that location, that is:

$$\text{LBMP}_k = \max\{\text{LBMP}_{ik}, i \in \text{locations that export power to location k}\} \tag{3}$$

Where: LBMP_{ik} is LBMP from location i that exported some power to location k.

d) In case of congestion, having determined LBMP at each location and further congestion cost can be determined, that is:

$$B_c = P_{ij}^{im}(\text{LBMP}_i - \text{LBMP}_j) \tag{4}$$

3. Results and Analysis

3.1. Simulation

Figure 2 is the electric power system that is taken as the numerical simulation to evaluate the proposed method. This system consists of 7 buses with three separate locations. In Location 1 consists of 3 buses (1, 2 and 5), and 3 Gencos connected to Bus 1, 2 and 5. Location 2 consists of 3 buses (3, 4 and 7), and 2 Gencos connected to Bus 4 and 7. Whereas at Location 3 consists of one bus that consist of only load.

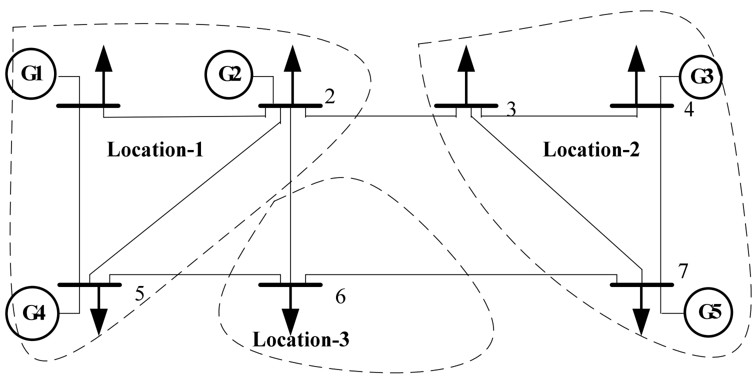

Figure 2. 7 Buses System

Furthermore, Table 2 and 3 contain the data of electric power systems with the basic 100MVA and 20kV. Table 2 contains data that consists of energy offers by GENCO in unit Rp/MWh, and the contrains are the limits of the active and the reactive power. While Table 3 contains the data of each line of grid.

The next step was formed some calculation cases of the electric power system above, namely to simulate the case of congestion and not congestion. The simulation results are described in detail as follows:

Table 2. Offer and Constrain GENCO

No.Bus	GENCO	Offer (Rp/MWh)	P (pu)	Q (pu)	Location
1	G1	9.6	0.30<P<1.30	-1.80<Q<1.80	1
2	G2	15.3	0.20<P<1.20	-1.25<Q<1.25	1
4	G4	8.8	0.25<P<1.80	-1.03<Q<1.50	2
5	G5	5.3	0.20<P<0.60	-1.25<Q<1.25	1
7	G7	10.5	0.25<P<1.60	-1.50<Q<1.50	2

Table 3. Line Data

From i	To j	R (pu)	X (pu)	Y (pu)	S_{max} (pu)
1	2	0.05	0.06	0.02	0.90
1	5	0.08	0.30	0.03	0.80
2	3	0.20	0.50	0.03	0.50
2	5	0.10	0.10	0.02	0.60
2	6	0.05	0.10	0.025	0.90
3	4	0.05	0.10	0.025	0.70
3	7	0.02	0.05	0.03	0.86
4	7	0.04	0.03	0.02	0.90
5	6	0.10	0.30	0.03	0.50
6	7	0.25	0.55	0.01	0.50

3.1.1. Case-1: Congestion

This case operates in heavy load conditions resulting in congestion on the connecting line between the two locations. This heavy load was shown by the Table 4, both the active and the reactive power.

Table 4. Load and Location

No. Bus	P (pu)	Q (pu)	Location
1	0.80	0.55	1
2	0.70	0.35	1
3	0.60	0.30	2
4	0.70	0.25	2
5	0.60	0.40	1
6	0.90	0.50	3
7	0.80	0.50	2

(a) Solution by EDM

The calculation results of EDM for the case can be seen in the fllowing tables. Economic Dispatch results are shown in Tabel 5(a). The results of the running load flow program are shown in the Tabel 5b, where generating bus voltages are set 1 pu and bus 7 as swing bus. Whereas the next tables are to check system constraints, power flow limits of the transmission reactive power limits of generators, and voltage limits of the buses.

Table 5. The Results of EDM
(a) Power optimal of generators

GENCO	λ (RP/MW)	P_{min} (MW)	P_{opt} (MW)	P_{max} (MW)
G1	9.60	30.1	130.0	130.0
G2	15.3	20.0	0.0	120.0
G4	8.80	25.3	180.0	180.0
G5	5.30	20.0	60.0	60.0
G7	10.25	25.5	130.0	160.0
Total load = 500.0 MW				

Note: generator at bus 2 lost in the auction.

(b) Voltage and power besed on EDM

No. Bus	V (kV)	δ (degri)	P_g (MW)	Q_g (MW)	P_d (MW)	Q_d (MW)
1	20.0	0.000	130.0	89.1	80.0	55.0
2	19.0	0.13	0.0	0.0	70.0	35.0
3	19.5	0.402	0.0	0.0	60.0	30.0
4	20.0	0.466	180.0	-45.4	70.0	25.0
5	20.0	-0.08	60.0	120.7	60.0	40.0
6	17.9	0.011	0.0	0.0	80.0	50.0
7	20.0	0.427	159.5	138.3	80.0	50.0
Losses =29.5+j 17.7 MVA			529.5	302.7	500.0	285.0

(c) Check line constraints

From i	To j	P_{ij} (MW)	Q_{ij} (MVar)	S_{ij} (MVA)	S_{ij}(max) (MVA)	Remarks
1	2	29.4	59.5	66.4	90	-
1	5	20.6	-20.5	29.1	80.0	-
2	3	-50.4	24.4	56.0	50.0	Over
2	5	-13.8	-33.8	36.5	60.0	-
2	6	21.4	39.8	45.2	90.0	-
3	4	-59.2	7.0	59.6	70.0	-
3	7	-58.2	-25.4	63.5	86.0	-
4	7	48.9	-62.6	79.5	90.0	-
5	6	5.2	32.8	33.2	50.0	-
6	7	-55.7	22.3	60.0	50.0	Over

(d) Check reactive power contraints of generators

GENCO	Q_{min} (MVar)	Q_{opt} (MVar)	Q_{max} (MVar)	Remarks
G1	-180.1	89.1	180.1	-
G4	-150.3	-45.4	150.3	-
G5	-125.4	120.7	125.4	-
G7	-150.5	138.3	150.5	-

(e) Check voltage contraints

No. Bus	V_{min} (kV)	V_{opt} (kV)	V_{max} (kV)	Remarks
1	18.0	20.0	22.0	-
2	18.0	19.0	22.0	-
3	18.0	19.5	22.0	-
4	18.0	20.0	22.0	-
5	18.0	20.0	22.0	-
6	18.0	17.9	22.0	Low
7	18.0	20.0	22.0	

(b) Solution by OPF

The calculation results of OPF for the case can be seen in the fllowing tables.

Table 6. The Results of OPF

(a) Voltage and power besed on OPF

No. Bus	V (kV)	δ (degri)	P_g (MW)	Q_g (MW)	P_d (MW)	Q_d (MW)
1	21.0	0.000	130.0	50.2	80.0	55.0
2	20.7	-0.015	20.0	76.0	70.0	35.0
3	21.4	0.211	0.0	0.0	60.0	30.0
4	22.0	0.251	180.0	13.7	70.0	25.0
5	20.9	-0.004	60.0	47.3	60.0	40.0
6	19.7	-0.021	0.0	0.0	80.0	50.0
7	21.7	0.231	122.9	73.2	80.0	50.0
Losses =12.9-j 24.6 MVA			512.9	260.4	500.0	285.0

(b) Power flow in line

From i	To j	P_{ij} (MW)	Q_{ij} (MVar)	S_{ij} (MVA)	S_{ij}(max) (MVA)	Remarks
1	2	27.7	0.8	27.7	90	-
1	5	22.3	-0.1	22.3	80.0	-
2	3	-37.5	11.5	39.3	50.0	-
2	5	-10.7	1.1	10.7	60.0	-
2	6	25.7	38.9	46.6	90.0	-
3	4	-50.4	-7.2	50.9	70.0	-
3	7	-50.1	-10.1	51.1	86.0	-
4	7	-58.2	-15.3	60.5	90.0	-
5	6	11.4	16.9	20.4	50.0	-
6	7	-44.4	8.9	45.3	50.0	-

The results of OPF method showed that there was no violation of constraints and they can be directly accepted by the system. The following table is a detailed comparison of the two methods.

Table 7. Comparation Results between EDM and OPF

Item	EDM	OPF
1. Number of line over load	2	0
2. Number of bus voltage out of constrain	1	0
4. GENCO at bus 2	off	on
5 .Losses	5,74%	2,51%

Table 7 shows that the OPF method is better than the EDM because no violation of system constraints and losses directly obtained by a smaller percentage. Then LBMP each location and capacity of each GENCO can be determined directly. The results by OPF are show in two tables below:

Table 8. Power for Location 1

No. Bus	DISCO (MW)	GENCO (MW)	Offer (Rp/MWh)
1	80	130	9.60
2	70	20	15.30
5	60	60	5.30
Total	210	210	-

Notes: Maximum NP = 15.30 RP / MWh
P^{im} = 0 MW
P^{ex} = 0MW

OPF results for location 1 are contained in Table 5 shows that the power generated is great than the power demanded at that location, or in this case there is no import or export power. So LBMP for this location falls on the price of the highest offer of GENCO that has been won in the auction, which is $LBMP_1$ = 15.30 Rp/MWh

Table 9. Power for Location 2

No. Bus	DISCO (MW)	GENCO (MW)	Offer (Rp/MWh)
3	60	0.0	0.00
4	70	180	8.80
7	80	123	10.50
Total	210	303	-

Notes: Maximum NP = 10.50 RP / MWh
P^{im} = 93 MW
P^{ex} = 0MW

OPF results for location 2 are contained in Table 6 shows that the power generated is great than the power demanded at that location, or in this case Location 2 imports power 93 MW to lacation 3. So LBMP for this location falls on the price of the highest offer of GENCO that has been won in the auction, which is $LBMP_2$ = 10.50 Rp/MWh.

Whereas LBMP at Location-3 can be calculated by Table 6b as the following:

a) From Location 1: P_{26} = 25.6 MW and P_{56}=11.4 MW. When reduced with loss total, then total imported power from Location 1 to Location 3 is P_{13}^{ex} = 35.6 MW.

b) From Location 2: P_{76} = 44.4 MW. So total imported power from Location 2 to Location 3 is P_{23}^{ex} = 44.4 MW

c) By using equation 3, then $\mathrm{LBMP}_3 = max\{15.30, 10.50\} = 15.30\mathrm{Rp/MWh}$

The following table shows the comparison of the simulation results of the two methods. Column 4 of the table consists of the calculation results after EDM results adjusted by giving quota to G2, as loser based on EDM results, 30 MW.

Table 10. Comparation Results between EDM and OPF

No.	Item	EDM	EDM)*	OPF
1	Number of line over flow	2	0	0
2	Number of bus voltage is violated	1	0	0
3	Number of GENCO is out contraint	0	0	0
4	Condition of G2 at bus 2	Off	on	on
5	Losses	5.74%	3.7%	2.5%
6	Quota of G1 at bus 1 [MW]	130.0	130.0	130.0
7	Quota of G2 at bus 2 [MW]	0.0	30.0	20.0
8	Quota of G4 at bus 4 [MW]	180.0	180.0	180.0
9	Quota of G5 at bus 5 [MW]	60.0	60.0	60.0
10	Quota of G7 at bus 7 [MW]	159.5	129.5	123.0
11	LBMP at Location 1 [Rp/MWh]	10.5	15.3	15.3
12	LBMP at Location 2 [Rp/MWh]	10.5	10.5	10.5
13	LBMP at Location 3 [Rp/MWh]	10.5	15.3	15.3

Note:)* after adjusted

Whereas congestion cost is very easy calculated with using equation 4 after LBMP for each location has determined, that is from OPF results:

P_{21}^{ex} =37.5 MW: CC_{21}=37.5x4.80= Rp 180.00

P_{23}^{ex} =44.4 MW: CC_{23}=44.4x4.80= Rp 213.12

So CC=Rp 393.12

3.1.2. Case-2: Normal

In this case the grid load is made lighter than case-1 as set forth in Table 11. Then it is done determination LBMP bersadasarkan OPF method.

Tabel 11. Load and Location

No. Bus	P_d (pu)	Q_d (pu)	Location
1	0.64	0.44	1
2	0.56	0.28	1
3	0.48	0.24	2
4	0.56	0..20	2
5	0.48	0.32	1
6	0.56	0.40	3
7	0.64	0.40	2

(a) Solution by OPF

The following tables contain the results of running OPF program.

Table 12. Results of OPF for Normal Case

(a) Active power at Location 1

No. Bus	DISCO (MW)	GENCO (MW)	Offer
1	64	130	9.60
2	56	0	15.30
5	48	60	5.30

Note: - Maximum NP = 9.60 Rp/MWh
-P^{ex} =22 MW
-P^{im} = 0 MW

(b) Active power at Location 2

No. Bus	Demand (MW)	GENCO (MW)	Offer
3	48	-	-
4	56	180	8.80
7	64	29	10.50

Note: - Maximum NP = 10.50 Rp/MWh
-P^{ex} =41 MW
-P^{im} = 0 MW

On the Location 1: Genco, G2, on the bus 2 is lose because it was too expensive, 15.3 Rp/MWh, and two others get maximum quota with a total power of 190MW. Power supply is smaller than the total demand, 224MW. This lack of supply as much as 34MW has been covered from the generators at Location 2. The maximum NP at Location 1, 9.6Rp/MWh, is offered by GENCO at Bus 1.

Location-2: Genco in the bus 4 has a maximum quota of 180MW due to its offer is very low and Genco in Bus 7 has a quota 29MW under the maximum capacity because a rather expensive. So producing power of Location 2 is 209MW which is more than the total demand, 168MW. It is over-supply is as much as 41MW and maximum NP is 10.5Rp/MWh.

In this case there were no congestion problems, so LBMP for three locations are the same, ie 10.5RP/MWh.

3.2. Analyses

In determining LBMP, not only the energy price determined for each location but also quota each Genco as the winner of the competition must also be determined. In this case the necessary assurance that the quota of each Genco that won the competition must be received by the grid. Whereas in determining LBMP will be affected by three component, ie offer by GENCOs (price and power capacity), request by DISCOs (price and power capacity) and grid constraints. Influence of GENCOs and DISCOs can be clearly seen as a supply-demand relationship alone. Electrical power business is not the same as comodity business at the other economic sectors because it have special problems, such as the losses can not be avoided and grid are limited in delivering power from all GENCOs to all DISCO. The existence of these specificities has made business at electrical power sector into a unique business.

EDM to determine LBMP is very simple because is not involve grid constraints so that the losses can not be directly obtained. In this method the loss problem will be resolved through load flow calculation based on the results of the EDM separately. The results of the case 1 manunjukan that two lines were overloaded (see Table 7). This is due to the offer of GENCOs at Location 2 lower than the offer of GENCOs at Location 1. It results in some power that has to be delivered to Location 1. However, the capacities of two lines are not quite able to deliver some power from Location 2. To solve this problem should be done adjustments of the results obtained until there are not line overloaded, ie by reducing the supply from Location 2 and accompanied addition supply of Location 1. For example, if quota of G2 from Location 1 is set 30MW, quoita of G7 at Location 2 has to be reduced 30MW.

EDM method can not provide the optimal results because power flows in the network are determined by running a load flow program. In the load flow program, the voltage magnitude of the generating buses have to be set, this will affect the reative power flows in the network and also will affect losses. Especially in heavy load conditions, adjusments must be made so that the results of the EDM can be applied to the network.

This is shown by Table 10, G2 is as the loser, according to the EDM results, have to be given a quota of 30 MW. It is larger than 10 MW from the OPF results, so favorable G2 owners. Besides losses is greater than 1.2% from the OPF results, it will affect additional quota on the G7 as the swing bus so that its quota is greater than 6.5 MW from OPF results.

The determination of LBMP through EDM will lead to the following three issues that must get seriously attention.

1) There are GENCOs benefited due to the addition of their quota, such as G2 and G7 in case 1 of the simulation results.
2) Losses are not optimal so cost of the losses will increase. It will harm DISCOs as responsible to the losses, [6]. This is shown by the simulation for case 1, losses increase 1.2% of optimal condition.
3) The power flows in the transmission branches are not equal to the optimal condition so that imfluences cost allocation of transmission usage, as stated in [7].

These are three issues above can be concluded that the determination of LBMP through EDM is not fair.

Solution by OPF, it is definitely no problem to the grid. It can be shown by the results of two cases in the above simulation, both for the cases of heavy load and light load. So using OPF does not need more adjusment because it is definitely the result can be directly applied to the grid. Thus LBMP each location and quota each GENCO that wins the competition can be directly determined, as shown in simulation on the Case 1 and Case 2 above.

4. Conclusion

For the light system load or the strong network, the application of EDM will not be a problem because the operator can run the load flow program with losses covered by GENCO which has quota below its maximum as the swing bus. However, when the heavy system load or there are congestion, then the application of EDM has a few problems, such as losses that has not been covered and its results can not be directly applied to the network. In this case the operator must look for the overflow lines and then determine the reduction of their power-flows with the reduction of quotas for the sensitive generators to those lines. It should be noted that the results of the adjusments can be ascertained that it will not fall to an optimal price. These conditions will create the situation of an unfair competition.

In determining LBMP must be conducted fairly to all participants of the competition. In this case it is required optimization method that guarantees the results fall in the value of the optimum price and these results should be able to be directly applied to the network. In addition, the optimization method used must have a running time of less than half an hour because electricity market designed in a hour ahead. This paper proposes an OPF with the reduction step that has been developed by [5] that has had the running time more quickly (see Table 1).

The results of OPF calculation have been able to be ascertained to be applied to the network. But it has very complex optimization problems when compared with EDM. However with the help of computer that works very fast with a large memory capacity and the progress in the develoment of OPF method, then OPF will be able to do determination LBMP as indicated by the above simulation.

Glossary of Terms

CC	=	Congestion cost	NYSO	=	New York Service Operator
EDM	=	Economic dispatch method	OPF	=	Optimal power flow
d	=	demand/load index	opt.	=	Optimal index
deg.	=	degree	pu	=	Per unit
DISCO	=	Distribution company	P	=	Active power
g	=	generator index	P^{ex}	=	Expor of active power
ISO	=	Independent service operator	P^{im}	=	Impor of active power
GENCO	=	Generator company	Q	=	Reactive power
kV	=	kilo Volt	R	=	Reactance of line
max.	=	maximum index	Rp	=	Unit currency
min.	=	minimum index	S	=	Amparent power
MVar	=	Mega Var	V	=	Voltage
MW	=	Mega watt	X	=	Reactance of line
MWh	=	Mega watt hour	Y	=	Admittance of line
No.	=	Number	δ	=	Phase angle
NP	=	Nodal price	λ	=	Lagrange coefficient

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