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LMP Calculation with Distributed Loss using GA based DCOPF

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In restructured electricity markets, an effective transmission pricing method is required to address transmission issues and to generate correct economic signals. Transmission line constraints can result in variations in energy prices throughout the network. These prices depend on generator bids, load levels and transmission network limitations. A congestion charge is incurred when the system is constrained by physical limits. Locational marginal pricing (LMP) has become popular method in restructured power markets to address the congestion price. This paper presents, Genetic Algorithm (GA) based DCOPF model to calculate LMP's at all buses considering concentrated loss model and a distributed loss model to remove the high mismatch at the slack bus. LMP decomposition is also given, which can be decomposed into energy price, congestion price and loss price. The developed models have been applied for IEEE 14 bus, New England 39 bus system and 75 bus Indian Power System. Comparison is made between Linear Programming (LP) based DCOPF using Power World Simulator and the developed GA based DCOPF for concentrated and distributed loss cases. Both fixed and linear bids are considered for generators. The load is assumed to be inelastic. Distributed loss model considering linear bids shows reduced generation fuel cost compared to concentrated loss model.

Keywords: LMP, Fixed bid, Linear bid, Generation shift factors, Delivery factors, Distributed loss, Genetic Algorithm.

1. INTRODUCTION

In April 2003 White Paper [17] the U.S. Federal Energy Regulatory Commission (FERC) proposed a market design for common adoption by U.S. wholesale power markets. The electric power industry has undergone deregulation around the world, a core tenet of which is to build an open-access, unambiguous and fair electricity markets. Proper and fair pricing of real power is an important issue in this competitive market. Core features of a market design include; a two settlement system consisting of a day-ahead market supported by a real-time market to ensure continual balancing of supply and demand for power; and grid congestion management by means of Locational Marginal Pricing (LMP).

Under a deregulated electricity market environment, transmission networks hold a vital role in supporting the transaction between producers and consumers. One drawback of transmission constraint is congestion. Congestion occurs when transmission lines or transformers operate at or above its thermal limits and this prevents the system operators from dispatching additional power from a specific generator. Congestion can result in an overall increase in the cost of power delivery. Presently there are two pricing structures [10] that are being used in a competitive energy market to account for congestion: the uniform pricing method market clearing price (MCP) and the nonuniform pricing method (LMP). In the first method, all generators are paid the same price (MCP) based on the bid of the marginal generator that would be dispatched in the absence of congestion. The second method (LMP) has been the basic approach in power markets to calculate nodal prices and to manage transmission congestion. The theory of spot price, which was first proposed by Schweppe et al. [1], is increasingly being employed in the form of (LMP) within an OPF framework.The LMP at a location is defined as the marginal cost to supply an additional increment of power to the location without violating any system security limits. Because of

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the effects of both transmission losses and transmission system congestion, LMP can vary significantly from one location to another. Mathematically, LMP at any node in the system is the dual variable (sometimes called a shadow price) for the equality constraint at that node (sum of injections and withdrawals is equal to zero). Or, LMP is the additional cost for providing one additional MW at certain node. Buyers pay ISO based on their LMP for dispatched energy. The ISO pays sellers based on their respective LMP's. The LMP difference between two adjacent buses is the congestion cost which arises when the energy is transferred from one location (injection) to the other location (withdrawal). Marginal losses represent incremental changes in system losses due to incremental demand changes. Incremental losses yield additional costs which are referred to as the cost of marginal losses [26]. Thus LMP is the summation of the costs of marginal energy, marginal loss and congestion. Therefore LMP is stated as follows:

LMP = generation marginal cost+ congestion cost+ loss cost (1)

LMP's can be derived using either an ACOPF model or a DCOPF model ([2], [3], [4], [5], [7], [8], [9]).

The ACOPF model is more accurate than the DCOPF model, but it is prone to divergence. Also, the ACOPF model can be up to 60 times slower than the DCOPF model [20]. The objective function of OPF is meeting the load in the power system while maximizing social surplus and respecting operational constraints. In the absence of price elasticity load (which is mostly the case in the real time market) maximising social welfare is equivalent to minimising the total production cost. In this paper we assumed load to be price inelastic. There are two approaches to calculate LMP's in RTM: ex post and ex ante. NY ISO uses ex ante prices as the real time prices and penalises non-performing resources on the basis of reduced generation quantity [11], whereas ISO NE, PJM and MISO adopt the ex post pricing that provides dispatch incentives on the ground of rational prices [12,13]. Both ex ante and ex post approaches have their own merits and demerits. For example ex ante pricing does not have a capability to penalise non-performing units, whereas ex post pricing has some difficulties in implementing co-optimisation of the energy and reserves [30]. In market planning and simulation, DC model is desired due to its robustness and speed. DCOPF is broadly employed by a number of industrial LMP simulators, such as ABB's Gid ViewTM, GE's MAPSTM, Siemens' Promod IVR, and Power World [18], [6]. Several papers have reported different models for LMP calculation. Reference [26] presented different methods and properties on LMP calculations based on DCOPF with and without loss. Reference [30] gives a systematic description on how the LMP's are produced; it also described both the modelling and implementation challenges and solutions. Reference [31] described ACOPF based LMP calculation considering distributed loss. Reference [28] demonstrated an iterative DCOPF based algorithm with lossless model, considering marginal losses, and with fictitious nodal demand model to calculate LMP. All these 3 models are solved with linear programming. Reference [29] presented Cummulant and Gram Charlier (CGC) method for calculating LMP and compared with Monte Carlo and point estimation method. This method combines the concept of Cummulants and Gram-Charlier expansion theory to obtain Probabilistic Distribution Functions (PDF) and Cummulative Distribution Function (CDF) of LMP. This method is complex and time consuming. Reference [25] presented Nodal pricing with Genetic Algorithm for congestion management with DCOPF for lossless system. Reference [14] gave description about components of nodal prices for electric power systems. Reference [21] presented a slack-bus-independent approach to calculate LMPs and congestion components. Reference [16] demonstrated the usefulness of dc power flow in calculating loss penalty factors, which has a significant impact on generation scheduling. The authors of [16] also point out that it is not advisable to apply predetermined loss penalty factors from a typical scenario to all cases. Reference [22] presented LMP simulation algorithms to address marginal loss pricing based on the dc model. Literature shows that dc model can be acceptable in optimal power flow studies if the line flow is not very high, the voltage profile is sufficiently flat, and the R/X ratio is less than 0.25 [23].

This paper provides a detailed explanation about concentrated loss DCOPF model and distributed loss DCOPF model. The derivation of LMP and LMP components based on the above two models is presented here. In concentrated loss DCOPF model total system loss is supplied by the slack bus which creates a burden on the slack bus. To eliminate a large mismatch at the slack bus, loss is distributed to all buses as an extra load.

In [28] LP based approach for concentrated loss DCOPF and distributed loss DCOPF model is given with piecewise linear cost curves but it does not give actual marginal cost of generation. The present paper proposed a GA based DCOPF with distributed loss model approach with linear incremental cost curve which gives true marginal cost of generation and mismatch at the slack bus is removed. The results of this method are compared with concentrated loss model. Both these models have been attempted for fixed generation bids and linear generation bids. Section 2 describes different types of bids used for generators. Section 3 discusses the problem formulation for LMP calculation using delivery factors for both concentrated loss and distributed loss models. Section 4 presented implementation of GA. Section 5 gives results and discussions for IEEE 14 bus system [27], New England 39 bus system [24] and 75 bus Indian power system. Section 6 concludes the paper.

2. TYPES OF GENERATOR BIDS

In general, generators bids depend on many factors, some of which (e.g. strategic behaviour) are difficult to model. To avoid excessive complexity, generators bids are assumed to be equal to their incremental costs for perfect competition. Two bidding models are generally used, namely: fixed generator bids (corresponding to piecewise-linear heat rates) and linear bids (corresponding to quadratic heat rates).

2.1 Fixed Bids

The heat rate curve is converted to an approximate fixed incremental heat rate for each unit through Linear regression method. The cost changes in steps with respect to generation. The fixed bid curve for piecewise linear cost characteristics is shown in Fig. 1.

2.2 Linear Bids

The non-smooth nature of the fixed bid in Fig. 1 may result in step changes in prices at certain load levels. One way to mitigate this is to use linear bids for the generating units. This will result in a much smoother supply curve as shown in Fig. 2.

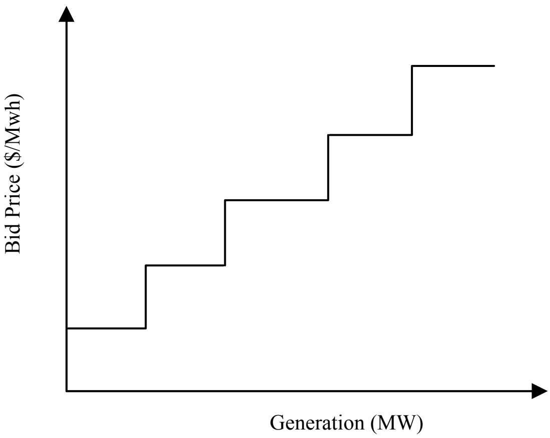

Figure 1: Fixed bids

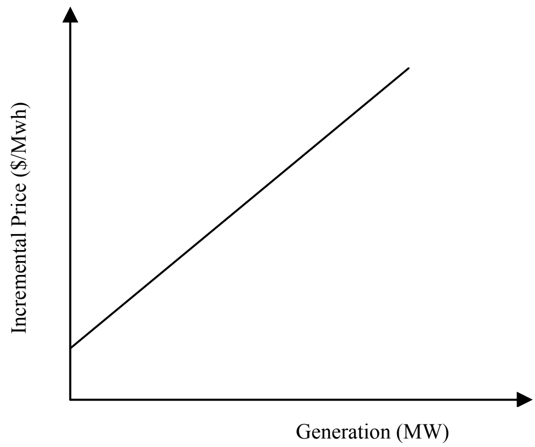

Figure 2: Linear bids

The generator cost curve is given by (2)

$$C_{G_i}(P_{G_i}) = a_i + b_i P_{G_i} + c_i P_{G_i}^2 \text{ (\$)} \tag{2}$$

where $C_{G_i}(P_{G_i})$ is the cost to unit i of generating P_{G_i} MW, a_i is the no-load cost, b_i is the linear cost coefficient and c_i is the quadratic cost coefficient of unit i. The incremental costs of the units can be modelled as fixed quantities (resulting in fixed bids Fig. 1.); or can be expressed as linear function of the unit outputs (resulting in linear bids Fig. 2.) as in (3).

$$\frac{dC_{G_i}(P_{G_i})}{dP_{G_i}} = b_i + c_i P_{G_i} \text{ (\$/Mwh)} \tag{3}$$

3. MATHEMATICAL FORMULATION FOR LMP CALCULATION

In literature LMP calculation with DCOPF with and without considering line losses for fixed bids is solved with Linear Programming approach [28]. In the present paper active power generations of the generators except slack generation are considered in chromosome using GA. The obtained PG's are used in calculation of LMP with and without loss for the congested transmission system. Generation Shift factors (GSF) have been used for the calculation of transmission line flows. Delivery factors (DF) at buses have been used to include the impact of marginal losses on LMP.

The location of reference bus or slack bus will not impact LMP values, when ignoring system losses. But the individual components of LMP depend on the location of reference bus. If transmission losses are balanced at reference bus, i.e., in concentrated loss model the bus LMP's definitely depends on the location of reference bus. In distributed loss model the bus LMP's will not change with respect to reference bus and are independent of the choice of reference bus. It should also be noted that actual GSF values depend on the choice of slack bus, although the line flow based on GSF is the same with different references buses.

3.1 Generation shift factor

Generation shift factor is the ratio of change in power flow of line 'k' to change in injection of power at bus 'i'. GSF coefficient can be computed as

$$GSF_{k-i} = \frac{(B_{(a,i)}^{-1} - B_{(b,i)}^{-1})}{X_k} \tag{4}$$

where B^{-1} = inverse of B (the imaginary part of Y bus matrix)
X_k = reactance of line k
a is sending bus and b is receiving bus of line k

3.2 Delivery factor

The delivery factor (DF) at the ith bus represents the effective MW delivered to the customers to serve the load at that bus.
It is defined as

$$DF_i = 1 - LF_i = 1 - \frac{\partial P_{loss}}{\partial P_i} \tag{5}$$

where LF_i = loss factor at bus i

$$P_{loss} = \sum_{k=1}^{M} F_k^2 \times R_k \tag{6}$$

$$F_k = \sum_{i=1}^{N} GSF_{k-i} \times P_i \tag{7}$$

where F_k = line flow of line k , R_k = resistance of line k,
$P_i = P_{G_i} - P_{D_i}$ = injection at bus i
GSF_{k-i} = generation shift factor to line 'k' from bus 'i'.
The loss factor (LF) at the i^{th} bus may be viewed as the change of total system loss with respect to a 1 MW increase in injection at that bus.

3.3 LMP calculation with concentrated marginal loss using GA based DCOPF

In this method the objective function is minimization of total production cost subjected to energy balance constraint and line flow constraints. However, in LMP based electricity markets, system marginal losses have significant impact on the economics of power system operation. So system marginal losses have to be taken into account for obtaining more accurate LMP's. In this model it is assumed that total system loss is supplied by slack bus generator. This problem is solved with GA and the total fuel cost is compared with LP approach. To simulate concentrated loss model with LP approach fixed bids in Power World Simulator, loss is calculated from Newton Raphson load flow by modifying the line data with resistance (R) taken as 10% of reactance (X). The algorithm for this problem can be framed as follows:

Minimize
$$J = \sum_{i=1}^{N} MC_i * P_{G_i} \tag{8}$$

$$\sum_{i=1}^{N} DF_i \times (P_i) + P_{loss} = 0 \tag{9}$$

$$F_k \leq \text{limit}_k \tag{10}$$

for k=1,2,……M

$$P_{G_i}^{\min} < P_{G_i} < P_{G_i}^{\max} \tag{11}$$

for i=1,2,……N

where
N = number of buses
M = number of lines
$MC_i = b_i + c_i P_{G_i}$ (\$/Mwh), marginal cost at Bus i
P_{G_i} = output power of generator at bus i (Mwh)
limit_k = thermal limit of line k.

DF_i = delivery factor at bus i
P_{loss} = total system loss of the system

P_{loss} in (9) is used to offset the doubled average system loss caused by the marginal loss factor (LF) and the marginal delivery factor (DF).

After getting power outputs of generators for the above dispatch, slack bus power is calculated using (9) and the price at the reference (slack) bus has to be calculated by substituting slack bus power either in fixed bids or linear bids. At the reference bus both loss price and congestion price are always zero. Therefore, the price at the reference bus is equal to the energy component.

Now the LMP formulation at a bus B can be written as

$$LMP_B = LMP^{energy} + LMP_B^{cong} + LMP_B^{loss} \quad (12)$$

The decomposition of LMP is shown here

$$LMP^{energy} = \lambda = \text{price at the reference bus} \quad (13)$$

$$LMP_B^{cong} = -\sum_{k=1}^{M} GSF_{k-B} \times \mu_k \quad (14)$$

where μ_k is the constraint cost or shadow price of line k, defined as:

$$\mu_k = \frac{\text{change in total cost}}{\text{change in constraint's flow}}$$

$$LMP_B^{loss} = \lambda \times (DF_B - 1) \quad (15)$$

(LMP_B^{loss} =0 for lossless power system)

3.4 LMP calculation with distributed marginal loss using GA based DCOPF

Previous model addresses the marginal loss price through the delivery factors. However, the line flow constraints in (10) still assume a lossless network. But the equality constraint in (9) gives total generation is greater than the total demand by the average system loss. This causes a mismatch at slack bus and this mismatch is absorbed by the system slack bus. If system demand is huge like a few GW, then the system loss may be in the order of hundreds of MW and this is not feasible to add that much amount of loss to slack bus. So to address this mismatch issue at slack bus, it is necessary that the line losses are represented in the transmission lines. This paper employs the concept of distributed loss to represent the losses of the lines connected to a bus. In this method system losses are distributed among all buses and eliminate the large mismatch at the reference bus. By this approach, loss in each transmission line is divided into two equal halves, and each half is added to the each bus end of the line as an extra load. So for each bus the total extra load is the sum of halves of line losses which are connected to that bus. Due to the distribution of loss to all buses loss price of LMP is reduced for the same loading level. The extra load at bus 'i' is assumed as E_i, and it is defined as follows:

$$E_i = \sum_{k=1}^{M_i} \frac{1}{2} \times F_k^2 \times R_k \quad (16)$$

Where

M_i = number of lines connected to Bus i.

The line flow F_k for this model is calculated as follows

$$F_k = \sum_{i=1}^{N} GSF_{k-i} \times (G_i - D_i - E_i) \quad (17)$$

The algorithm for this problem is same as in section 3.3. After getting power outputs of generators, LMP's at all buses are calculated using (12), (13), (14), and (15). With this approach the fuel cost is reduced than the concentrated loss model and the burden on the slack bus is eliminated.

4. IMPLEMENTATION OF GENETIC ALGORITHM APPROACH FOR LMP CALCULATION

Genetic algorithms are implemented as a computer simulation in which a population of abstract representations (called chromosomes) of candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem evolves toward better solutions. GAs start with random generation of initial population and then the selection, crossover and mutation are performed until the best population is found. The present work employed roulette wheel parent selection technique, Single point Crossover and bit wise mutation.

In this method power generations of generators (P_{G_i}) except slack bus are taken as the control variables in the chromosomes. The problem is formulated as minimizing the objective function (8) subjected to (9) as equality and (10) as inequality constraints.

4.1 Constraints Handling

Constraints are handled by using penalty function approach. If an individual S_j is a feasible solution and satisfies all constraints, its fitness will be measured by taking the reciprocal of the fuel cost function else it need to be penalized. Using the exterior penalty function approach, the violated operating constraints are incorporated as penalties in objective function.

Calculate the GA fitness function, FF = 100/ (1+ J+ penalties).The penalties are calculated for (9), (10) and slack bus power if they are violated as follows:

Penalty function for line flows:

pcost_f= lambda_f(k)*df*(|pflow(k)|-limit)^2

Penalty function for power balance:

pcost_error= lambda_error*(error)^2

Penalty function for slack bus power:

pcost_s=lambda_s*ds* (pgen (nslack)-s_limit)^2

where lambda_f(k), df, lambda_error, lambda_s, ds are all constants and are taken same value for all cases in each bus system.

4.2 Algorithm for LMP Calculation using GA based DCOPF Approach

Step 1: Read no. of buses, no. of lines, slack bus number, and Bus data. Read GA parameters like population size, chromosome length, no. of units, maximum no. of generations, elitism probability, crossover probability, mutation probability, and epsilon. Read a, b, c coefficients; min. and max. limits of generators. Read line data including line thermal limits.

Step 2: Generate randomly power generations of all generators except slack generator and decode them.

Step 3: Calculate Generation shift factors using (4)

Step 4: Calculate initial line flows using the formula (7)

Step 5: Calculate the system loss i.e., P_{loss} for each line using (6) for both models.

Step 6:Calculate the extra load at each bus 'i' using (16) from initial line flows for distributed marginal loss case, and then calculate new line flows using (17).
Step 7: Calculate delivery factors at each bus using the formula (5).
Step 8: Calculate P_{gen} of slack bus using (9) for both models.
Step 9: Check for line flow limits (10). If the line limits are violated add penalties to objective function.
Step 10: Check for slack bus power limits. If it violates the limits add penalties to objective function.
Step 11:Calculate the marginal fuel costs of all units with the randomly generated PG's; calculate the total cost (8) and then calculate the fitness function = 100/ (1+ total cost+ penalties).
Step 12: Sort the chromosomes in the descending order of fitness.
Step 13: Is iteration = max. no. of iterations. If yes stop else go to step 14.
Step 14: If fitness (1) == fitness (psize)→problem converged
Calculate the energy price of the reference bus either with fixed bids or with linear bids and then calculate LMP's at all buses using (12) and the decomposition of LMP using (13),(14),(15). STOP.
Step 15: Calculate load payments to ISO, ISO payments to generators and ISO profit for all the cases & STOP.
Step 16: Use selection, crossover and mutation operators. Generate new population.
iteration = iteration +1; Go to step 4.

5. CASE STUDIES

The developed GA based DCOPF for concentrated loss and distributed loss models for LMP calculation are applied on IEEE 14bus system [27], New England 39 bus system [24] and 75 bus Indian power system. GA parameters used are Population size: 40, Number of bits for each generator in the chromosome: 12, Elitism probability: 0.15, Crossover probability: 0.85, Mutation probability: 0.01, Tolerance: 0.0001. IEEE 14 bus system has 2 generators, 39 bus system has 10 generators and 75 bus system has 15 generators. The proposed GA based approach for concentrated loss model in fixed bids is compared with LP based DCOPF using Power world simulator and distributed loss model is compared with concentrated loss model in both fixed and linear bids. In LP approach for concentrated loss case, loss is calculated from base case data using ac load flow and is added to the slack bus as load. It is observed that in distributed loss model fuel cost is reduced than concentrated loss model.

5.1 IEEE 14 Bus Test System

Table I presents the active power generations of generators for the IEEE 14 bus system for all cases. For the base case loading, 9th line connecting 4-9 buses is congested with both LP approach and GA approach and its shadow price is 109.253$/MWhr. The corresponding LMPs at all buses are presented in Tab. II. The decomposition of LMP for both models is shown in Tab. III. The generation redispatch for concentrated loss method with GA approach leads to considerable savings in the fuel costs compared to LP approach whereas with distributed loss approach fuel cost is still reduced. From the LMP values it can be observed that loads away from generators have more locational marginal prices, because of the addition of congestion costs and loss costs. Fig. 3 presents a comparison of optimal fuel costs and Fig. 4 shows ISO profit comparison for all the cases studied. Fig. 5 shows the LMP's comparison for all methods. Fig. 6 shows the simulation circuit of concentrated loss model with LP approach fixed bids in Power World Simulator.

Table. I : Active power generations of generators for concentrated and distributed loss models

Generator bus No.	Power Generations in MW with concentrated loss			Power Generations in MW with distributed loss	
	LP approach Fixed bids	GA approach		GA approach	
		Fixed bids	Linear bids	Fixed bids	Linear bids
1 (slack bus)	147.143	144.9	144.9	140.482	140.482
2	117	117.623	117.623	122.003	122.003
System Loss(MW)	5.143	3.527	3.527	3.485	3.485
Total fuel cost ($/hr)	3238.46	3232.49	3091.672	3231.063	3004.002
Load payment to ISO ($/hr)	5005.321	5107.109	4964.398	5150.962	4917.841
ISO profit ($/hr)	1766.861	1874.61	1872.726	1919.898	1913.838

Table. II : LMP's at all buses for both models

Bus No.	LMP's at all buses ($/MWh)				
	Concentrated loss model			Distributed loss model	
	LP approach Fixed bids	GA approach		GA approach	
		Fixed bids	Linear bids	Fixed bids	Linear bids
1	12.34	12.34	11.8	12.34	11.47
2	12.16	12.28	11.74	12.274	11.40
3	11.64	12.12	11.56	12.113	11.21
4	11.20	11.58	11.03	11.576	10.68
5	13.02	13.34	12.79	13.34	12.45
6	25.95	26.28	25.73	26.27	25.39
7	30.49	30.86	30.31	30.85	29.97
8	30.49	30.86	30.31	30.85	29.97
9	40.63	41.00	40.45	41.00	40.11
10	38.02	38.40	37.85	38.40	37.51
11	32.09	32.45	31.9	32.45	31.56
12	27.11	27.48	26.93	27.48	26.59
13	28.02	28.40	27.85	28.39	27.51
14	35.12	35.55	34.99	35.54	34.65

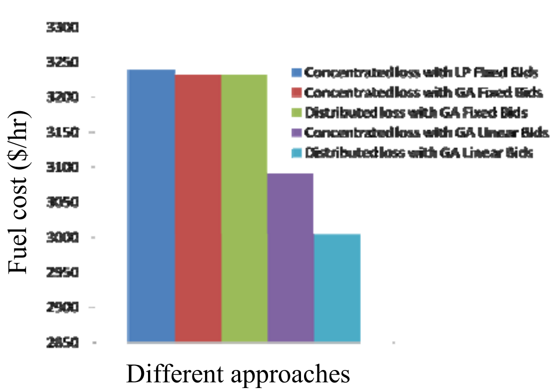

Figure 3: Fuel cost comparison graph for IEEE 14 bus system

Table. III : LMP decomposition at all buses for both models

Bus no	Decomposition of LMP with concentrated loss case with GA fixed bids				Decomposition of LMP with distributed loss case with GA fixed bids			
	Energy price	Congestion price	Loss price	LMP ($/MWh)	Energy price	Congestion price	Loss price	LMP ($/MWh)
1	12.34	0	0	12.34	12.34	0	0	12.34
2	12.34	-0.18	0.12	12.28	12.34	-0.18	0.11	12.27
3	12.34	-0.69	0.47	12.11	12.34	-0.69	0.46	12.11
4	12.34	-1.13	0.37	11.58	12.34	-1.13	0.37	11.57
5	12.34	0.68	0.32	13.34	12.34	0.68	0.31	13.34
6	12.34	13.6	0.33	26.28	12.34	13.6	0.32	26.27
7	12.34	18.14	0.37	30.86	12.34	18.14	0.37	30.85
8	12.34	18.14	0.37	30.86	12.34	18.14	0.37	30.85
9	12.34	28.29	0.37	41.00	12.34	28.29	0.36	41.00
10	12.34	25.68	0.38	38.4	12.34	25.68	0.37	38.4
11	12.34	19.75	0.36	32.45	12.34	19.75	0.36	32.45
12	12.34	14.76	0.38	27.48	12.34	14.76	0.37	27.48
13	12.34	15.67	0.38	28.4	12.34	15.67	0.38	28.39
14	12.34	22.77	0.43	35.55	12.34	22.77	0.43	35.54

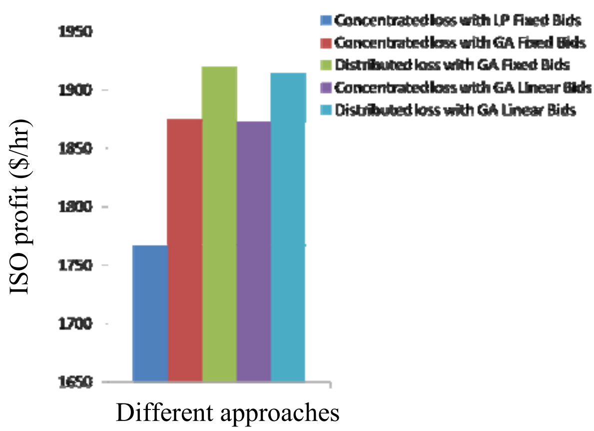

Figure 4: ISO profit comparison graph for IEEE 14 bus system

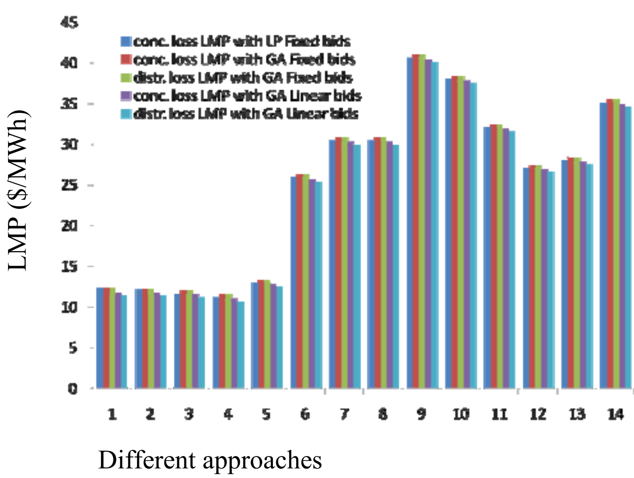

Figure 5: LMP's comparison graph for IEEE 14 bus system

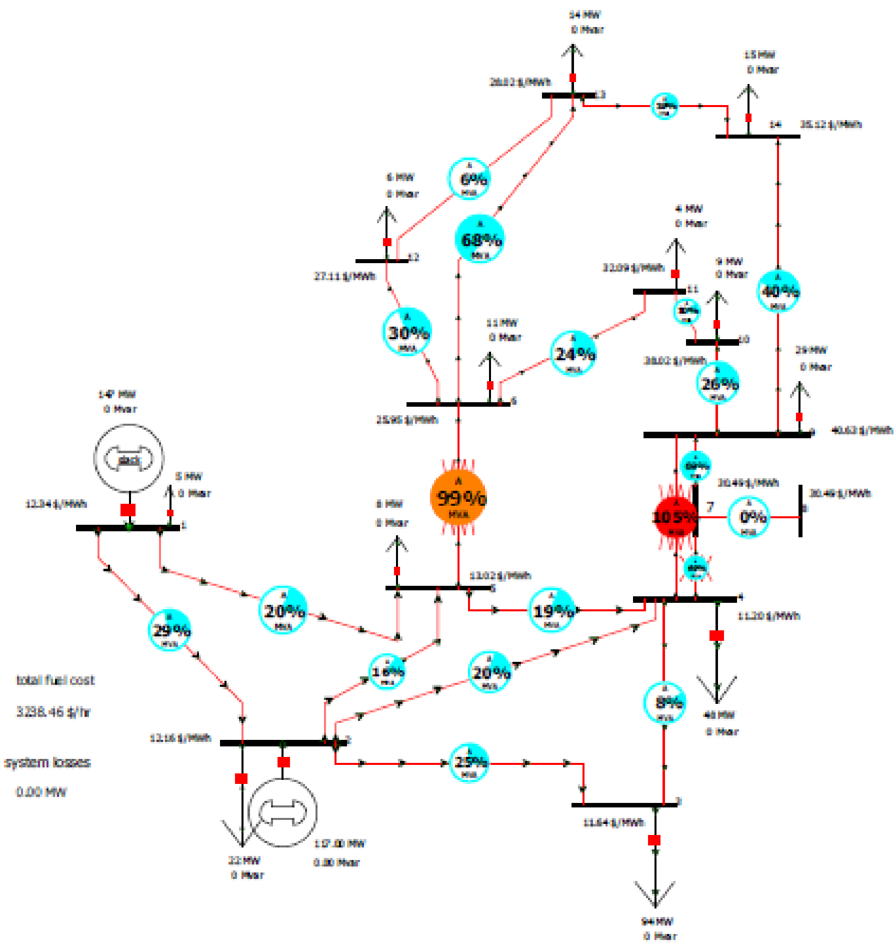

Figure 6: Power world simulation diagram of IEEE 14 bus system for concentrated loss model with LP approach fixed bids

5.2 New England 39 bus test system

For this system also congestion occurred for base case loading only. The generation dispatch for New England 39 bus system [24] are presented in Tab. IV. For concentrated loss case with LP approach 37 and 39 lines are congested whereas only 37th line is congested with GA approach in concentrated and distributed loss cases for both fixed bids and linear bids. Fig. 7 shows the comparison of fuel costs and Fig. 8 shows the comparison of ISO profit for 39 bus system for all the cases studied. In this system also distributed model gives better optimal values of fuel cost. LMP's also calculated at all buses and the comparison graph of LMP's for different methods is shown in Fig. 9. The shadow price for both the congested lines is 2.9 $/MWhr.

Table. IV: Active power generations of generators for concentrated and distributed loss models

Generator bus No.	Power Generations in MW with concentrated loss			Power Generations in MW with distributed loss	
	LP approach	GA approach		GA approach	
	Fixed bids	Fixed bids	Linear bids	Fixed bids	Linear bids
30	220	330.79	292.23	25.95	289.37
31(slack bus)	643.3	641.5	639.66	609.21	609.19
32	750	514.94	660.96	573.70	716.015
33	650	566.98	604.96	643.62	599.43
34	608	455.56	435.2	581.24	428.23
35	605	587.33	727.34	659.37	705.39
36	406	584.96	511.17	511.17	425.28
37	640	534.59	467.03	635.79	491.204
38	777.3	874.76	742.63	845.15	816.87
39	885	1091.33	1099.73	1099.73	1099.73
System Loss (MW)	34.14	32.28	30.45	34.47	30.257
Total fuel cost ($/hr)	83403.645	51850.4	42440.64	51651.58	41809.87
Load payment to ISO ($/hr)	86633.59	50470.72	40992.06	50676.14	40641.87
ISO profit ($/hr)	3229.945	-1379.68	-1448.57	-975.43	-1168.004

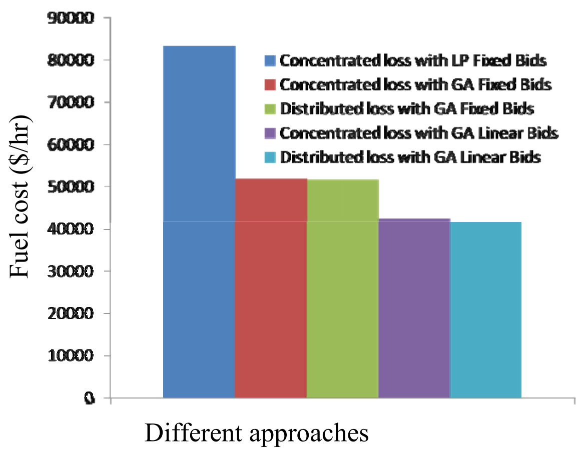

Figure 7: Fuel cost comparison graph for 39 bus New England system

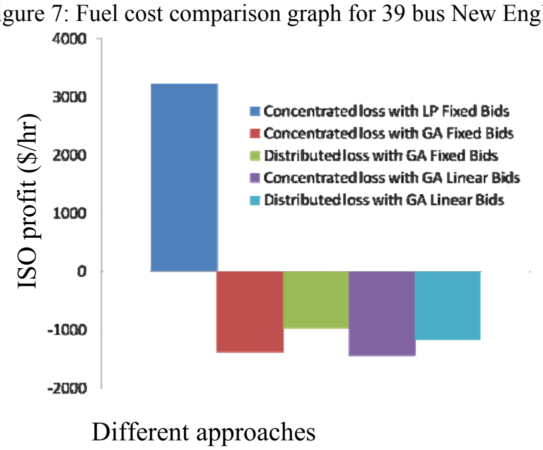

Figure 8: ISO profit comparison graph for 39 bus New England system

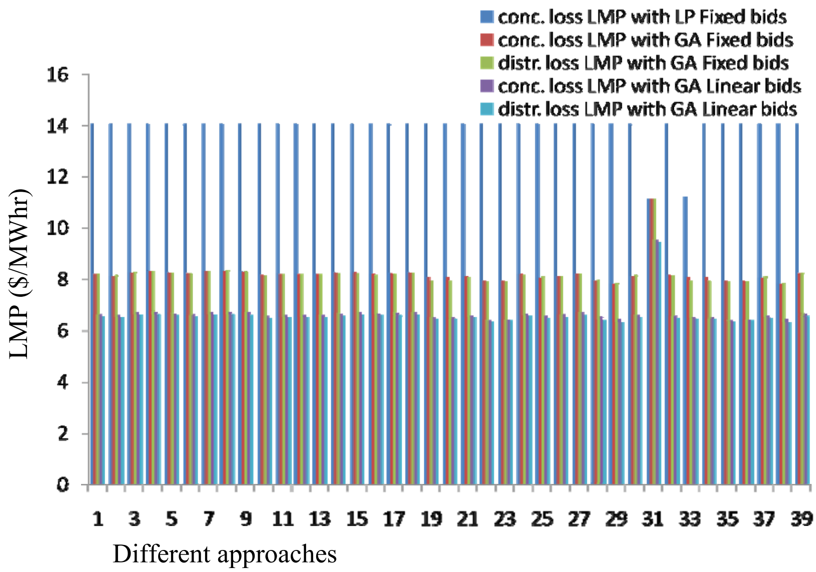

Figure 9: LMP's comparison graph for 39 bus New England system

5.3 75 bus Indian Power system

Similar observations as in the cases of 14 and 39 bus systems are made when the developed algorithm is tested on 75 bus Indian power system. For base case loading of this system 9th line connecting 4-28 buses is congested in concentrated and distributed loss cases of both LP and GA approaches with both fixed and linear bids. The corresponding generations are listed in Tab. V. The LMPs at all buses are calculated (but not reported here). The fuel cost comparison graph is shown in Fig. 10 and and Fig. 11 shows ISO profit comparison for all the cases studied. The shadow price of congested line is 3.67$/MWhr.

Table. V: Active power generations of generators for concentrated and distributed loss models

Generator bus No.	Power Generations in MW with concentrated loss			Power Generations in MW with distributed loss	
	LP approach Fixed bids	GA approach		GA approach	
		Fixed bids	Linear bids	Fixed bids	Linear bids
1(slack bus)	795.367	682.857	732.056	655.121	655.121
2	360	195.444	191.92	202.886	202.886
3	280	279.937	279.93	279.937	279.937
4	185	185.858	185.94	189.062	189.062
5	25	275.953	271.96	271.968	271.968
6	220	219.952	219.95	219.952	219.952
7	160	159.967	159.96	159.967	159.967
8	180	179.962	179.96	179.962	179.962
9	525	342.382	25	337.5	337.5
10	180	179.962	179.96	179.962	179.962
11	209	208.955	208.95	208.955	208.955
12	775	962.500	1431.25	962.5	962.5
13	1000	954.296	761.96	980.242	980.242
14	250	249.945	249.94	249.945	249.945
15	554	553.870	553.87	553.87	553.87
System Loss (MW)	130.247	63.725	64.54	63.715	63.715
Total fuel cost ($/hr)	63427.678	59505.029	51217.544	59505.278	49927.845
Load payment to ISO ($/hr)	62641.35	59476.755	51068.13	60139.684	50345.943
ISO profit ($/hr)	-786.328	-28.273	-149.414	634.406	418.098

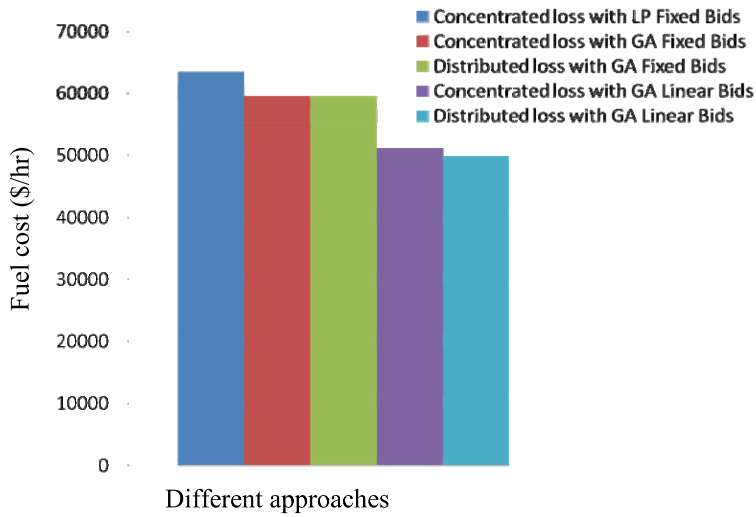

Figure 10: Fuel cost comparison graph for 75 bus Indian Power system

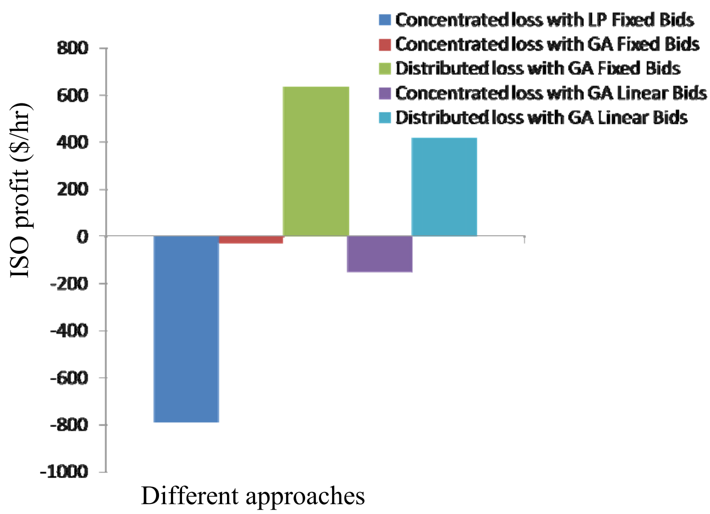

Figure 11: ISO profit comparison graph for 75 bus Indian Power system

6. CONCLUSIONS

This paper presented distributed loss method with Genetic Algorithm for LMP calculation, considering transmission constraints. Fuel cost minimization is taken as the objective function for this work. This is attempted with two types of bids i.e., fixed bids and linear bids for the generators. The proposed distributed loss approach is compared with the concentrated loss approach for IEEE 14 bus, New England 39 bus and 75 bus Indian power systems. It is observed that considerable savings in total fuel cost of generators can be achieved with distributed loss approach with linear bids. LMP's with linear bids are calculated to avoid the non smooth nature of bid curve in fixed bids. In all the case studies, the distributed loss with GA approach shows a reliable convergence with optimized fuel cost values.

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