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AN OPTIMUM LOCATION OF DISTRIBUTED GENERATION FOR SOCIAL SURPLUS MAXIMIZATION IN DEREGULATED ELECTRICITY MARKET WITH INELASTIC LOADS

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ABSTRACT

This paper presents the impact of Distribution Generation (DG) on congestion, loss, Locational Marginal Pricing (LMP), and Social Surplus in the Optimum Power Flow (OPF) based restructured electricity market. The issue of perfect placement of DG to reduce congestion and also lower LMPs is formulated with the objective of social surplus maximization. In this work, the seed genetic algorithm method by using DC Optimal Power Flow (DCOPF) is proposed to calculate LMPs at all buses while maximizing social surplus or minimizing fuel cost. Different scenarios for LMP determination i.e. not considering losses, losses are considered but concentrated at reference bus, and losses are distributed at all buses have been examined. Linear bids are assumed for generators. Here, the load is considered as fixed i.e. inelastic. The impact of DG on loss, congestion, LMP, and social surplus has been presented in IEEE 14- Bus system.

Keywords: *DC Optimal Power Flow, Distributed Generation, Electricity Market, Locational Marginal Pricing, and Social Welfare.*

1. INTRODUCTION

In the year 2003 Energy regulatory commission of federal government suggested a market model for general acceptance by wholesale electricity markets in the United States of America. Worldwide electric power industry is being deregulated to provide competition [1]. One of the important aspects of deregulation is to provide open access, nondiscriminatory and fair power market. Appropriate and impartial pricing of electricity is crucial problem in the deregulated electricity market. An important feature of a market model consists of two part settlement system. First part is day-ahead market uphold by a real-time market to secure continuous adjustment of supply and load for electric power. Second part is spot pricing mechanism to control grid congestion.

Transmission network play important role in transmitting the electrical energy from producers to Consumers in restructured electricity market setting. Congestion is one of the main drawbacks in transmission network. Congestion arises if transmission lines or transformers transmit power beyond heat constraints. Congestion restricts the system operators from transmitting extra power from particular generator. Congestion can hike the cost of power delivery to consumers. Right now there are two pricing methods practiced in the competitive electricity market to accommodate congestion. One is the uniform pricing scheme in which all the generators are compensated the same price i.e. market clear price (MCP) depend on the offer of the marginal generator that will be supplying power when congestion is not present. Another method is the non uniform pricing method also called locational marginal pricing (LMP), in which nodal prices are calculated to manage transmission congestion. Schweppe et al [2] first suggested the spot price which is mostly used for LMP modeling. LMP or spot price for a particular bus is described as the marginal cost to deliver an extra increment of power to that bus subject to not contravene system security constraints. LMP can change automatically from one bus to another bus due to the consequence of transmission losses as well as transmission system constraints. Computationally, LMP at any bus in the system is the dual price variable or also called as shadow price for equality constraint at that node. That is the addition of injection power and withdrawal power at that bus is equal to zero. LMP is the extra cost for supplying one MW extra at certain bus. ISO receives money from customers depending on the LMP for the supplied energy. Generators receive amount from ISO depend on their respective LMP. Congestion price is LMP variation amidst two neighboring buses. LMP variation happen if the electrical energy is transmitted from injection bus to withdrawal bus. Marginal losses show incremental variation in system losses due to incremental demand variation. Incremental losses bring in extra costs which indicate the cost of marginal losses. Hence LMP is equal to the addition of congestion cost, marginal loss cost, and marginal generation cost. Congestion component remains invariant with reference to LMP at particular bus.

In real time market load is mostly constant, i.e. price elasticity of load is zero. In this situation maximizing social welfare is equivalent to minimizing the generation cost. In this paper load is assumed to be constant.

LMP will be determined by two methods in real time market. One is ex post method and another is ex ante method. ISONE, PJM, and MISO implement the ex post pricing method, which arrange incentives to dispatch based on rational prices [3,4]. NYISO adopt ex ante pricing method, which penalizes non fulfilling generators based on reduced generation quantity [5]. Both methods have their own advantages and disadvantages. For instance, ex post pricing have few obstacles in implementing co-optimization of the energy and reserves[13], whereas ex ante pricing scheme has no capacity to penalize underperforming units.

LMP will be calculated by employing ACOPF approach or a DCOPF approach [6-12]. The objective function of OPF is maximizing social surplus while meeting the load and satisfying operational constraints. DCOPF method is suitable for market planning and simulation owing to its toughness and fast. DCOPF is mainly used by many industrial LMP simulators such as ABB's GridViewTM, GE's MAPSTM, Siemen's Promod IVR and power world [14],[15].

In literature various methods were described for determination of LMP. Components of spot prices were described in [16]. In the reference[17] advantages of DC power flow for determining loss penalty factors that has important influence on generation scheduling was also suggested. Further the drawback of using predetermined loss penalty factors from a typical example to all situations was also described. Determination of LMPs and congestion components by using reference bus independent method was depicted in ref [18]. DC power flow method was used to solve marginal loss components of LMPs in [19]. It was reported in [20] in detail that DC Power flow model will be adequate in OPF calculations whenever the line flow is not extreme large, the voltage profile is adequately horizontal and the R/X proportion is not greater than 0.25. DCOPF by using Genetic algorithms for loss less system was elaborated for congestion problems in [21]. Various techniques for LMP composition using DCOPF for loss and loss less system implemented in [22]. Reference [23] presented for LMP calculation for three loss cases, i.e. loss is not considered case, loss is considered but concentrated at slack bus case, and loss is assumed to be distributed at all buses using linear programming method with linear cost curves. LMP was determined using Cumulant & Gram-Charier (CGC) technique and matched it with Monte Carlo and point estimation method in [24]. That approach blends two views of cumalants and gram charlier expansion theory to achieve Probabilistic Distribution Function (PDF) and Cumulative Distribution Function (CDF), which are used for estimating LMPs. This approach will take more time and also difficult. Process of LMP determination is efficiently reported in [13]. Issues and solutions arise during modeling and implementations are also explained in above reference. LMP computation taking into account distributed loss using ACOPF out lined in [25].

Seed genetic algorithm based DCOPF for calculation of social surplus is introduced in this article considering three different loss cases with linear incremental cost curves. The above three cases are examined by placing DG in the system and also by not placing DG in the system. The computation of LMPs and decomposition of LMP components for the three scenarios are explained in this paper. Entire system loss is delivered by reference bus in concentrated loss model. This produces a more load on the reference bus. This issue at the reference bus can be solved by sharing losses to all buses as an additional load in the case of distributed loss model.

2. SOCIAL WELFARE

The sum of the net producer's surplus, ISO surplus and consumer's surplus is called the social surplus or social welfare or global welfare. It quantifies the overall benefit that arises from trading. The global welfare is maximum when a competitive market is allowed to operate freely and the make price settles at the intersection of the supply and demand curves. Assume that the market clearing price is 'P' and the market clearing volume is 'q' as shown in figure-1. Under these conditions the Suppliers profit is the area labeled 'A' and merchandise surplus is equal to the sum of the areas labeled 'B' and 'C'. Supplier's surplus is defined as the amount of revenue received by supplier from selling the power to ISO minus the cost of supplying the power. Merchandise surplus is the amount received by the ISO from consumers minus the amount paid by the ISO to suppliers. Consumers' surplus is defined as the amount consumer is willing to pay, minus actual amount paid by the customer to ISO for consuming the power. In this paper consumer load is assumed as fixed, hence consumers surplus is nil.

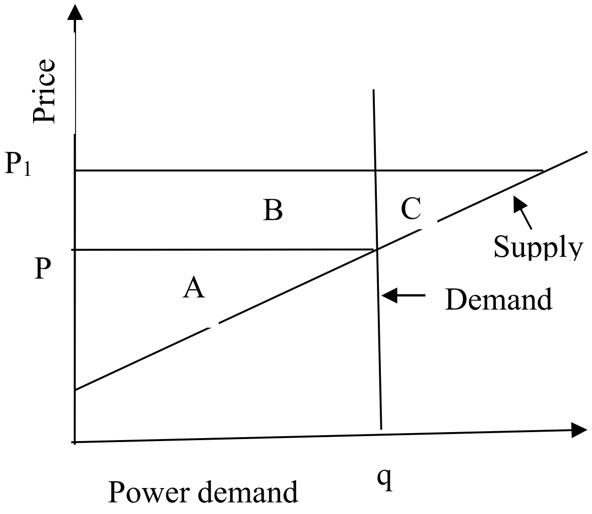

Fig.1: Social welfare in Single Auction Model

When there is no congestion and loss, the market clearing price is equal to the LMP at given bus. When congestion occurs in the transmission system, the LMP at that bus will increase from 'P' to 'P_1,' which includes congestion price and loss price. The ISO collets the difference (P_1 -P) for each MW traded. The total amount collected by ISO in the form of congestion taxes is equal to the sum of areas B and C, which is also called as merchandising surplus. Global welfare is the sum of supplier's surplus and merchandise surplus. Due to congestion the global welfare reduces by an amount equal to the area labeled C. The reduction in social surplus is known as dead weight loss. It is caused by the price distortion due to congestion. The area due to dead weight loss is neither useful to supplier nor useful to customer or ISO. This is one of the major draw backs in electricity trading during system congestion.

3. MATHEMATICAL FORMULATION FOR SOCIAL SURPLUS ESTIMATION

In this article active power generations of all generators baring reference generator are taken into consideration in chromosome employing seed genetic algorithm. The achieved power generations are employed in determination of LMP by considering losses and also not considering losses to the congested transmission system. Generation Shift Factor (GSF) has been employed to determine transmission line losses. Delivery Factors (DF) at all buses are employed for inclusion of losses on LMP.

In no loss case, LMP values are independent of location of slack bus. However the individual components of LMP depend on the location of reference bus. In concentrated loss case, where in losses are balanced at slack bus, the bus LMPs relying on the location of slack bus. In distributed loss case the bus LMPs are not relying on the preference of slack bus. However, the actual GSF values relying on the preference of reference bus.

3.1 Generation Shift Factor

The proportion of variation in power flow of line 'k' to variation in power injected at bus 'i' is called Generation Shift Factor (GSF). It can be calculated by employing (1).

$$GSF_{K-1} = (X_{a,i} - X_{b,i}) / X_K \tag{1}$$

Where $X_{a,i}$ and $X_{b,i}$ are the elements of the 'X' matrix and ' X_k ' is the reactance of line 'k'.

‘a’ , ‘b’ are sending and receiving end buses of line ‘k’.

3.2 Delivery Factor

The active MW supplied to the customers to serve the load at that bus is called delivery factor. It is explained as shown in (2).

$$DF_i = 1 - LF_i = 1 - \partial P_{loss} / \partial P_i \tag{2}$$

$$P_{loss} = \sum_{k=1}^{M} F_k^2 \times R_k \tag{3}$$

$$F_k = \sum_{i=1}^{N} GSF_{k-i} \times P_i \tag{4}$$

$$\frac{\partial P_{loss}}{\partial P_i} = \sum_{k=1}^{M} \frac{\partial}{\partial P_i}(F_k^2 \times R_k)$$

$$= \sum_{k=1}^{M} R_k \times 2 F_k \times \frac{\partial F_k}{\partial P_i}$$

$$= \sum_{k=1}^{M} 2 \times R_k \times GSF_{k-i} \times (\sum_{j=1}^{N} GSF_{k-j} \times P_j) \tag{5}$$

LFi shows the loss factor at bus i as detailed in (2)-(4). It can be determined by employing (5). The power flowing through the line ‘k’ is denoted by ‘F$_k$‘. The resistance of line ‘k’ is shown as ‘R$_k$’. ‘P$_i$’ shows the injected power at bus ‘i’. Load factor will be noted as the variation of entire system loss corresponding to 1 MW raise in injection at that bus. The loss factor at a particular bus can be either negative or positive. Positive loss factor implies that an increase of injection at that bus may raise the loss, however negative loss factor suggest that an increase of injection at that bus may decrease loss.

3.3 Social Surplus Estimation

3.3.1 Case.1: Losses are not considered

The issue of minimization of total generation cost considering load balance and load flow constraint is considered in this case. The issue is worked out with seed genetic algorithm. The LMPs are computed from the achieved generator power outputs. ISO payment to generators, ISO paid by load, total ISO benefit and social surplus are also calculated.

The objective function is

$$\text{Min. } \sum_{i=1}^{N} \{(MC_i * P_{Gi}) + (MC * P_{DG})\} \tag{6}$$

$$\text{S.t: } \sum_{i=1}^{N} (P_{Gi} + P_{DG}) = \sum_{i=1}^{N} P_{Di} \tag{7}$$

$$F_K \le Limit_K , K = 1,2,3....M \tag{8}$$

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} , i = 1,2,3...N \tag{9}$$

$$P_{DG}^{\min} \le P_{DG} \le P_{DG}^{\max} \tag{10}$$

where ‘N’ is the no. of buses,
‘M’ is the no. of lines,
‘MC$_i$’ is the marginal cost at bus i i.e. (b $_i$ + 2c $_i$ .PG$_i$) in $/MWh,
MC is the marginal cost at bus i due to Distributed Generator,
‘PG$_i$’ is the generation of Central Generator at bus i in MWh,
‘PG’ is the generation of Distributed Generator at bus i in MWh,
‘PDi is the load at bus ‘i’,
‘limit$_k$‘ is heat constraint of line ‘k’.

Reference bus power is determined by employing (7) after obtaining generation of generators for this optimization problem. Next the reference bus price is computed by employing reference bus power in linear bids. The two prices i.e. loss price and also congestion price are invariably nil near reference bus. Hence, the price at the slack bus “i” is said to be equal to only energy component. The LMP composition at bus B will be formulated as shown below.

$$LMP_B = LMP_B^{energy} + LMP_B^{cong} + LMP_B^{loss} \tag{11}$$

The Spot price is decomposed as explained here under.

$$LMP_B^{energy} = \lambda \tag{12}$$

λ = price at the slack bus

$$LMP_B^{cong} = -\sum_{k=1}^{M} GSF_{K-B} \times \mu_k \tag{13}$$

Where ‘μ$_k$’ is called as the constraint price of line “k” and it is described as follows

μ_k = (Variation in entire cost) / (Variation in Constraint’s flow)

$$LMP_B^{loss} = \lambda \times (DF_B - 1) \tag{14}$$

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

In this case the losses are not considered; hence LMP at bus b is equal to the summation of energy component and the congestion component at bus b. Even for a lossless system, congestion may arise due to any constraint violation but the loss component is nil. In this situation the

Social Welfare = Supplier Surplus (SG) + ISO surplus (SM)

Where SG =[LMP ($/MWh) × Power generated(MW)] – Cost of Generated Power.

SM =[LMP($/MWh)× Power consumed (MW)] – [LMP ($/MWh) ×Power generated (MW)]

3.3.2 Case.2: Losses are assumed concentrated at slack bus.

Generation cost minimization considering demand balance and load flow limitations is the import issue here. Losses will play vital role on the economy during operation of power system in nodal price based power market. Hence losses are considered for achieving more exact LMPs. In this case it is considered that the entire loss is provided by reference bus generator. The problem is solved with seed genetic algorithm and the social welfare t by placing DG in the system is compared with not placing DG in the system. The loss is tagged on to the reference bus as additional demand by changing the resistance of line.

$$\text{Min}\sum_{i=1}^{N}\{(MC_i * P_{Gi})+(MC * P_{DG})\} \qquad (15)$$

$$\text{S.t:}\sum_{i=1}^{N}\{DF_i\times(P_i)\}+P_{loss}=0 \qquad (16)$$

$$F_K \leq \lim it_K, K=1,2,3\ldots.M \qquad (17)$$

$$P_{Gi}^{\min}\leq P_{Gi}\leq P_{Gi}^{\max}, i=1,2,\ldots.N \qquad (18)$$

$$P_{DG}^{\min}\leq P_{DG}\leq P_{DG}^{\max} \qquad (19)$$

Where 'P_{loss}' is the entire system loss. P_{loss} in (16) is used to cancel out the twice average power system loss induced by the marginal loss factor (LF) and line marginal delivery factor (DF). Later the power generations of generators for the above optimization problem are calculated. Next power at the reference bus is computed by employing (7) or (14) and reference bus price is determined by supplanting slack bus power in linear bids. The loss price and also the congestion price are invariably nil at slack bus. Hence the price at the slack bus is equivalent to the energy part.

System losses and congestion introduce merchandising surplus (SM) or ISO surplus. For a lossless system, with congestion SM may not be zero and can be either positive or negative. If the two effects, losses and congestion, are considered jointly, SM is usually greater than zero. SM can be adopted as a measure of congestion costs and is a reasonable metric to compare the congestion impact on LMPs.

SM will be used to know congestion impact under different load elasticity conditions. The absolute value of SM decreases with an increase in elasticity. In a lossless system, for infinite elasticity, SM is zero as in an unconstrained market. The demand responsiveness can play a major role in competitive electricity markets, particularly in the case of congestion. In this paper load is assumed as fixed i.e. load elasticity is considered as zero. Social welfare is computed similar to no loss case. i.e.

Social Welfare = Supplier Surplus (SG)+ ISO Surplus(SM)

3.3.3 Case.3: Losses are assumed distributed at all buses.

The delivery factors are used for determining the marginal loss price in concentrated loss case. Nonetheless, the line flow limitation in (17) still considers a loss less network. On the other hand equality limitation in (16) gives entire generation is more than the entire demand by the aggregate system loss. It creates a imbalance at reference bus and this imbalance is absorbed by the system reference bus. In case the system load is very high like in GW, then the loss will also be very high like in MW. In that case it is very much difficult to tag on entire loss to reference bus. The loss in any line is split into two equivalent parts and after that each part is tagged on to the bus end of line by treating it an additional load. The entire additional load at each bus is equal to the addition of halves of line losses which are tagged on to that bus.

$$E_i = \sum_{k=1}^{M_i} \frac{1}{2} \times F_k^2 \times R_k \quad (20)$$

Where 'E$_i$' is the additional load at bus 'i'.

'M$_i$' is no. of lines tagged on to bus i.

The load flow for the line F$_k$ to this case is determined using (21)

$$F_K = \sum_{i=1}^{N} GSF_{K-i} \times (P_{Gi} - P_{Di} - E_i) \quad (21)$$

The algorithm for solving this issue is similar as mentioned for case 2. Spot prices at each bus will be computed by employing (11)-(14). Because loss is considered as distributed load , ISO receives loss cost from consumers and hence difficulty on reference bus is removed.

4. SOCIAL WELFARE CALCULATION USING GENETIC ALGORITHM METHOD

Genetic Algorithms are used for optimization problems in which a population of abstract representatives (called chromosomes) of candidate solutions (called individuals) emerge almost better results. The first population of Genetic Algorithm begins by random selection. Later selection, cross over, and mutation will be calculated till the perfect population is determined. Generally genetic algorithms will take more time to converse for a perfect result. This problem will be overcome by seeding the first population with feasible solutions so that the search will start in promising areas of the solution space. This paper uses roulette wheel method for selection of parent, single point for cross over and bitwise for mutation.

4.1 Seeding for Genetic Algorithm:

The fastness of Genetic Algorithm will increase if search will begin in assuring areas of search zone. For this it is suggested to seed the starting population from a case based on already computed issues rather than employing the conventional random selection. This will give best result every time with genetic algorithm. The achieved best result is stored as starting population and this population is termed as seed. Since the search procedure every time begins with the same starting population in the seeding technique for genetic algorithm, the chances of obtaining the perfect result every time will be more.

Power generations of generators (PGi) barring reference bus are considered as the control variables in the chromosomes. The issue is formulated as minimizing the objective function (6) satisfying (7) or (16) as equality constraint and (11), (12) as inequality constraints

4.2 Constraint Handling

Constraints are managed using penalty function method. If an individual Si is a suitable solution and fulfill all constraints, its fitness will be determined by taking the reciprocal of the generation cost function otherwise it is required to be penalized. The contravene operation constraints are incorporated as penalties in objective function in exterior penalty function method.

Determine the genetic algorithm fitness function. FF = 100/(1+J+penalties). If the constraints are violated, the penalties are determined for (7), (16), (18) and slack bus power as mentioned below.

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 fixed values. They will not change for all three loss cases.

5. OVERALL COMPUTATIONAL PROCEDURE FOR SOLVING SOCIAL SURPLUS IN SINGLE AUCTION MODEL EMPLOYING GENETIC ALGORITHM DEPENDENT DCOPF METHOD

Rule.I:Read number of lines, number of buses, reference bus number, and data of bus.

Rule.II: Read Genetic Algorithm particulars viz. size of population, length of chromosome, number of units, the highest number of generations, probability of cross over, probability of elitism, probability of mutation, and value of epsilon.

Rule.III: Read maximum and minimum limitations of generators and also coefficient of generators i.e. a,b, and c.

Rule.IV: Read data of line and also heat constraints of line.

Rule.V: Create power generations of total generators randomly baring reference generator after that decode these generations. Similarly generate randomly power demands of all customers and decode them.

Rule.VI: Determine Generation shift factors by applying (1).

Rule.VII: Compute starting line flows by employing (4).

Rule.VIII:Compute the total loss ie p_{loss} in all lines applying (3) to cases 2 and 3.

Rule.IX: Compute the additional load at all buses employing (20) from starting line flows to case 3 after that compute latest line flows employing (21).

Rule.X: Determine loss factors applying (5) and next delivery factors at all buses applying (2).

Rule.XI: Determine Pgen of reference bus by applying (8).

Rule.XII:Verify line flow constraints as per (8). Add penalties to objective function if the line flow constraints are contravened.

Rule.XIII:Verify reference bus power constraints. Add penalties to objective function if slack bus power constraints are contravened.

Rule.XIV:Compute the social surplus by applying (6) on the randomly created power generation for three loss cases and next compute the fitness function by adding penalties to the objective function.

Rule.XV:Arrange chromosomes in the decreasing order of fitness. Compute the energy price at the slack bus using linear bids and next determine LMP at each bus by applying (11) and the components of LMP using (12),(13), and (14).

Rule.XVI: If iteration is equal to maximum number of iterations stop, otherwise move to rule XVII.

Rule.XVII: problem is converged if fitness (1) is equal to fitness (psize)

Rule.XVIII:Compute the ISO payment to generators by multiplying the power generation at particular bus and the LMP at that bus. Also compute supplier's surplus at each generator by deducting fuel cost from ISO payment to generators.

Rule.IX: Compute the consumers payment to ISO by multiplying the load at particular bus and the LMP at that bus. Also compute the ISO profit by deducting ISO payment to generators from load payment to ISO for three cases. STOP.

Rule.XX: Create latest population by employing operators of selection, crossover, and mutation.

Iteration = iteration +1. Move to rule (VII).

6. RESULTS AND ANALYSIS

Seed Genetic algorithm based DCOPF is employed on the IEEE-14 bus system [26] for social welfare calculation to all three different loss cases: loss is not considered, loss is considered but assumed to be concentrated at reference bus, and loss is assumed to be distributed at all buses. There are two central generators in IEEE-14 bus system. The cost characteristics of central generator-1 are taken as $100+1.083(PG)+0.074(PG)^2$ and the cost characteristics of the central generator-2 are taken as $70+1.033(PG)+0.089(PG)^2$. The cost characteristics of Distributed Generator are taken as 40(PDG)+0.01 (PDG)2 [27]

The following parameters are employed in this case study for genetic algorithm. Population size is taken as 40, number of bits in the chromosome to each generator are assumed to be 12, crossover probability is considered as 0.85, elitism probability is taken as 0.15, mutation probability is assumed to be 0.0001. The result obtained is the best solution after 20 different genetic algorithm runs.

Results for all three loss cases i.e. loss is not considered case, loss is considered but assumed to be concentrated at reference bus, and loss is assumed to be distributed at all buses for IEEE 14 bus system are shown in below mentioned tables and figures for DG connected case. Further these results are compared with the base case results i.e. when DG is not connected to the system mentioned in reference [28].

Social surplus values for all three loss cases for both DG connected and DG not connected scenarios are shown in table-1. It is observed that in all three loss cases, social surplus is maximum when DG is connected at any one bus compared to scenario when DG is not at all connected to system. Further Social surplus is maximum in all three loss cases when DG is connected at Bus 5 compared to when DG is connected to remaining buses. The social surplus when DG is connected at bus 5 is 3775.75$/hr, 4292.55$/hr, and 4312.98$/hr for loss not considered case, loss is concentrated at slack bus case, and loss is distributed at all buses case respectively, which are on higher side when compared to corresponding values for DG not connected to the system cases. The congestion at line connecting buses 4-9 is 105% in all three loss cases when D.G is not connected to the system. But the congestion on the same line in all the three loss cases is not reduced and it is same i.e. 105% when D.G is connected at bus 5. Whereas Congestion is 93.4% in no loss case, 93.4% in concentrated loss case, and 93.5% in distributed loss case when D.G is connected at bus 11. This means there is no congestion at all in three loss cases when DG is connected at bus 11.Social surplus is reduced in no loss case, in concentrated loss case, in distributed loss case when D.G is connected at bus 11 as compared to D.G connected at bus 5. But congestion is totally eliminated when DG is connected at bus 11.Since social surplus is more when DG is connected at bus 11 compared to when DG is not connected to the bus it is preferred to connect DG at bus 11.

LMP values at each bus when DG is connected at bus 11 are listed in table-2 for all three loss cases. It is observed that LMP values at all buses when DG is connected at bus 11 are less than LMP values when DG is not connected to the system in all three loss cases. Highest LMP in concentrated loss and without DG connected case is 51.5$/MWh at bus 9, which has come down to 21.2$/MWh when DG is connected at bus 11. Similarly highest LMPs in no loss and concentrated loss cases when DG not connected scenario are 45.76$/MWh, 51.60$/MWh respectively at bus 9, which have come down to 20.14$/MWh,20.93$/MWh respectively when DG is connected at bus 11. It can be noticed from the LMP values that loads distant from generators have high LMPs due to the inclusion of congestion costs and loss costs. In DG connected cases due to elimination of congestion LMPs have come down to very low values

For no loss case social surplus, LMPs, and other particulars are shown in fig-2, fig-3, and table-3 when DG is placed at bus 11 and also when DG is not connected to the system. Since load is assumed as inelastic, it is fixed at 259 MW. Central Generator-1 dispatched 141.37 MW, Central generator-2 dispatched 117.62 MW to meet the 159 MW load of consumers when the DG is not connected to the system. Whereas Central Generator-1 dispatched 128.76 MW, Central generator-2 dispatched 120.23 MW and Distributed Generator dispatched 10.01 MW to meet the same load when DG is connected to the system. Before connecting DG at bus 11, congestion on line connecting buses 4-9 is 104.68%.With the placement of DG at bus 11, in no loss case, congestion on line connecting between buses 4-7 is 93.4%. That is congestion is totally eliminated with DG placement at bus 11. Because of this congestion cost is zero on this line and also on other lines which lead to reduction of LMPs at all buses by placing DG when compared to not placing DG in the system. Due to contribution of all these factors social surplus is increased to highest from 1492.73 $/hr when DG is not connected case to 2008.81$/hr when DG is connected at bus 11.

For concentrated loss case Social surplus, LMPs, and other particulars are shown in fig-4, fig-5, and table-4 when DG is placed at bus 11 and also when DG is not connected to the system. Since load is assumed as inelastic, it is fixed at 259 MW. Central Generator-1 dispatched 144.9 MW and Central generator-2 dispatched 117.62 MW to meet the 259 MW load of consumers and also to meet loss of 3.5 MW when the DG is not connected to the system. Whereas Central Generator-1 dispatched 131.99 MW, Central generator-2 dispatched 120.03 MW and Distributed Generator dispatched 10.01 MW to meet the same load and also 3.3MW losses when DG is connected to the system.When DG is connected at bus 11 losses have come down from 3.5MW in no DG connected case to 3.3 MW when DG is connected to the system. Before connecting DG at bus 11, congestion on line connecting buses 4-9 is 104.68%.With the placement of DG at bus 11, in concentrated loss case, congestion on line connecting between buses 4-7 is 93.4%. That is congestion is totally eliminated with DG placement at bus 11. Because of this congestion cost is zero on this line and also on other lines which lead to reduction of LMPs at all buses by placing DG when compared to not placing DG in the system. Due to contribution of all these factors i.e. loss reduction and elimination of congestion social surplus is increased to highest from 1492.73 $/hr when DG is not connected case to 2008.81$/hr when DG is connected at bus 11.

For distributed loss case Social surplus, LMPs, and other particulars are shown in fig-6, fig-7, and table-5 when DG is placed at bus 11 and also when DG is not connected to the system. Since load is assumed as inelastic, it is fixed at 259 MW. Central Generator-1 dispatched 140.48 MW and Central generator-2 dispatched 122 MW to meet the 259 MW load of consumers and also to meet loss of 3.5 MW when the DG is not connected to the system. Whereas Central Generator-1 dispatched 130.18 MW, Central generator-2 dispatched 122.03 MW and Distributed Generator dispatched 10.01 MW to meet the same load and losses of 3.31MW when DG is connected to the system.When DG is connected at bus 11 losses have come down from 3.5MW in no DG connected case to 3.31 MW when DG is connected to the system. Before connecting DG at bus 11, in distributed loss case congestion on line connecting buses 4-9 is 104.68%.With the placement of DG at bus 11, congestion on line connecting between buses 4-7 is 93.56%. That is congestion is totally eliminated with DG placement at bus 11. Because of this congestion cost is zero on this line and also on other lines which lead to reduction of LMPs at all buses by placing DG when compared to not placing DG in the system.

Max LMP has come down from 51.60 $/MWh at bus 9 to 20.93$/Mwh, and cost of generation has come down from 3064$/hr in no DG case to 2736$/hr in DG present case due to the placement of low cost Distributed Generator.Due to contribution of all these factors i.e. loss reduction and elimination of congestion social surplus is increased to highest from 1492.73 $/hr when DG is not connected case to 2008.81$/hr when DG is connected at bus 11.

In this work the impact of Distributed Generation in Smart Grid on Social Surplus and Locational Marginal Price in Deregulated Electricity Market is evaluated and compared with Traditional Grid where power is generated by only Central Generators. In ref [28] Social Surplus and Locational Marginal Price was calculated in a restructured electricity market with different loss cases using seed genetic Algorithm. But in that work influence of Distributed Generation in the Grid was not considered. Before connecting D.G to the Grid social surplus was 1492.73$/hr , 1840.47$/hr, 1837.65$/hr with no loss case , concentrated loss case, and Distributed loss case respectively. After connecting D.G to the bus at 11 , the social surplus increased to 2008.81$/hr, 2226.84/$/hr, 2153.41$/hr with no loss case, concentrated loss case, distributed loss case respectively. LMP's also have come down at all buses when DG is connected to the Smart Grid at bus 11.

Hence it is preferred to place DG at bus 11 to increase social surplus, to reduce losses, and to eliminate congestion in deregulated competitive electricity market.

In this work the consumers load is assumed as price inelastic. The consumers load will not change with the change of electricity price. Only Generators will participate in bidding. Hence this model is called single Auction model. In deregulated electricity market if both Generators and consumers participate in bidding then only market power will mostly reduce and efficiency will improve. This is the limitation in this work. This limitation can be overcome by considering consumers load as elastic. That is consumers load will change with the change of price of electricity.

7. CONCLUSION

The impact of distributed generation on congestion, different types of losses, and locational marginal pricing in the optimum power flow based wholesale electricity market is discussed in detail along with the analytical data. The difficulties in the proper placement of the Distributed Generation are evaluated for the handling of congestion. Also, the locational marginal pricing is reduced to maximize social welfare. The proposed Genetic

Algorithm is used to determine the locational marginal pricing at different buses. Locational marginal pricing without losses, concentrated losses, and distributed losses are explained successfully. The effect of Distributed Generation on congestion, loss, and social surplus has been studied.

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Table.1. Social surplus with and without placement of DG at all buses in all three loss cases

Bus-number for DG location	***No loss case***		***Concentrated loss case***		***Distributed loss case***	
	No DG	***With DG***	***No DG***	***With DG***	***No DG***	***With DG***
3	1492.73	3726.47	1840.47	4237.09	1837.65	4108.75
4	1492.73	3735.22	1840.47	4249.26	1837.65	4111.86
5	1492.73	3775.75	1840.47	4292.55	1837.65	4312.98
6	1492.73	2082.41	1840.47	2303.77	1837.65	2152.00
9	1492.73	2082.41	1840.47	2302.39	1837.65	2150.63
10	1492.73	2082.41	1840.47	2302.14	1837.65	2150.38
11	1492.73	2008.81	1840.47	2226.84	1837.65	2153.41
12	1492.73	2082.41	1840.47	2302.46	1837.65	2150.70
13	1492.73	2013.37	1840.47	2230.86	1837.65	2150.34
14	1492.73	2016.79	1840.47	2232.96	1837.65	2151.36

Table.2. *LMPS at all buses in single auction model with and without location of DG at bus 11.*

Bus Number	***LMP's in $/MWh at all Buses in the single auction model***					
	Without loss case		***Concentrated loss case***		***Distributed loss case***	
	Without DG	With DG	Without DG	With DG	Without DG	With DG
1	22.00	20.14	22.52	20.62	22.62	20.35
2	21.85	20.14	22.56	20.79	22.67	20.52
3	21.42	20.14	22.69	21.38	22.80	21.09
4	21.05	20.14	22.08	21.21	22.18	20.93
5	22.58	20.14	23.80	21.12	23.90	20.84
6	33.43	20.14	36.74	21.13	36.84	20.85
7	37.24	20.14	41.36	21.21	41.46	20.93
8	37.24	20.14	41.36	21.21	41.46	20.93
9	45.76	20.14	51.50	21.20	51.60	20.93
10	43.57	20.14	48.91	21.21	49.01	20.92
11	38.59	20.14	42.95	21.15	43.05	20.93
12	34.40	20.14	37.99	21.21	38.09	20.87
13	35.17	20.14	38.91	21.23	39.01	20.93
14	41.13	20.14	46.09	21.31	46.20	20.95

Table.3. *Social surplus and other parameters with and without placement of DG at bus 11 in No loss case in the single auction model*

Particulars	***Central generator-1 out Put in MW***	***Central Generator-2 out put in MW***	***Distributed Generator Output in MW***	***Total Generation in MW***	***Loss in MW***	***Load in MW***	***Congestion at line connecting buses 4-9***	***Supplier Surplus***	***Consumer Surplus***	***ISO Surplus***	***Social Surplus in $/hr***
Without DG	141.37	117.62	No DG	259	Nil	259	104.68%	-44.94	Nil	1537.67	1492.73
With DG	128.76	120.23	10.01	259	Nil	259	93.4%	2008.81	Nil	Nil	2008.81

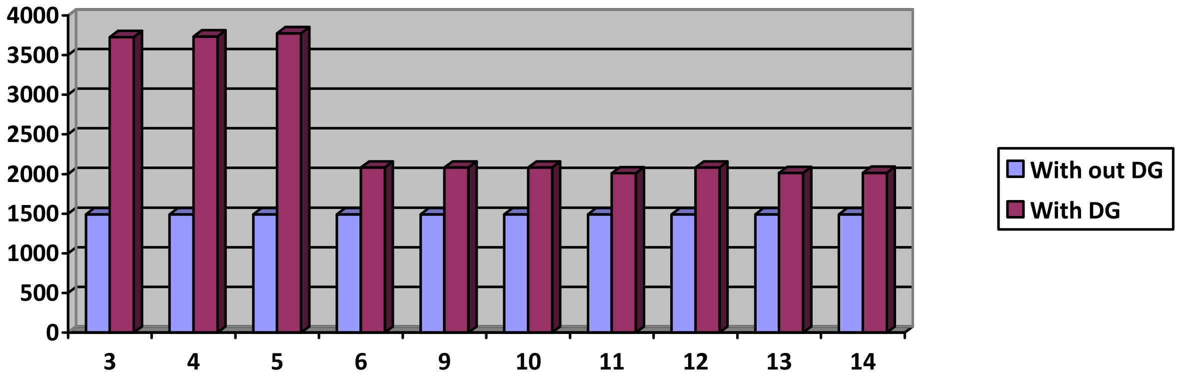

Figure 2: Social surplus with and without placement of DG at each bus in no loss case

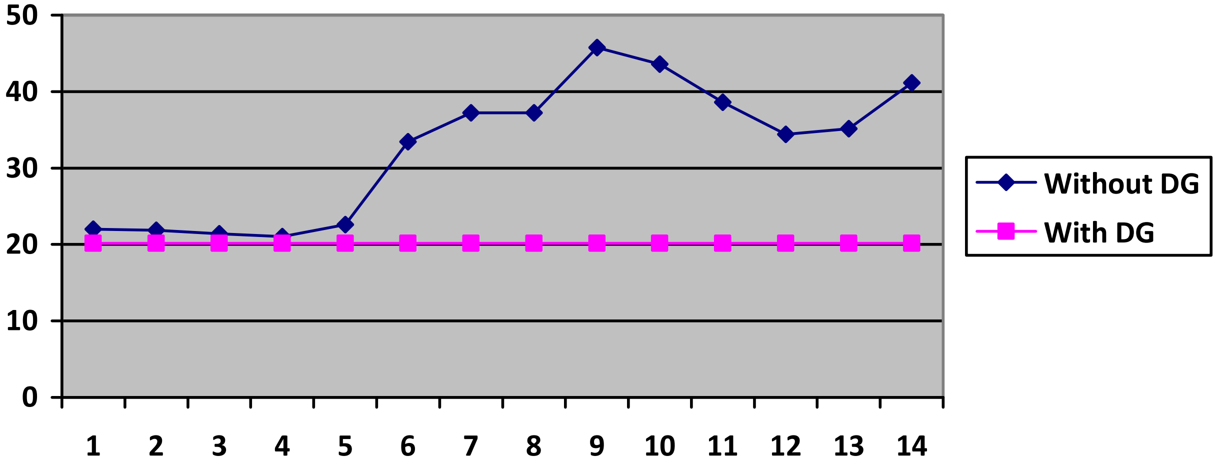

Figure 3: LMPs in $/MWh at all buses with and without placement of DG at bus 11 in no loss case.

Table.4. *Social surplus and other parameters with and without placement of DG at bus 11 in Concentrated loss case in the single auction model*

Particulars	***Central generator-1 out Put in MW***	***Central Generator-2 output in MW***	***Distributed Generator Output in MW***	***Total Generation in MW***	***Loss in MW***	***Load in MW***	***Congestion at line connecting buses 4-9***	***Supplier Surplus***	***Consumer Surplus***	***ISO Surplus***	***Social Surplus in $/hr***
Without DG	144.9	117.62	No DG	262.50	3.5	259	104.68%	-34.14	Nil	1874.61	1840.47
With DG	131.99	120.03	10.01	262.50	3.3	259	93.43%	2160.30	Nil	66.53	2226.84

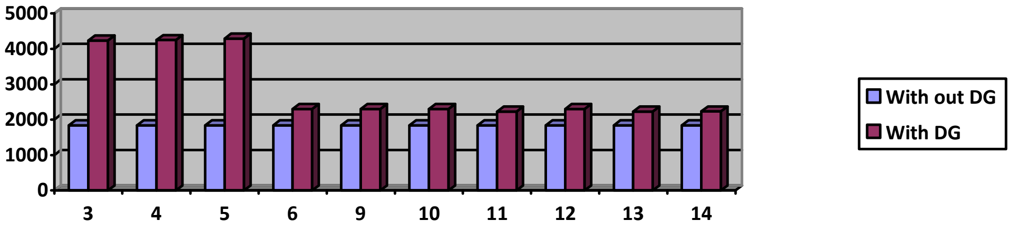

Figure 4: Social surplus with and without placement of DG at each bus in concentrated loss case

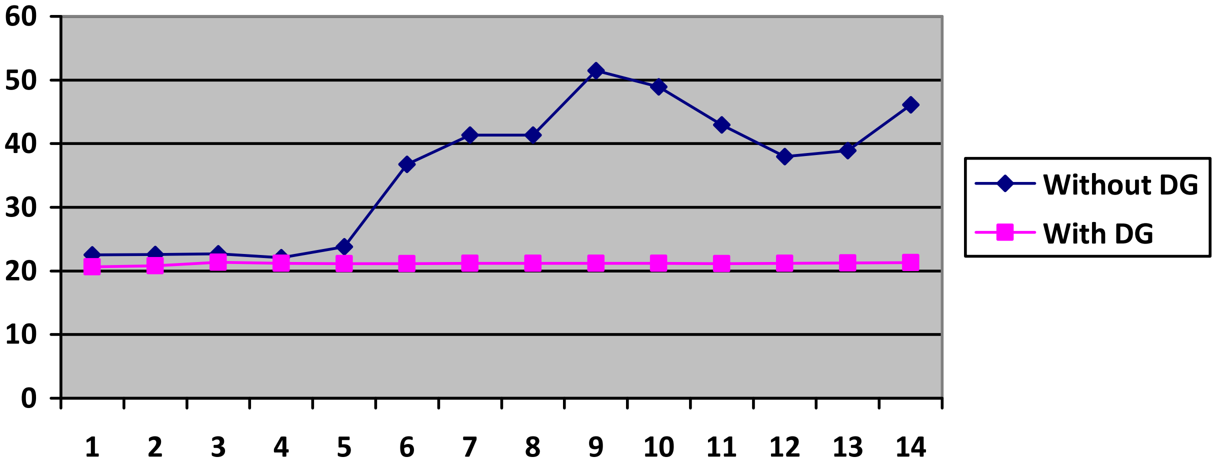

Figure 5: LMPs at all buses in $/MWh with and without placement of DG at bus 11 in Concentrated loss case

Table.5. *Social surplus and other parameters with and without placement of DG at bus 11 in Distributed loss case in the single auction model*

Particulars	***Central generator-1 output in MW***	***Central Generator-2 output in MW***	***Distributed Generator output in MW***	***Total Generation in MW***	***Loss in MW***	***Load in MW***	***Congestion at line connecting buses 4-9***	***Supplier Surplus***	***Consumer Surplus***	***ISO Surplus***	***Social Surplus in $/hr***
Without DG	140.48	122	No DG	262.48	3.5	259	104.75%	-36.06	Nil	1874	1837
With DG	130.18	122.03	10.010	262.4	3.31	259	93.56%	2085.67	Nil	65.35	2151.02

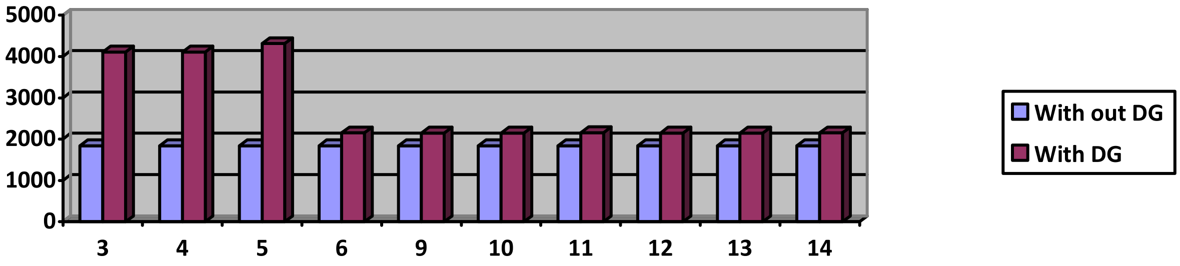

Figure 6: Social surplus with and without placement of DG at each bus in distributed loss case

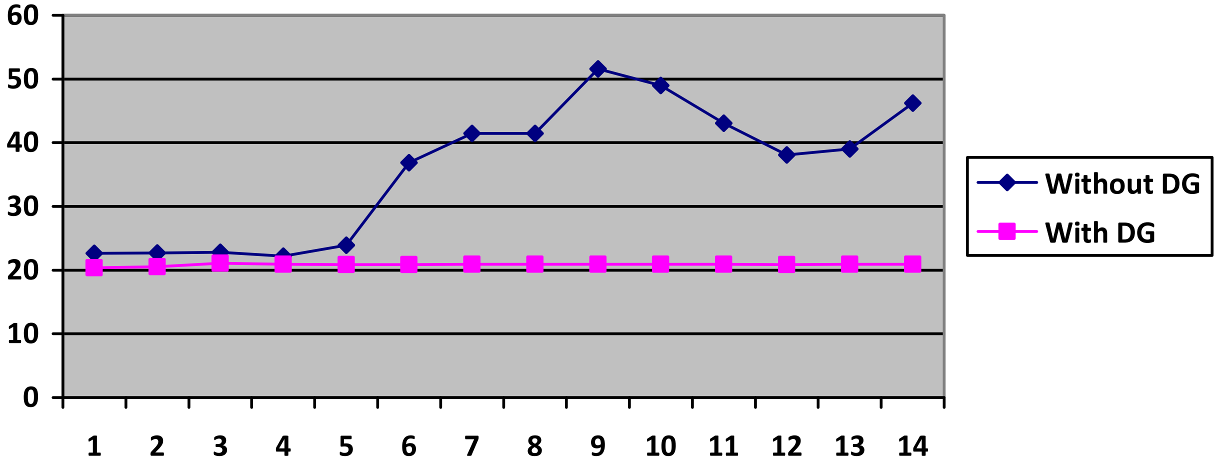

Figure 7: LMPs at all buses in $/MWh with and without placement of DG at bus 11 in Distributed loss case