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IMPACT OF DISTRIBUTED GENERATION IN SMART GRID ON SOCIAL SURPLUS AND LOCATIONAL MARGINAL PRICE IN DEREGULATED POWER MARKET WITH ELASTIC 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 BAT 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 elastic. The impact of DG on loss, congestion, LMP, and social surplus has been presented in IEEE 14- Bus system.

Keywords: BAT Algorithm, *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.

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].

Lack of demand elasticity confers market power on suppliers and demand response is important in mitigating market power. Social welfare maximization in double auction electricity market i.e. consumer also participate in bidding is studied in detail in [27-31].

For single objective optimization problem involving highly nonlinear design functions, Global optimality is not easy to attain. Metaheuristic algorithms are very powerful in dealing with this kind of optimization. Preliminary studies show that a new metaheuristic algorithm, called Bat algorithm, a real coded algorithm is very promising and could outperform existing algorithms. Hence in this paper Bat algorithm has been proposed for solving DCOPF based LMP calculation considering three different loss cases with elastic loads.

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The above three cases are examined by placing DG in the system and also by not placing DG in the system. Placing DG in the Grid is one of important aspect of Smart Grid. 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.

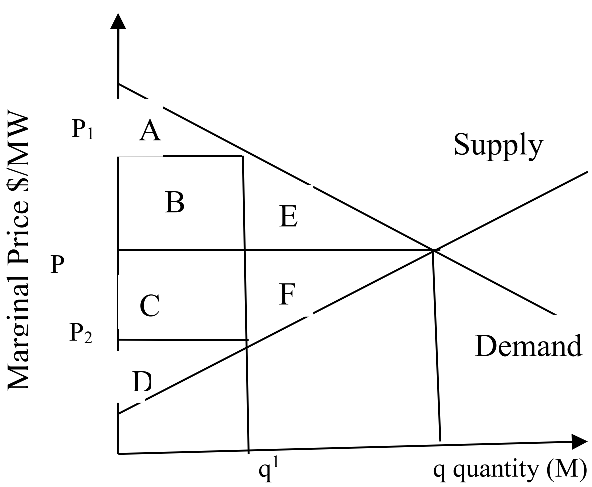

Fig.1: Social Syrplus In Double Auction Model

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 sum of areas labeled 'A', 'B', and 'E' and producers surplus is equal to the sum of the areas labeled 'C','D', and 'F'. 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. 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.

The quantity of power traded decreases from q to q1 when congestion occurs in the transmission system. The corresponding prices are p1 and P2 called locational marginal prices which include congestion price and loss price. The consumer's surplus reduces to area 'A' and the producers surplus reduces to area 'D'. The ISO collects the difference p1-p2 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. Merchandise surplus is the amount received by the ISO from consumers minus the amount paid by the ISO to suppliers. Due to congestion the social welfare reduces by an amount equal to sum of areas E and F. This reduction in social welfare is called the dead loss weight and is the result of the reduction in the amount traded caused by the price distortion. Dead weight loss is not useful either to supplier or to consumer or to ISO. This is the main disadvantage with congestion in electricity trading

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 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).

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

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).

$$DF_i = 1 - LF_i = 1 - \partial P_{loss} / \partial P_i \quad (2)$$

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

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

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

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

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

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 objective of social welfare maximization is widely accepted as basis of problem formulation in competitive electricity market. Objective function is formulated as quadratic benefit curve submitted by buyers minus quadratic bid curve supplied by sellers minus quadratic cost function supplied by DG owner. The objective function is subjected to Load balance and Load flow constraints as detailed below.The objective function is :

Max.

$$\sum_{i=1}^{n} \{B_i(P_{Di}) - C_i(P_{Gi})\} - C(P_{DG}) \quad (6)$$

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

$$F_K \le Limit_K, K = 1,2,3....M \quad (8)$$

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

$$P_{DG}^{\min} \le P_{DG} \le P_{DG}^{\max} \quad (10)$$

$$P_{Di}^{\min} \le P_{Di} \le P_{Di}^{\max} \text{ fori=1,2,3..N} \quad (11)$$

where 'N' is the no. of buses,
'M' is the no. of lines,
'Bi(PDi)' is the consumer benefit function at bus i i.e. (bDi - 2cDi.PDi) in $/MWh,
Ci(PGi)' is the Central Generator offer Price at bus i. i.e.(bGi+2cGi.PGi) in $/MWh,
'C(PDG)' is the cost characteristic of DG i.e.(bDG+2cDGPDG) in $/MWh.
'PGi' is the generation of Central Generator at bus i in MWh,
'PDG' is the generation of Distributed Generator in MWh,
'PDi' is the load at bus 'i','limitk' 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.

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

The Spot price is decomposed as explained here under.

$$LMP_B^{energy} = \lambda \quad (13)$$

λ = price at the slack bus

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

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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)

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

($LMP_B^{loss} = 0$ 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.

$$\text{Max} \sum_{i=1}^{n} \{(B_i(P_{Di}) - C_i(P_{Gi})\} - C\,P_{DG} \quad (16)$$

$$\text{S.t:} \sum_{i=1}^{N} \{DF_i \times (P_i)\} + P_{loss} = 0 \quad (17)$$

$$F_K \le \lim it_K, K = 1,2,3 \dots M \quad (18)$$

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}, i = 1,2,\dots N \quad (19)$$

$$P_{DG}^{\min} \le P_{DG} \le P_{DG}^{\max} \quad (20)$$

$$P_{Di}^{\min} \le P_{Di} \le P_{Di}^{\max} \text{ for i=1,2,..N} \quad (21)$$

Where 'P_{loss}' is the entire system loss. P_{loss} in (17) 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 (17) 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 (18) still considers a loss less network. On the other hand equality limitation in (17) 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.

$$E_i = \sum_{k=1}^{M_i} \frac{1}{2} \times F_k^2 \times R_k \qquad (22)$$

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 (23)

$$F_K = \sum_{i=1}^{N} GSF_{K-i} \times (P_{Gi} - P_{Di} - E_i) \qquad (23)$$

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 BAT ALGORITHM METHOD

In this paper, a metaheuristic search algorithm, called Bat algorithm, which is a real coded algorithm has been proposed for solving DCOPF based spot price calculation with different loss cases for a congested system.

Bat Algorithm:

The basic steps of Bat algorithm for single objective optimization are outlined here. The echolocation characteristics of micro bats can be idealized to develop various bat-inspired algorithms or bat algorithms. In the basic bat algorithm developed by Yang, the following approximate or idealized rules were used.

1.All bats use echolocation to sense distance, and they also 'know' the difference between food/prey and background barriers in some magical way;

2.Bats fly randomly with velocity v_1 at position x_i with a frequency f_{min}, with varying wavelength λ and loudness A_0 to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission r∈ 2 [0, 1], depending on the proximity of their target;

3. Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_0 to a minimum constant value A_{min}.Generally frequency f is selected in the range of [f_{min}, f_{max}] corresponding to the wavelength range of [λ_{min}, λ_{max}]. For example frequency in the range of [20 kHz, 500 kHz] corresponds to wave-lengths of range of 0.7–17 mm. The ranges can be chosen freely to suit different applications.

Bat motion

Bat position x_i and velocity v_i in a d-dimensional search space at a time step 't' are updated using (24)–(26).

$$f_i = f_{min} + (f_{max} - f_{min})\beta \qquad (24)$$

$$v_i^{t+1} = v_i^t + (x_i^t - x^*) f_i \qquad (25)$$

$$x_i^{t+1} = x_i^t + v_i^t \qquad (26)$$

Where $\beta \in$ [0, 1] is a random vector drawn from a uniform distribution. Here 'x' is the current global best location (solution) which is located after comparing all the solutions among all the 'n' bats at each iteration 'i'. As the product $\lambda_i f_i$ is the velocity increment, we can use f_i (or λ_i) to adjust the velocity change while fixing the other factor λ_i (or f_i), depending on the type of the problem of interest. In this paper f_{min} = 0 and f_{max} = 1 are used. Initially, each bat is randomly assigned a frequency which is drawn uniformly from [f_{min}, f_{max}].

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For the local search part, once a solution is selected from among the current best solutions, a new solution for each bat is generated locally using random walk

$$x_{new} = x_{old} + \varepsilon A^{t} \quad (27)$$

where ε is a random number vector drawn from [-1, 1], while $A^{t} = \langle A_i^{t} \rangle$ is the average loudness of all the bats at this time step.

The update of the velocities and positions of bats have some similarity to the procedure in the standard particle swarm optimization, as f_i essentially controls the pace and range of the movement of the swarming particles. To a degree, BA can be considered as a balanced combination of the standard particle swarm optimization and the intensive local search controlled by the loudness and pulse rate.In this method power generations of generators (PG_i) except slack bus are taken as the control variables in the chromosomes. The problem is formulated as minimizing the objective function (6) subjected to (7) or (17) as equality and (8),(9),(10),(11) as inequality constraints.

Loudness and pulse emission

Furthermore, the loudness A_i and the rate r_i of pulse emission have to be updated accordingly as the iterations proceed. As the loudness usually decreases once a bat has found its prey, while the rate of pulse emission increases, the loudness can be chosen as any value of convenience. For example, we can use A_0 = 100 and Amin = 1. For simplicity, we can also use A0 = 1 and A_{min} = 0, assuming A_{min} = 0 means that a bat has just found the prey and temporarily stop emitting any sound.

$$A_i^{t+1} = \alpha A_i^{t}, r_i^{t} = r_i^{o}[1-\exp(-\gamma t)] \quad (28)$$

where α and γ are constants. For any 0 < α < 1 and γ > 0, we have

$$A_i^{t} \to 0, r_i^{t} \to r_i^{o}, \text{ as } t \to \infty \quad (29)$$

In the simplest case, we can use $\alpha = \gamma$, and we have used $\alpha = \gamma = 0.9$ in our simulations. Bat algorithm is very promising for solving non-linear global optimization problems.

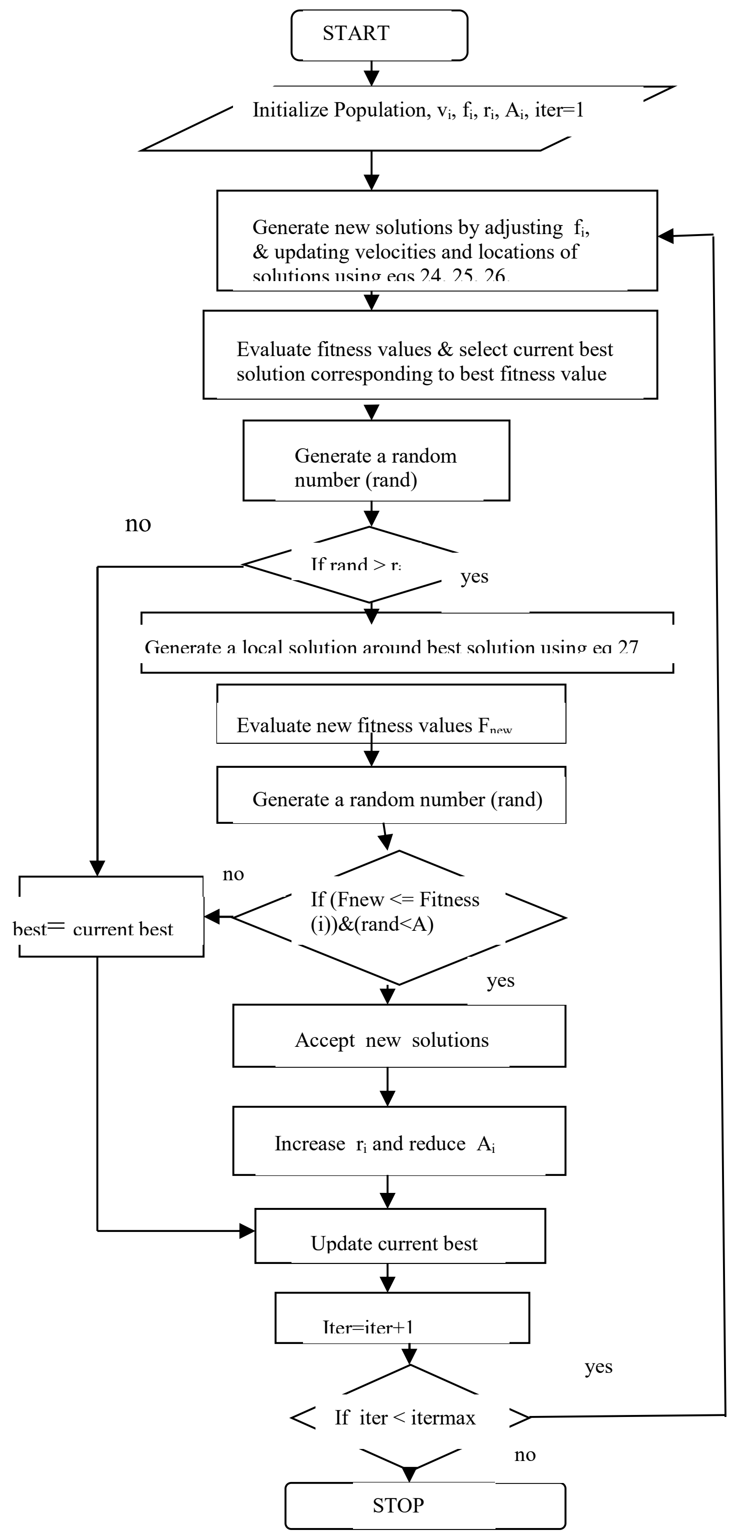

Fig.2. Flow Chart Of BAT Algorithm

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.PSEUDO CODE:

Initialize the bat population x_i (i = 1, 2, . , n) and v_i

Initialize frequencies f_i, pulse rates r_i and the loudness A_i

while (t < Max number of iterations)

Generate new solutions by adjusting frequency, and updating velocities and locations/solutions (24)–(26)

Select a solution among the best solutions

if (rand > r_i)

Generate a local solution around the selected best solution

end if

Evaluate new solutions

if (rand < Ai & $f(x_i) < f(x^*)$)

Accept the new solutions

Increase r_i and reduce A_i

end if

Rank the bats and find the current best x

end while

6. RESULTS AND ANALYSIS

BAT algorithm based DCOPF is employed on the IEEE-14 bus system [32] for social welfare calculation to all three different loss cases. 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(P DG)+0.01 (PDG)^2 [33].

The following parameters are employed in this case study for Bat algorithm. BA parameters used are Population size: 25(10-25) Loudness: 0.25(0-1), pulse rate: 0.5(0-1), f_{min}=0, f_{max}=0.02, $\alpha = 0.9$, $\gamma = 0.9$.

Results for all three loss cases for IEEE 14 bus system are shown in below mentioned tables and figures for DG connected case and DG not connected case. 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 in most cases 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 48868.6$/hr, 48839.8$/hr, and 48868.6$/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 108% in all three loss cases when D.G is not connected to the system. Whereas Congestion is 103% in no loss case, 103% in concentrated loss case, and 106% in distributed loss case when D.G is connected at bus 5. This means congestion is reduced at all in three loss cases when DG is connected at bus 5.Since social surplus is more and also congestion is reduced when DG is connected at bus 5 compared to when DG is not connected to the bus, it is preferred to connect DG at bus 5.

LMP values at each bus when DG is connected at bus 5 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 5 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 109.55$/MWh at bus 6, which has come down to 99.97$/MWh when DG is connected at bus 5. Similarly highest LMPs in no loss and concentrated loss cases when DG not connected scenario are 94.66$/MWh, and 107.07$/MWh respectively, which have come down to 85.77$/MWh, and 30.27$/MWh respectively when DG is connected at bus 5. 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 reduction of congestion LMPs have come down to very low values.

For no loss case social surplus, LMPs, and other particulars are shown in fig-3, fig-4, and table-3 when DG is placed at bus 5 and also when DG is not connected to the system. Since load is assumed as elastic, it is increased to 262MW when compared to load in inelastic load case which is fixed at 259MW. Central Generator-1 dispatched 146.95 MW, Central generator-2 dispatched 114.98MW to meet the 262 MW load of consumers when the DG is not connected to the system. Whereas Central Generator-1 dispatched 86.84 MW, Central generator-2 dispatched 77.54MW and Distributed Generator dispatched 97.92 MW to meet the same load when DG is connected to the system. Before connecting DG at bus 5, congestion on line connecting buses 4-9 is 108%, with the placement of DG at bus 5, in no loss case, congestion on the same line connecting between buses 4-7 is 103%. That is congestion is reduced with DG placement at bus 5. Because of this effect, congestion cost is reduced 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 48743.7 $/hr when DG is not connected case to 48868.6$/hr when DG is connected at bus 5.

For concentrated loss case Social surplus, LMPs, and other particulars are shown in fig-5, fig-6, and table-4 when DG is placed at bus 5 and also when DG is not connected to the system. Since load is assumed as elastic, it is increased to 262 MW when compared to load in inelastic load case. Central Generator-1 dispatched 150.59 MW and Central generator-2 dispatched 114.98 MW to meet the 262 MW load of consumers and also to meet loss of 3.6 MW when the DG is not connected to the system. Whereas Central Generator-1 dispatched 88.88 MW, Central generator-2 dispatched 77.54 MW and Distributed Generator dispatched 97.92 MW to meet the same load and also 2.04 MW losses when DG is connected to the system.When DG is connected at bus 5 losses have come down from 3.64 MW in no DG connected case to 2.04 MW when DG is connected to the system. Before connecting DG at bus 5, congestion on line connecting buses 4-9 is 108%.With the placement of DG at bus 5, in concentrated loss case, congestion on line connecting between buses 4-7 is 103%. That is congestion is reduced with DG placement at bus 5. Because of this congestion cost is reduced on this line and also on other lines. This leads 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 reduction of congestion social surplus is increased to highest from 48659.5 $/hr when DG is not connected case to 48868.6 $/hr when DG is connected at bus 5.

For distributed loss case Social surplus, LMPs, and other particulars are shown in fig-7, fig-8, and table-5 when DG is placed at bus 5 and also when DG is not connected to the system. Since load is assumed as elastic, it is increased to 265 MW when compared to load in inelastic case. Central Generator-1 dispatched 134.45 MW and Central generator-2 dispatched 130.84 MW to meet the 265 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 103.42 MW, Central generator-2 dispatched 67.99 MW and Distributed Generator dispatched 91.92 MW to meet the same load and losses of 1.79MW when DG is connected to the system. When DG is connected at bus 5 losses have come down from 3.5MW in no DG connected case to 1.79 MW when DG is connected to the system. Before connecting DG at bus 5, in distributed loss case congestion on line connecting buses 4-9 is 108%.With the placement of DG at bus 5, congestion on line connecting between buses 4-7 is 106%. That is congestion is reduced with DG placement at bus 5. Because of this congestion cost is reduced 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.

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 [26] Social Surplus and Locational Marginal Price was calculated in a restructured electricity market with different loss cases using seed genetic Algorithm by assuming consumer loads as inelastic. In this work consumer loads are assumed elastic. The loads of consumers will change with the price of electricity. Further in this work BAT algorithm is used for solving the problem.When D.G is connected at bus 5 social surplus is increased to 48868.6$.hr, 48839.8$/hr, and 48868.6$/hr in no loss case, concentrated loss case, and distributed los case respectively

Hence it is preferred to place DG at bus 5 to increase social surplus, to reduce losses, and to reduce congestion in deregulated competitive electricity market.

In this work the impact of Distributed Generation in Smart Grid on social surplus is evaluated. Smart Grid consists of Distributed Generation, Storage Batteries etc. Impact of storage Batteries on social surplus is not considered in this article. This is the limitation in this work. This limitation can be overcome by connecting Storage Batteries to the Grid at optimum location for the objective of social welfare maximation.

7. CONCLUSION

The impact of distributed generation on Social surplus, 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 BAT 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.

REFRENCES:

[1]Singh.H, Hao.S, Papalexopoulos.A, “Transmission congestion management in competitive electricity markets” IEEE Trans Power System, Vol.13, No.2, May 1998,pp.672–680.

[2] Schweppe.F.C, Caramanis.M, Tabors.R, Bohn.R. “Spot pricing of electricity”. Kluwer Academic Publishers,Boston,1988.

[3]PJM Training Materials-LMP 101, PJM.

[4]FERC electric rate schedule. ISO-New England;2001.

[5]NYISO Transmission & Dispatch Operations Manual, NYISO; 1999.

[6] Rivier M, Perez-Arriaga IJ, Luengo G. JUANAC,”a model for computation of spot prices in interconnected power systems”. In: Proceedings of the 10th power systems computation conference (PSCC). Graz, Austria; August 1990. p. 254–261.

[7] Hogan WW:” Contract networks for electric power transmission: technical reference, John F. Kennedy School of Government, Harvard University; Cambridge, February 1992.

[8] Ring B.J: ”Dispatch based pricing in decentralized power systems”, Ph.D dissertation, Univ. Canterbury, Christchurch, New Zealand; 1995.

[9] Ring BJ, Grant Read E: “A dispatch based pricing model for the New Zealand electricity market. In: Einhorn.M, Siddiqi.R, editors. Electricity transmission pricing and

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

technology. Kluwer Academic Publishers, Boston, 1996. p. 183– 206.

[10] Baughman ML, Siddiqi SN, Zarnikau JW, "Advanced pricing in electrical systems" Part I: Theory, IEEE Trans Power System ,Vol.12,1997,p.p.489–495.

[11] Baughman ML, Siddiqi SN, Zarnikau J, "Advanced pricing in electrical systems", Part II: Implications, IEEE Trans Power Systems, Vol.12,1997,p.p.:496–502.

[12] Alvey T, Goodwin D, Ma X, Streiffert D, Sun D,"A security constrained bid-clearing system for the New Zealand wholesale electricity market", IEEE Trans Power System,Vol.13, May 1998,p.p.340–346.

[13]Litvinov E. "Design and operation of the locational marginal prices-based electricity markets", IET Gen. Transm. Distrib 2010; Vol.4(2),2010,p.p.315–323.

[14] Clayton RE, Mukerji. R, "System planning tools for the competitive markets", IEEE Comput Appl Power,9(3),1996,p.p.50–55.

[15] Yang J, Li F, Freeman L.A.A.,"A market simulation program for the standard market design and generation/transmission planning", In: Proc IEEE power Eng. Soc General Meeting; 2003. P.p. 442–446.

[16] Chen Luonan, Suzuki Hideki, Wachi Tsunehisa, Shimura Yukihiro," Components of nodal prices for electric power systems", IEEE Trans Power Syst,Vol.17(1),2002,

[17] Ramos JLM, Exposito AG, Moron FJC, Becerra SN," On the use of loss penalty factors for generation scheduling. In: Proc IEEE power Eng. Soc. annual meeting, vol. 2; 2003. p. 926–931.

[18] Litvinov E, Zheng T, Rosenwald G, Shamsollahi ," Marginal loss modeling in LMP calculation", IEEE Trans Power Syst.Vol.19(2),2004,p.p.880–888.

[19] Li F, Pan J, Chao H," Marginal loss calculation in competitive spot market", In: Proc IEEE Int. Conf. Deregulation, Restructuring Power Technol (DRPT), vol. 1; 2004. p.p. 205–209.

[20] Purchala K, Meeus L, Dommelen DV, Belmans R,"Usefulness of dc power flow for active power flow analysis". In: Proc IEEE Power Eng.Soc Annual meeting; 2005. p.p. 454–459.

[21] Nabav SMH, Jadid Shahram, Masoum MAS, Kazemi A,"Congestion management in nodal pricing with genetic algorithm",International conference on power Electronics, Drives and Energy systems, PEDES; 2006.

[22] Fu Yong, Li Zuyi,"Different models and properties on LMP calculations", IEEE Power Engineering Society General meeting; 2006

[23] Li Fangxing, Bo Rui,"DCOPF-based LMP simulation: algorithm, comparison with ACOPF, and sensitivity", IEEE Trans Power Syst.Vol.22(4),2007.

[24] A.Rahimi Nezhad, G.Mokhtari, M.Davari, A.Roghani Araghi , S.H.Hosseinian, GB Gharehpetian, " A new high accuracy method for calculation of LMP as a random variable", International conference on electric power and energy conversion systems, EPECS; 2009.

[25] Hu Zechun, Cheng Haozhong, Li Furong," An iterative LMP calculation method considering loss distributions",IEEE Trans Power Syst. Vol.25(3),2010.

[26] M.Murali, M.Sailaja Kumari, M.Sydulu, "Estimation of Locational Marginal Price in a Restructured Electricity Market with Different loss cases using Seed Genetic Algorithm", Arabian Journal of Science and Engineering, 2014, pp.1089-1106.

[27]Rajesh Rajaraman, Jayant V.Sarlashkar, Fernando L.Alvarado,"The effect of Demand Elasticity on security prices for the POOLCO and multi-lateral contract models",IEEE Trans. on Power Systems, Vol.12, No.3, August 1997, p.p.1177-1184.

[28] J.D.Weber, T.J.Overbye,"A Two-Level Optimization Problem for Analysis of Market Bidding Strategies", IEEE Power Engineering Society Summer meeting,1999.

[29] Ettore Bompard,Enrico Carpaneto, Gianfranco Chicco,"The Role of Load demand elasticity in congestion management and pricing", IEEE Power Engineering Society Summer meeting,2000.

[30] Paolo Marannino,Riccardo Vailati, Fabio Zanellini,Ettore Bompard,George Gross,"OPF tools for optimal pricing and congestion management in a two sided auction market structure", IEEE Power Tech Proceedings,2001.

[31] James D.Weber,Thomos J.Overbye," An Individual Welfare Maximization Algorithm for Electricity Markets",IEEE Transactions on Power Systems,Vol.17,No.3,August 2002,p.p.590-596.

[32]Iyambo PK, Tzoneva R,"Transient stability analysis of the IEEE 14-bus electric power system", IEEE conference, Africon; 2007

[33] Durga Gautam ,Mithulananthan Nadarajah,"Influence of Distributed Generation on Congestion and LMP in competitive Electricity Market", International Journal of Electrical and computer Engineering, vol.4,No.3,2010, p.p.605-612.

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	48743.7	48764.4	48659.5	48746.2	48489.9	48268.7
4	48743.7	46953.3	48659.5	46947.4	48489.9	48813.7
5	48743.7	48868.6	48659.5	48839.8	48489.9	48868.6
6	48743.7	47864.6	48659.5	47828.4	48489.9	47782.9
9	48743.7	48680.2	48659.5	48615.1	48489.9	48094.1
10	48743.7	47265	48659.5	47214.2	48489.9	47320.3
11	48743.7	47457.8	48659.5	47441.4	48489.9	47724.2
12	48743.7	47446.6	48659.5	47390.3	48489.9	47965.7
13	48743.7	47745.7	48659.5	47718.5	48489.9	47737.5
14	48743.7	46797.8	48659.5	46785.6	48489.9	45980.2

Table.2. *LMPS at all buses in double auction model with and without location of DG at bus 5.*

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	22.83	13.94	23.37	14.24	20.98	16.39
2	23.09	14.20	23.93	14.65	21.48	16.33
3	23.85	14.95	25.49	15.89	22.98	16.19
4	24.49	15.60	26.09	16.51	23.6	15.54
5	21.83	12.94	22.81	13.23	20.33	17.34
6	94.66	85.77	109.55	99.97	107.07	30.27
7	56.39	47.49	64.06	54.47	61.57	34.83
8	56.39	47.49	64.06	54.47	61.57	34.83
9	73.17	64.27	84.03	74.45	81.55	44.97
10	76.99	68.09	88.61	79.01	86.12	42.38
11	85.67	76.78	98.92	89.32	96.43	36.45
12	92.96	84.07	107.63	98.01	105.13	31.49
13	91.64	82.74	106.06	96.44	103.56	32.41
14	81.24	72.35	93.77	84.13	91.27	39.55

Table.3. *Social surplus and other parameters with and without placement of DG at bus 5 in No loss case in the double 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	146.95	114.98	No DG	262	Nil	262	108%	2958.32	40198.85	5586.63	48743.7
With DG	86.84	77.54	97.92	262	Nil	262	103%	822.81	42383.3	5662.46	48868.6

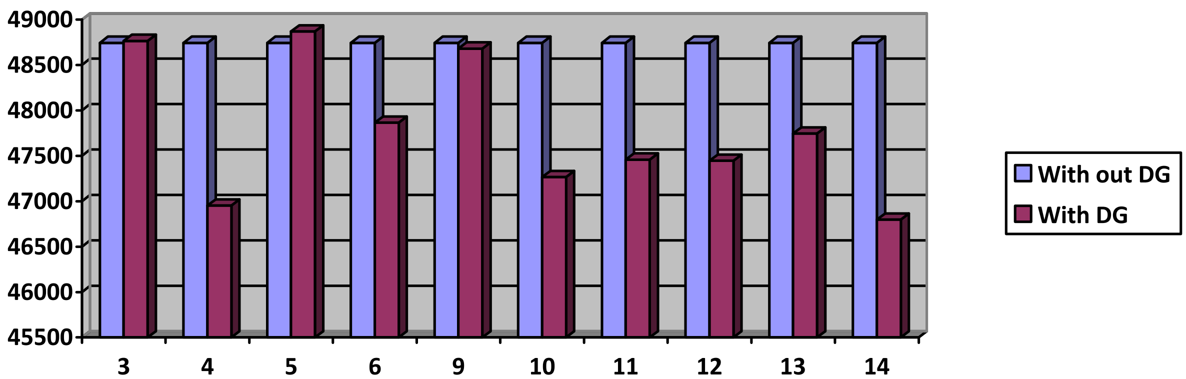

Figure 3: Social surplus with and without placement of DG at each bus in no loss case

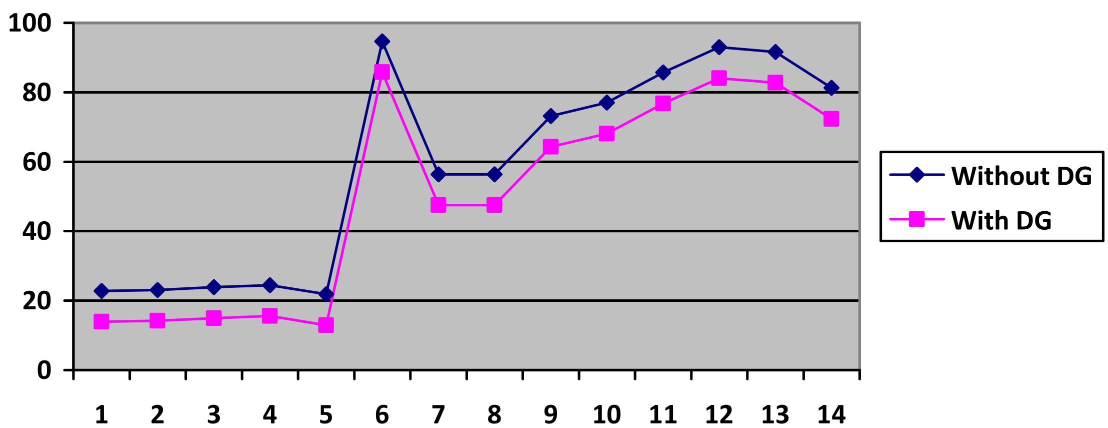

Figure 4: LMPs in $/MWh at all buses with and without placement of DG at bus 5 in no loss case.

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Table.4. *Social surplus and other parameters with and without placement of DG at bus 5 in Concentrated loss case in the double 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	150.59	114.98	No DG	270	3.64	265	108%	3134.05	38787.7	6737.79	48659.5
With DG	88.88	77.54	97.92	264.35	2.04	262.31	103%	822.81	51624	5662.46	48868.6

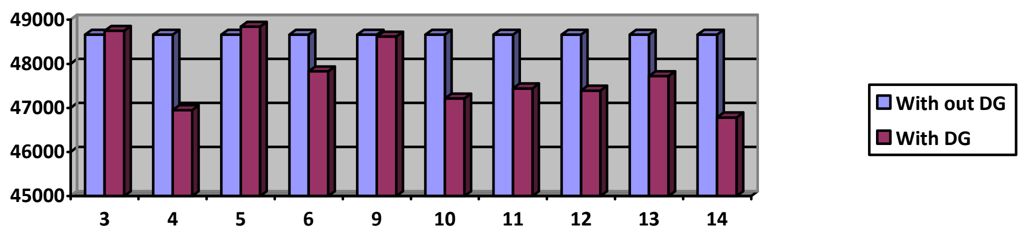

Figure 5: Social surplus with and without placement of DG at each bus in concentrated loss case

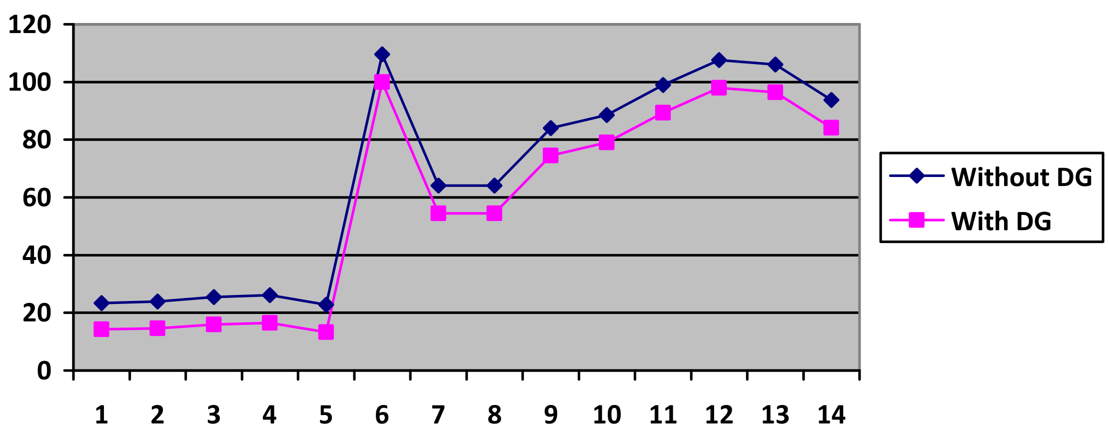

Figure 6: LMPs at all buses in $/MWh with and without placement of DG at bus 5 in Concentrated loss case

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Table.5. *Social surplus and other parameters with and without placement of DG at bus 5 in Distributed loss case in the double 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	134.45	130.84	No DG	270	3.5	265	108%	2489.33	39315.2	6685.34	48489.9
With DG	103.42	67.99	91.92	263.3	1.79	261.54	106%	1452.97	45343.5	2017.25	48813.7

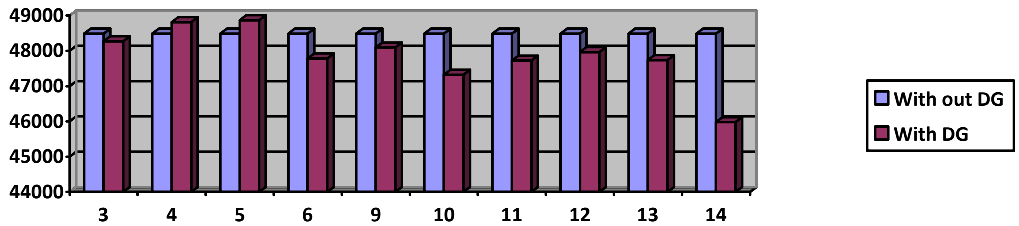

Figure 7: Social surplus with and without placement of DG at each bus in distributed loss case

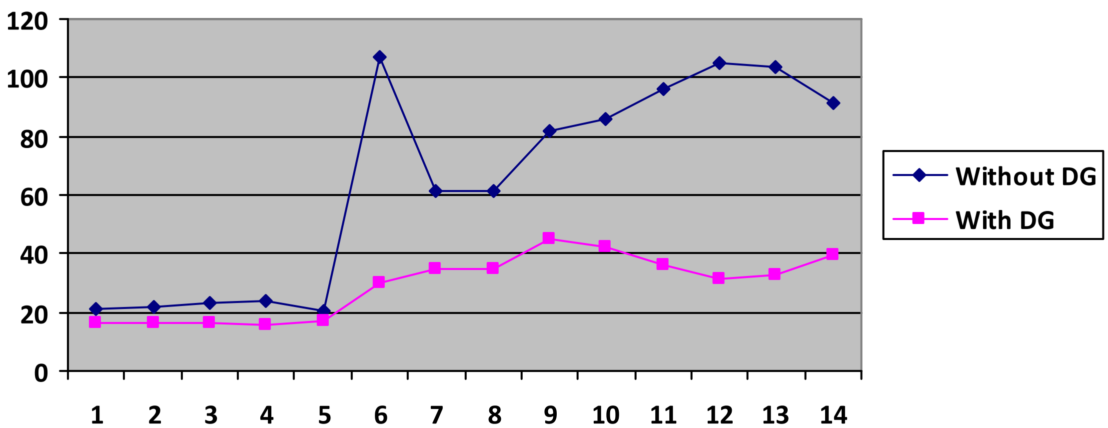

Figure 8: LMPs at all buses in $/MWh with and without placement of DG at bus 11 in Distributed loss case