Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol 3, No 3, 2012

Determination of Spot Price and Optimal Power Flow in Deregulated Power System

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Abstract

In this paper, determinations of spot price with optimal power flow and important factors that may affect generating companies' profit margins through wholesale electricity trading are discussed. These factors include spot price, generators' efficiencies and capabilities, types of generators owned, fuel costs, transmission losses and settling price variation. It demonstrates how proper analysis of these factors using the solutions of Optimal Power Flow (OPF), can allow companies to maximize overall revenue. And through this OPF analysis, companies will be able to determine, for example, which generators are most economical to run, best locations for generators to be situated at, and also the scheduling of generators as demand changes throughout the day. It illustrates how solutions of OPF can be used to maximize companies' revenue under different scenarios. In this paper above tasks are demonstrated on 124-bus Indian utility real-life system and results have been presented and analyzed. All simulations are performed by using Power World Simulator software.

Keywords: OPF, Electricity Market, Spot Price

1. Introduction

In the past, the electricity industry was government-controlled and also monopolistic. However over the past decade, the industry in many countries including part of India had undergone significant changes and was restructuring for a free market, also known as deregulation (Xie 2000). This led to a competitive market whereby customers are able to choose their electricity supply from a number of generating companies and retailers. In this deregulated market, it is essential for generating companies to plan their operations efficiently, so as to minimize operating costs while maximizing their profit margins (Geerli 2003).

There are many factors involved in the successful operation of a power system. The system is expected to have power instantaneously and continuously available to meet power demands. It is also expected that the voltage supplied will be maintained at or near the nominal rated value. Not only must the demands be met at all times, the public and employees should not be placed in hazard by operations of the system. At the same time proper operating procedures must be observed to avoid damage to equipment or other facilities of the system. All of these operating requirements must be achieved simultaneously (Miller 1970).

Other than those mentioned above, one of the most important factors is the operating cost. Generation and distribution of power must be accomplished at minimum cost but with maximum efficiency. This involves the real and reactive power scheduling of each power plant in such a way as to minimize the total operating cost of the entire network. In other words, the generator's real and reactive powers are allowed to vary within certain limits so as to meet a particular load demand with minimum fuel cost. This is called the Optimal Power Flow (OPF) or sometimes known as the Optimal Power Dispatch or Economic Dispatch (ED) problem (Happ 1974).

The objective of this paper is to demonstrate how generating companies can utilize solutions of OPF to minimize costs while maximizing profit margin in a deregulated wholesale market environment. Thus, there is a need to understand how the local electricity market operates.

2. Modelling of Optimal Power Flow Problem

In the solution of OPF, the main objective is to minimize total operating costs of the system. In OPF, when the load is light, the cheapest generators are always the ones chosen to run first. As the load increases, more and more expensive generators will then be brought in. Thus, the operating cost plays a very important role in the solution of OPF (Momoh 1997).

In all practical cases, the cost of generator i can be represented as a cubic function of real power generation expressed in \$/hr,

$$C_i = (\alpha_i + \beta_i P_i + \gamma_i P_i^2 + \xi_i P_i^3) * \text{fuel cost} \tag{1}$$

Where Pi is the real power output of generator i, and α, β, γ and ξ are the cost coefficients. Normally, the cost coefficients remain constant for a generator. The last term in the equation is the fuel cost, expressed in Rs. /MBtu.

Another important characteristic of a generator is the incremental cost, also known as marginal cost. It is a measure of how costly it will be to produce the next increment of power. The incremental cost can be obtained from the derivative of C_i of equation (1) with respect to P_i,

$$\frac{\partial C_i}{\partial P_i} = (\beta_i + 2\gamma_i P_i^2 + 3\xi_i P_i^2) * \text{fuel cost} \tag{2}$$

Which is expressed in Rs./MWHr.

The transmission losses become a major factor in a large interconnected network whereby power is being transmitted over long distances. A common function to represent total system real power losses in terms of the total real power output is the Kron's loss formula,

$$P_L = \sum_{i=1}^{ng} \sum_{j=1}^{ng} P_i B_{ij} P_j + \sum_{i=1}^{ng} B_{oi} P_i + B_{oo} \tag{3}$$

Where P_L is the total real power losses, and Bij are the loss coefficients or B coefficients (Grainger 1994).

Optimal dispatch can be seen generally as a constrained optimization problem. When solving a constrained optimization problem, there are two general types of constraints, which are equality and inequality constraints. Equality constraints are constraints that always need to be enforced.

The constrained optimization problem can be solved using the Lagrange Multiplier method, and for simplicity, only the maximum and minimum real power limits are included as the inequality constraints.

The total operating cost of all generators in a system is given by,

$$C_t = \sum_{i=1}^{ng} C_i \tag{4}$$

Where ng is the number of generator buses.

The total real power generation is then given by,

$$\sum_{i=1}^{ng} P_i = P_D + P_L \tag{5}$$

Where $P_{i(min)} \leq P_i \leq P_{i(max)}$, P_D is the total real power demand, and P_L is the total system real power loss [9].

The Lagrange Multiplier can then be expressed as,

$$\ell = C_t + \lambda(P_D + P_L - \sum_{i=1}^{ng} P_i) + \sum_{i=1}^{ng} \mu_{i(max)} (P_i - P_{i(max)}) + \sum_{i=1}^{ng} \mu_{i(min)} (P_i - P_{i(min)}) \quad (6)$$

Where the term second term is the equality constraint, while the last two terms are inequality constraints in equation (6) (Momoh 1999).

Note that both $\mu_{i(max)}$ and $\mu_{i(min)}$ are equal to zero if $P_{i(min)} \leq P_i \geq P_{i(max)}$, which means that the inequality constraints are inactive. The constraints will only be active when violated, which means $P_i > P_{i(max)}$ or $P_i < P_{i(min)}$. This is known as the Kuhn-Tucker necessary conditions of optimality, following the conditions below,

$$\frac{\partial \ell}{\partial P_i} = 0 \quad (7)$$

$$\frac{\partial \ell}{\partial \lambda} = 0 \quad (8)$$

$$\frac{\partial \ell}{\partial \mu_{i(min)}} = P_i - P_{i(min)} = 0 \quad (9)$$

$$\frac{\partial \ell}{\partial \mu_{i(max)}} = P_i - P_{i(max)} = 0 \quad (10)$$

The optimal solution can then be obtained by solving for the condition, $\frac{\partial \ell}{\partial P_i} = 0$ (Sun 1984).

3. The Spot Price

A centralized economic dispatch is employed to determine the market clearing price, the power generation and demand levels of all units and consumers. The competition in the electricity market must been encourage for investments to the new technology and more productive electrical source.

The participants in deregulated power market are independent power producer, Distribution Company. Bids are for supplying loads because all participants in the power system each other effect. The bids are been received by independent system operator. Independent System Operator (ISO) analyzes the power system situation, develop strategies and define transactions among participants by looking for the minimum price that satisfies the power demand (Davison 2002).

According to many system operations each power production participant defines its own resource scheduling and sends a bid to the ISO for supplying other loads. The participants submit hourly offers that contain quantity and price, and they receive dispatch instructions from the ISO for each 5-min period. ISO determines transaction between participants according to their bids and power demand (Rodriguez 2004, Aganagic 1998, Wen 2001 and Chattopadhyay 2001). Transaction payments are defined as the product of the spot price and power transactions for each participant.

In a real competitive power market, no participant can absolutely control the power system operation. It means that the participants can not significantly affect the existing spot prices by adjusting their bids but mostly match the spot price with their marginal costs. Therefore the minimum power system operation cost and the maximum participant benefit are reached at the same time in a real competitive power market.

Electricity in the National Electricity Market (NEM) can be either traded through retail or wholesale trading or even through contracts. Note that this paper only emphasizes on the wholesale trading of the spot market. All wholesale electricity must be traded through the spot market; generators are paid for the electricity they sell to the pool while retailers and wholesale end- users pay for the electricity they use from the pool. It is a process whereby prices for electricity are set and then settled. This pool is the way which short-term operation of the power system is centrally.

In this spot market, generating companies can choose whether to commit their generators and make it available for dispatch. Once they have decided to commit, they must submit a bid for the opportunity to run their generators. A bid is the "sell offer" submitted for a particular amount of electricity selling at a particular price. Generating companies can change their bids or submit re-bids according to a set of bidding rules. After receiving all the bids, NEM will then selects the generators required to run and when to run at different times of the day, based on the most cost-efficient supply solution to meet specific demand. This ensures electricity is supplied at the lowest possible price. As mentioned above, the spot market allows instantaneous matching of supply against demand.

4. Test Case

In a competitive electricity market, there will be many market players such as generating companies (GENCOs), transmission companies (TRANSCOs), distribution companies (DISCOs), and system operator (SO). Similarly Andhra Pradesh State Electricity Board (APSEB) is divided into Andhra Pradesh Generating Company (APGENCO), Andhra Pradesh Transmission Company (APTRANCO) and Andhra Pradesh Distribution Company (APDISCO). All are operating with independent companies under the government of Andhra Pradesh. APDISCO is again divided into four companies as Northern Power Distribution Company Limited (NPDCL), Central Power Distribution Company Limited (CPDCL), Eastern Power Distribution Company Limited (EPDCL), and Sothern Power Distribution Company Limited (SPDCL).

At present APGENCO is operating with Installed Capacity of 8923.86 MW (Thermal 5092.50MW and 3831.36MW) along with Private sector of 3286.30MW and Central Generating Stations (CGS) share of 3209.15MW.

For this case study total APGENCO, Private sector and Two Generating stations (bus 1 (2600MW), bus 115 (1500MW)) from CGS is considered. APTRANSCO is considered at 220kV level. Each DISCO is considered as one area.

A 124-bus Indian utility real-life power system is used for portfolio analysis in different operating scenarios. The generators' efficiencies and capabilities, types of generators owned, fuel costs, transmission losses and spot price variation are some of the factors that can affect generating companies' profit margins in a deregulated market environment. This section demonstrates that through proper analysis of these factors, generating companies can utilize solutions of OPF to maximize their profit margins through the wholesale spot market.

This analysis is discussed under different case studies as follows

Case 1: All the generators are operating without considering Minimum MW limit, with Maximum MW limit and with CGS Share.

Case 2: All the generators are operating with considering Minimum and Maximum MW limit and with CGS Share.

Case 3: All the generators are operating with considering Minimum and Maximum MW limit and without CGS Share.

Case 4: Some expensive Generators are shutdown, remaining all the generators are operating with considering Minimum and Maximum MW limit and without CGS Share.

The generators' bids are assumed to be 10% higher than the generators' costs and the spot price is determined by the highest generator's bid.

Profit (Rs. /MWHr) = Spot Price (Rs. /MWHr) – Cost (Rs. /MWHr)

Profit (Rs. /Hr) = Profit (Rs. /MWHr) x Gen MW

Results of Total Generation, Load, Losses, CGS Share, Spot price, Cost of Generation, Profits of Generator are given in Tables from 1 to 6. Power Exchange from 400kV lines, Cost functions of Generators are given in Tables 7 and 8.

In case 1, the OPF program set most expensive generators generation to zero. In case 4, Spot price is reduced by shutting down the most expensive generators. The generators which are not committed to dispatch are not shown in Tables.

Compared to all the Cases in Case 1 cost of generation is less because of considering the CGS share, in Case 2 also CGS share considered but by imposing of Minimum MW limits to generators some of expensive generators are committed to dispatch.

Comparing with Case 4, in Case 3 Spot Price, Cost of Generation and Profits are more because some more expensive generators are committed to dispatch and losses are reduced. Case 3 will give more profits to generator companies and Case 4 will give benefit to the consumer.

Results showed that profits are positively-related to the spot price and the load demand. In other words, profits increase as the spot price increases with the load demand. This is because the spot price is determined from the highest generator's bid, and expensive generators are required when the load demand is high, which will set a high spot price.

It is also realized that cheaper generators will have higher profit margins regardless of the spot prices. Therefore, it is advantageous for companies to own a greater number of cheap generators along with a few expensive ones. Those expensive generators can be used as backup units for emergencies and perhaps also used to set high spot prices which are beneficial to the cheaper generators.

5. Conclusion

This paper demonstrated that the proper scheduling of generators by using OPF minimized the total system losses and therefore increased generators efficiencies. It shows that the OPF algorithm had solved the case more cost-efficiently. Therefore increases the revenues of company in deregulated power system. It is also realized that cheaper generators will have higher profit margins regardless of the spot prices. Therefore, it is advantageous for companies to own a greater number of cheap generators along with a few expensive ones. Those expensive generators can be used as backup units for emergencies and perhaps also used to set high spot prices which are beneficial to the cheaper generators. From these results, it can be concluded that types of generators owned by companies and that spot price variation can greatly affect their overall revenue. The results are certainly useful in an online environment of deregulated power system to perform the transactions between buyer and seller for APGENCO, APTRANSCO, and APDISCOMs.

References

Aganagic. M, Abdul-Rahman. K. H, Waight. J. G, Spot Pricing of Capacities for Generation and Transmission of Reserve in An Extended Poolco Model, *IEEE Transaction on Power Systems*: 13(3), 1128-1134, 1998.

Chattopadhyay. D, Gan. D, Market dispatch incorporating stability constraints, *Electrical Power and Energy Systems:* 23, 459-469, 2001.

Davison. M, Anderson. C. L, Marcus. B, Anderson. K, Development of a Hybrid Model for Electrical Power Spot Prices, *IEEE Transaction on Power Systems*: 17(2); 257-264, 2002.

Geerli. N.S, Yokoyama. R, Electricity pricing and load dispatching in deregulated electricity market, *Electrical Power and Energy Systems*: 25:491-498, 2003.

Grainger. J. J and Stevenson. W. D, Power System Analysis, McGraw-Hill, New York, 1994.

Happ. H. H, "Optimal Power Dispatch," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-93, No. 3, May/June 1974, pp. 820-830.

Miller. R. H and Malinowski. J. H, "Economic Operation of Power Systems," Power System Operation, 3rd Edition, McGraw-Hill, New York, 1970, pp. 63-82.

Momoh. J. A, Koessler. R. J and Bond. M. S, "Challenges to Optimal Power Flow," IEEE Transactions on Power Systems, Vol. 12, No. 1, February 1997, pp. 444-455.

Momoh. J. A, El-Hawary. M. E and Adapa. R, "A Review of Selected Optimal Power Flow Literature to 1993 Part I: Nonlinear and Quadratic Programming Approaches," IEEE Transaction on Power Systems, Vol. 14, No. 1, February 1999, pp. 96-104.

Rodriguez. C. P, Anders. G. J, Energy Price Forecasting in the Ontario Competitive Power System Market. *IEEE Transaction on Power Systems*: 19(1), 366-373, 2004.

Sun. D. I, Ashley. B, Brewer. B, A. Hughes. A and Tinney. W. F, "Optimal Power Flow By Newton Approach," IEEE Transaction on Power Apparatus and Systems, Vol. PAS-103, No. 10, October 1984, pp. 2864-2880.

Wen. F, David. A. K, Optimal bidding strategies for competitive generators and large consumers. *Electrical Power and Energy Systems*: 23, 37-43, 2001.

Xie. K, Song. Y. H, Stonham. J, Yu. E, Liu. G, Decomposition model and interior point methods for optimal spot pricing of electricity in deregulation environments, *IEEE Transaction on Power Systems*: 15(1): 39-50, 2000.

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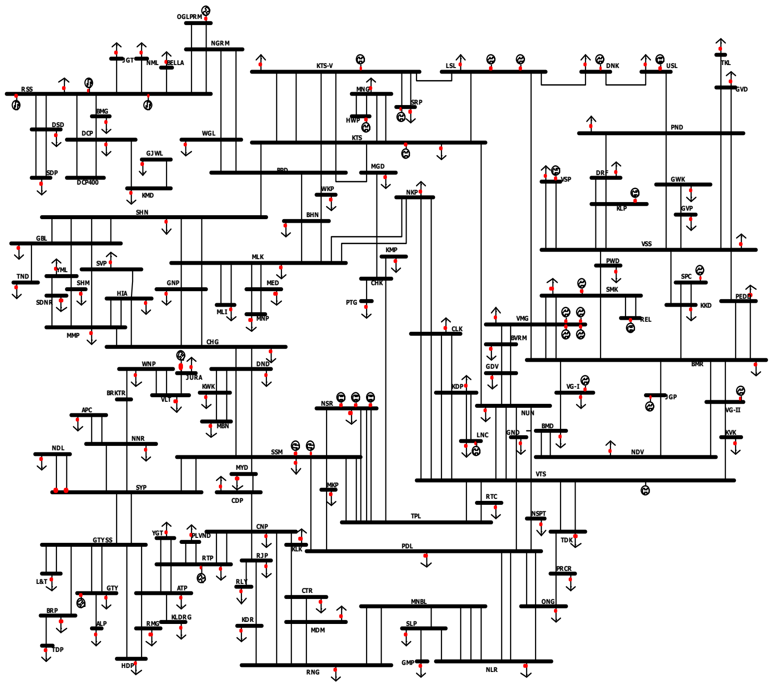

Figure 1. 124-bus Indian utility real-life Power system.

Table 1. Details of Total Generation, load, Losses, CGS Share, Spot price and Cost of Generation

	Case 1	Case 2	Case 3	Case 4
Total MW Generation	7874.40	8970.00	10522.22	10573.50
Total MW Load	7492.00	8707.00	10272.30	10237.00
Total MW Losses	382.43	263.04	250.62	336.55
CGS Share	2834.00	1833.00	0000.00	0000.00
Spot Price (Rs./MWHr)	20322.30	6385.69	6385.69	3078.74
Cost of Generation (Rs.)	17113247.45	28948151.25	32097310.86	27564664.90

Table 2. Details of Area wise generation and load

	Case 1		Case 2		Case 3		Case 4	
Area Name	Generation MW	Load MW	Generation MW	Load MW	Generation MW	Load MW	Generation MW	Load MW
1	2484.20	2382.00	3190.80	2382.00	3190.8	2382.00	2763.30	2382.00
2	1936.56	1793.00	1165.73	1093.00	1794.99	1778.00	1804.36	1670.00
3	2296.14	2239.00	2167.88	2139.00	2988.28	2970.00	2401.50	2970.00
4	1157.54	1078.00	2445.63	3093.00	2548.15	3143.00	3604.36	3215.00

Table 3. Generator Costs, Bids, Spot Price and Profits of Case 1

Bus No.	Bus Name	Area Name	Gen MW	Cost Rs./Hr	Cost Rs./MWHr	Bid Rs./MWHr	Profit Rs./Hr
1	RSS	1	1376.38	2595011	1885.39	2073.93	25376196.51
1	RSS	1	27	17968.04	665.48	732.03	530734.06
27	OGLPRM	1	500	1320868	2641.74	2905.91	8840282.44
29	KTS-V	1	36.82	680242.9	18474.82	20322.30	68024.18
31	LSL	1	460	93139.27	202.48	222.72	9255118.73
31	LSL	1	84	15410.96	183.46	201.81	1691662.24
46	SSM	2	783.58	438618.7	559.76	615.74	15485529.11
46	SSM	2	770	179931.5	233.68	257.05	15468239.48
54	NSR	2	91.38	160844.8	1760.17	1936.19	1696207.02
61	GTY	2	57.6	10559.36	183.32	201.65	1160005.12
85	VTS	4	1157.54	2943588	2542.97	2797.27	20580287.28
104	SPC	3	102.44	276381	2697.98	2967.78	1805435.42
105	JGP	3	208.7	454122.6	2175.96	2393.55	3787141.43
107	REL	3	220	547566.2	2488.94	2737.83	3923339.80
111	USL	3	240	48595.89	202.48	222.73	4828756.11
113	DNK	3	25	9121	364.84	401.32	498936.50
115	KLP	3	1500	3311632	2207.75	2428.53	27171817.56
128	JURA	2	234	112716.9	481.70	529.87	4642701.31
Total Generation (MW)			7874.44		Total Profit (Rs./Hr)		146810414.31

Table 4. Generator Costs, Bids, Spot Price and Profits of Case 2

Bus No.	Bus Name	Area Name	Gen MW	Cost Rs./Hr.	Cost Rs./MWHr	Bid Rs./MWHr	Profit Rs./Hr
1	RSS	1	37.5	117139.3	3123.71	3436.09	122324.11
1	RSS	1	8.1	17968.04	2218.28	2440.10	33756.05
1	RSS	1	1560	2824532	1810.60	1991.66	7137144.46
27	OGLPRM	1	300	1088868	3629.56	3992.51	826839.44
29	KTS-V	1	600	1356062	2260.10	2486.11	2475352.37
30	KTS	1	432	955528.5	2211.87	2433.06	1803089.54
31	LSL	1	138	93139.27	674.92	742.41	788085.95
31	LSL	1	25.2	15410.96	611.55	672.70	145508.43
32	SRP	1	68.4	244115.3	3568.94	3925.83	192665.95
34	HWP	1	21.6	73126.58	3385.49	3724.04	64804.32
46	SSM	2	437.22	438618.7	1003.20	1103.52	2353332.66
46	SSM	2	335.25	179931.5	536.71	590.38	1960871.05
54	NSR	2	18	11837.9	657.66	723.43	103104.52

54	NSR	2	27	17751.14	657.45	723.19	154662.49
54	NSR	2	260.24	160844.8	618.06	679.87	1500967.22
61	GTY	2	17.28	10559.36	611.07	672.18	99785.36
72	RTP	4	1050	2938797	2798.85	3078.74	3766177.75
85	VTS	4	1030.63	2744347	2662.79	2929.06	3836937.10
91	LNC	4	365	1008416	2762.78	3039.06	1322360.88
96	VG-I	3	30.6	164094.5	5362.56	5898.82	31307.65
97	VG-II	3	51.6	276708.8	5362.57	5898.83	52792.79
100	VMG	3	116.4	586681.3	5040.22	5544.24	156613.04
100	VMG	3	141.84	618037.5	4357.29	4793.01	287708.81
100	VMG	3	66	285514.4	4325.98	4758.57	135941.10
100	VMG	3	133.5	534269.2	4002.02	4402.22	318220.40
104	SPC	3	62.34	208215.4	3340.00	3674.00	189868.48
105	JGP	3	62.6	210135.6	3356.80	3692.48	189608.58
106	SMK	3	93	539881.3	5805.18	6385.69	53987.89
107	REL	3	66	293466.2	4446.46	4891.10	127989.34
111	USL	3	240	48595.89	202.48	222.73	1483969.71
113	DNK	3	25	9121	364.84	401.32	150521.25
115	KLP	3	1064	2622751	2464.99	2711.49	4171623.46
118	VSP	3	15	49831.05	3322.07	3654.28	45954.30
128	JURA	2	70.74	112716.9	1593.40	1752.74	339006.82
Total Generation (MW)			8970.04		Total Profit (Rs./Hr)		36422883.28

Table 5. Generator Costs, Bids, Spot Price and Profits of Case 3

Bus No.	Bus Name	Area Name	Gen MW	Cost Rs./Hr.	Cost Rs./MWHr	Bid Rs./MWHr	Profit Rs./Hr
1	RSS	1	37.5	117139.3	3123.71	3436.09	122324.11
1	RSS	1	8.1	17968.04	2218.28	2440.10	33756.05
1	RSS	1	1560	2824532	1810.60	1991.66	7137144.46
27	OGLPRM	1	300	1088868	3629.56	3992.51	826839.44
29	KTS-V	1	600	1356062	2260.10	2486.11	2475352.37
30	KTS	1	432	955528.5	2211.87	2433.06	1803089.54
31	LSL	1	138	93139.27	674.92	742.41	788085.95
31	LSL	1	25.2	15410.96	611.55	672.70	145508.43
32	SRP	1	68.4	244115.3	3568.94	3925.83	192665.95
34	HWP	1	21.6	73126.58	3385.49	3724.04	64804.32
46	SSM	2	812.49	438618.7	539.85	593.83	4749690.55
46	SSM	2	516	179931.5	348.70	383.57	3115084.52
54	NSR	2	18	11837.9	657.66	723.43	103104.52

54	NSR	2	27	17751.14	657.45	723.19	154662.49
54	NSR	2	244.68	160844.8	657.37	723.10	1401605.88
61	GTY	2	17.28	10559.36	611.07	672.18	99785.36
72	RTP	4	1050	2938797	2798.85	3078.74	3766177.75
85	VTS	4	1133.15	2905298	2563.91	2820.30	4330646.97
91	LNC	4	365	1008416	2762.78	3039.06	1322360.88
96	VG-I	3	30.6	164094.5	5362.56	5898.82	31307.65
97	VG-II	3	51.6	276708.8	5362.57	5898.83	52792.79
100	VMG	3	116.4	586681.3	5040.22	5544.24	156613.04
100	VMG	3	141.84	618037.5	4357.29	4793.01	287708.81
100	VMG	3	66	285514.4	4325.98	4758.57	135941.10
100	VMG	3	133.5	534269.2	4002.02	4402.22	318220.40
104	SPC	3	146.64	351519.3	2397.16	2636.87	584878.32
105	JGP	3	208.7	454122.6	2175.96	2393.55	878570.92
106	SMK	3	93	539881.3	5805.18	6385.69	53987.89
107	REL	3	220	547566.2	2488.94	2737.83	857285.60
111	USL	3	240	48595.89	202.48	222.73	1483969.71
113	DNK	3	25	9121	364.84	401.32	150521.25
115	KLP	3	1500	3311632	2207.75	2428.53	6266902.56
118	VSP	3	15	49831.05	3322.07	3654.28	45954.30
128	JURA	2	159.54	112716.9	706.51	777.16	906056.09
Total Generation (MW)			10522.22		Total Profit (Rs./Hr)		44843399.97

Table 6. Generator Costs, Bids, Spot Price and Profits of Case 4

Bus No.	Bus Name	Area Name	Gen MW	Cost Rs./Hr.	Cost Rs./MWHr	Bid Rs./MWHr	Profit Rs./Hr
1	RSS	1	8.1	17968.04	2218.28	2440.10	6969.75
1	RSS	1	1560	2824532	1810.60	1991.66	1978302.46
29	KTS-V	1	600	1356062	2260.10	2486.11	491182.37
30	KTS	1	432	955528.5	2211.87	2433.06	374487.14
31	LSL	1	138	93139.27	674.92	742.41	331726.85
31	LSL	1	25.2	15410.96	611.55	672.70	62173.29
46	SSM	2	813.68	438618.7	539.06	592.96	2066490.44
46	SSM	2	517.2	179931.5	347.90	382.68	1412392.81
54	NSR	2	245.88	160844.8	654.16	719.58	596155.84
54	NSR	2	28.2	17751.14	629.47	692.42	69069.33
54	NSR	2	19.2	11837.9	616.56	678.21	47273.91
61	GTY	2	18.48	10559.36	571.39	628.53	46335.76
72	RTP	4	1050	2938797	2798.85	3078.74	293880.25

85	VTS	4	2189.4	4563554	2084.42	2292.87	2176916.41
91	LNC	4	365	1008416	2762.78	3039.06	115324.13
104	SPC	3	207.8	455497.4	2192.00	2411.20	184264.73
105	JGP	3	208.7	454122.6	2175.96	2393.55	188410.46
107	REL	3	220	547566.2	2488.94	2737.83	129756.60
111	USL	3	240	48595.89	202.48	222.73	690301.71
113	DNK	3	25	9121	364.84	401.32	67847.50
115	KLP	3	1500	3311632	2207.75	2428.53	1306477.56
128	JURA	2	161.73	112716.9	696.94	766.64	385207.73
Total Generation (MW)			10574		Total Profit (Rs./Hr)		6297221.91

Table 7. Power Exchange from 400kv lines

Sl. No.	Bus No.	Bus Name	Case 1	Case 2	Case 3 & 4	Sl. No.	Bus No.	Bus Name	Case 1	Case 2	Case 3 & 4
1	1	RSS	-1819	-1819	-1819	15	61	GTY	281	281	281
2	4	DCP400	405	405	405	16	66	CNP	-73	-373	79
3	9	MLK	412	612	412	17	68	CDP	-58	-58	-58
4	11	GJWL	211	211	211	18	74	MDM	-1	-1	-1
5	15	MMP	749	1149	749	19	75	CTR	24	24	24
6	20	GNP	542	542	542	20	78	MNBL	1079	1079	000
7	27	OGLPR	178	178	178	21	84	TPL	107	107	000
8	35	BPD	144	144	144	22	85	VTS	-499	-2000	-1213
9	37	WGL	147	147	147	23	87	NUN	370	370	000
10	45	MBN	189	289	250	24	100	VMG	-548	-548	-548
11	50	GTY SS	54	54	54	25	102	VSS	335	335	000
12	52	NNR	778	778	778	26	112	GWK	396	396	000
13	54	NSR	46	46	000	27	115	KLP	-801	-701	-801
14	56	VLT	186	186	186	CGS Share (MW)			2834	1833	0000

Table 8. Details of Generator Cost Functions

Bus Number	Bus Name	α_i (Rs./Hr)	β_i (Rs./MWHr.)	Min MW	Max MW
1	RSS	55639.27	1640	37.5	62.5
1	RSS	17968.04	0	8.1	27
1	RSS	874531.9	1250	1560	2600
27	OGLPRM	740867.6	1160	300	500
29	KTS-V	636061.6	1200	600	1000
30	KTS	402568.5	1280	432	720
31	LSL	93139.27	0	138	460
31	LSL	15410.96	0	25.2	84

32	SRP	114155.3	1900	68.4	114
34	HWP	34246.58	1800	21.6	36
46	SSM	438618.7	0	270	900
46	SSM	179931.5	0	231	770
54	NSR	160844.8	0	244.68	815.6
54	NSR	17751.14	0	27	90
54	NSR	11837.9	0	18	60
61	GTY	10559.36	0	17.28	57.6
72	RTP	1080297	1770	630	1050
85	VTS	1126256	1570	1056	1760
91	LNC	366016	1760	109.5	365
96	VG-I	108096.5	1830	30.6	102
97	VG-II	182280.8	1830	51.6	172
100	VMG	364143.8	1790	141.84	472.8
100	VMG	167374.4	1790	66	220
100	VMG	353881.3	2000	116.4	388
100	VMG	261929.2	2040	133.5	445
104	SPC	102237.4	1700	62.34	207.8
105	JGP	105593.6	1670	62.61	208.7
106	SMK	353881.3	2000	93	310
107	REL	184566.2	1650	66	220
111	USL	48595.89	0	72	240
113	DNK	9121	0	7.5	25
115	KLP	941632.4	1580	900	1500
118	VSP	22831.05	1800	15	25
128	JURA	112716.9	0	70.2	234