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Research Article

Optimal Bidding Strategy in Power Market before and after Congestion Management Using Invasive Weed Optimization

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Abstract: Power companies world-wide have been restructuring their electric power systems from a vertically integrated entity to a deregulated, open-market environment. Previously, electric utilities usually sought to maximize the social welfare of the system with distributional equity as its main operational criterion. The operating paradigm was based on achieving the least-cost system solution while meeting reliability and security margins. This often resulted in investments in generating capacity operating at very low capacity factors. Decommissioning of this type of generating capacity was a natural outcome when the vertically integrated utilities moved over to deregulated market operations. This study proposes an optimizing base and load demand relative binding strategy for generating power apprises of different units in the investigated system. Afterwards, congestion effect in this biding strategy is investigated. The described systems analysis is implemented on 5 and 9 bus systems and optimizing technique in this issue is the Invasive Weed Optimization algorithm; the results are then compared by GA. Finally, examined systems is simulated by using the Power World software; experimental results show that the proposed technique (Invasive Weed Optimization) is a high performance by compared GA for the congestion management purposes.

Keywords: Congestion management, genetic algorithm, invasive weeds optimization, local marginal price, power flow, power market, power world software

INTRODUCTION

Since the last two decades, many electric utilities world-wide have been forced to change their ways of doing business, from vertically integrated functioning to open-market systems. The reasons have been many and differed across regions and countries.

In developing countries, the main issues have been high demand growth associated with inefficient system management and irrational tariff policies, among others (Goncalves and Vale, 2003). This has affected the availability of capital investment in generation and transmission systems. In such a situation, many countries were forced to restructure their power sectors under pressure from international funding agencies. On the other hand, in developed countries, the driving force has been to provide the customers with electricity at lower prices and to offer them greater choice in purchasing electricity (Huang and Ping, 2001; Taylor *et al*., 2002).

In front of the days restructuring, the power grid used to be operated by vertically integrated utilities, who had control over both generation and transmission appliances (Perveen and Srivastava, 2000).

There are several methods to the congestion management. One of these methods is capacitance auction. Independent system operator auctions are some of the determined transmission generally (partially) in a short time and typically are transmissions which happens congestion to them. In the Pool Markets congestion management using Load flow and (LMP) is done (Henry *et al*., 2003; Lo *et al*., 2000).

The Independent System Operator (ISO) is a regulating entity autonomous from the electric companies and optimizes the overall system operation. Spot pricing theory is used for economic generation and load dispatch. Under the pool system, locational prices are computed by the marginal cost of optimal power flow solutions (Hajimirsadeghi and Lucas, 2009; Mehrabian and Yousefi-Koma, 2007).

In this study, Power Transfer Distribution Factors (PTDF) is used to congestion management implementation.

Following this tradition, in Mehrabian and Lucas (2006) proposed the Invasive Weed Optimization (IWO) a derivative-free, met heuristic algorithm, mimicking the ecological behavior of colonizing weeds. This algorithm is then applied to investigation the problem and also to analysis the effect of each unit to the local marginal price.
Comparison the results obtained with GA reflects the superiority of IWO in a statistically significant fashion.

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In a final manner, examined systems are simulated by using the Power World software to check the results (Power World, 2008; Power World Negative LMPs, 2008). In this study Invasive Weed Optimization (IWO) algorithm is utilized to optimal bidding strategy in power market; the evaluation is applied before and also after congestion management. The achieved results from Invasive weed optimization algorithm are finally compared with the Genetic algorithm. Experimental results show that in this purpose, the IWO algorithm has high performance and overcomes to GA method.

MATHDOLOGY

Problem formulation: The load flow p_{ij} through the transmission line i-j is a function of the line reactance x_{ij} , the voltage magnitude v_i, v_j and the phase angle between the sending and receiving end voltages δ_i-δ_j as shown in Eq. (1):

$$p_{ij} = \frac{V_i V_j}{x_{ij}} \sin(\delta_i - \delta_j) \tag{1}$$

The Transmission Line Relief (TLR) sensitivity values at all the load buses for the most overloaded transmission line are regarded and used for calculating the essential load curtailment for the alleviation of the transmission congestion. The TLR sensitivity at a bus *k* for a congested line *i-j* is S_{ij}^k and is computed as below:

$$S_{ij}^k = \frac{\overline{\Delta P_{ij}}}{\Delta P_k} \tag{2}$$

The excess power flow on transmission line *i-j* is written below:

$$\overline{\Delta P_{ij}} = P_{ij} - \overline{P_{ij}} \tag{3}$$

where,

P_{ij} = The Actual power flow through transmission line *i-j*

$\overline{P}_{ij}$ = Flow limit of transmission line *i-j* (New England ISO, 2008; Yan, 1999).

The new load P_k^{new} at the bus *k* can be calculated by:

$$P_k^{new} = P_k - \frac{S_{ij}^k}{\sum_{i=1}^{N} S_{ij}^l} \overline{\Delta P_{ij}} \tag{4}$$

where,

P_k^{new} = Load after curtailment at bus *k*

P_k = Load before curtailment at bus *k*

S_{ij}^k = Sensitivity of power flow on line *i-j* due to load change at bus *k*

N = Total number of load buses

Genetic Algorithm (GA): Our genetic algorithm is an ad-hoc one based on a classical structure. The outline steps are http://www.obitko.com/tutorias), (Kazemi *et al*., 2011):

1. **Start:** Generate random population of *n* chromosomes (suitable solutions for the problem)
2. **Fitness:** Evaluate the fitness *f(x)* of each chromosome *x* in the population
3. **New population:** Create a new population by repeating following steps until the new population is complete
4. **Selection:** Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected)
5. **Crossover:** With a crossover probability cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents
6. **Mutation:** With a mutation probability mutate new offspring at each locus (position in chromosome)
7. **Accepting:** Place new offspring in a new population
8. **Replace:** Use new generated population for a further run of algorithm.
9. **Test:** If the end condition is satisfied, stop and return the best solution in current population
10. **Loop:** Go to step 2

Invasive Weed Optimization (IWO): The Invasive weed optimization algorithm was developed by Mehrabian and Lucas (2006). IWO algorithm is a new search method, which makes use of mechanisms inspired by the natural behavior of weeds in colonizing and seeking a suitable place for growth and reproduction. IWO algorithm is a numerical stochastic search algorithm mimicking natural behavior of weeds in colonizing and finding suitable place for growth and reproduction. This technique is motivated by a common phenomenon in agriculture that is colonization of invasive weeds. Weeds have shown very robust and versatile nature which turns them to undesirable plants in agriculture. Recent experiences in implementing the IWO algorithm in a number of different application domains (Mehrabian and Lucas, 2006; Hajimirsadeghi and Lucas, 2009) have shown considerable advantages over both classical algorithms and other bio-inspired techniques. The overall algorithm is summarized as below:

```
1. Generate random population of N0 solutions
2. For iter = 1: maximum number of generations
a. Compute maximum and minimum fitness in the colony
b. For each individual w ∈ W
i. Compute number of seeds for w according to its fitness
ii. Randomly distribute generated seeds over the search space
    with normal distribution around the parent plant w
iii. Add the generated seeds to the solution set, W
c. If (|W| = N)>p_max
i. Sort the population W in descending order of their fitness
ii. Truncate population of weeds with smaller fitness until N = p_max
3. Next iter
```

Fig. 1: Pseudo code for IWO algorithm

Initialization: A finite number of weeds are initialized at the same element position of the conventional array, which has a similar spacing of λ/2 between elements in neighbor.

Reproduction: Each member of the population is allowed to produce seeds conditional upon its own, as well as the colony's lowest and highest cost, such that, the number of seeds produced by a weed grows linearly from lowest possible seed for a weed with worst cost.

Spatial distribution: The produced seeds are being randomly distributed over the *d* dimensional search space by normally distributed random numbers by a zero mean and variable variance. This step ensures that the genesis seeds will be generated around the parent weed, leading to a local search around each plant. However, the Standard Deviation (SD) of the random function is made to reduce over the iterations.

If sd_{Max} and sd_{Min} be the maximum and minimum standard deviation and if *Pow* be a real number, then the standard deviation for a particular iteration may be given as in Eq. (5):

$$sd_{Iter} = \left(\frac{Iter_{\max} - Iter}{Iter_{\max}}\right)^{Pow} \left(sd_{Max} - sd_{Min}\right) + sd_{Min} \tag{5}$$

This step guarantee that the probability of dropping a seed in a distant area reduces nonlinearly with iterations, which results in grouping fitter plants and elimination of unsuitable plants. Since, this is a selection mechanism of IWO.

Competitive exclusion: If a plant leaves no offspring then it would go vanished, otherwise they would take over the world. Thus, there is a requirement of some kind of competition between plants for restricting maximum number of plants in a colony. At the first, the plants in a colony will reproduce fast and all the produced plants will be comprised in the colony, until the number of plants in the colony reaches a maximum value pop_{max}. In any event, it is hoped that by this time the fitter plants have reproduced more than undesirable plants. After that, the seeds and their parents ranked together and those with better fitness survive and become reproductive (Mehrabian and Yousefi-Koma, 2007). The pseudo code for IWO is presented in Fig. 1.

BIDDING STRATEGY BEFORE CONGESTION MANAGEMENT FOR BOTH CASES

Bidding strategy is described by suggesting transactions in the market. Energy selling prices by the power generation units and energy purchasing prices by the clients are recommended to the power market. The whole market zones try to maximize the social welfare index. Bidding strategy with no congestion can be presented as below (Mehrabian and Yousefi-Koma, 2007; Viond *et al*., 2010):

$$Min..Obj \rightarrow f_k = \sum_{j=1}^{NG} C_j(p_j) - \sum_{i=1}^{NL} B_i(d_i) \tag{6}$$

$$with B_i(d_i) = b_i d_i^t - 1/2 d_i^t p_{jj} \tag{7}$$

$$C_j(j) = b_i p_j^t - 1/2 d_j^t p_{jj} \tag{8}$$

$$subject.to \rightarrow \sum_{j=1}^{NG} p_j = \sum_{i=1}^{NL} d_i \tag{9}$$

$$p_j^{\min} \le p_j \le p_j^{\max}$$

where,

- i = Customers load index
- j = Generators index
- NL = The number of consumption loads
- NG = The number of generators
- B_i = The i^th customer's profit function
- P_j = The delivery power of j^th unit

C_j = The jth generator's cost function
d_j = The quantity of consumption power in the jth unit

Case A. 5 bus system:

Bidding strategy after congestion management: Since the electricity market has been deregulated the participants have a variety of choices to improve their standing in the market. A set of different bidding strategies may be adopted by the participants in order to maximize their profit. In this study, by neglecting the losses in the load flow is advised and is as:

$$Min \Delta p^t \omega \tag{10}$$

$$\left|p_{ij}\right| \le \left|p_{ij}^{\max}\right| \tag{11}$$

$$\sum_{i \in NG} \Delta p_i = 0 \tag{12}$$

$$p_j^{\min} \le p_j \le p_j^{\max} \tag{13}$$

where, the requirement power of consumption loads vector is described by consumption loads power differences. And ω is a weight matrix as $\Delta p = [\Delta p_1 \ldots \Delta p_n]$. ω in this study is advised as a 3×3 uniform one matrix (Sun *et al*., 2003; Silpa, 2007).

5 bus system data: In this section a 5 bus system by 3 generator units, 2 customers (loads) and 6 transmission lines is analyzed. Cost functions and profits to the presented system are described in Table 1. For a suitable analysis on the costs, two different states are demonstrated to the system.

Table 1: Related data for cost functions in 5 bus system

Generators	Cost function	p_j^{min}	p_j^{max}
Genco. 1	$0.003\ (p_1)^2+7.2p_1+640$	0 (MW)	150 (MW)
Genco. 2	$0.002\ (p_2)^2+6.3p_2+360$	0 (MW)	100 (MW)
Genco. 3	$0.004\ (p_3)^2+6.8p_3+120$	0 (MW)	100 (MW)
Loads	Profit function	Peak load	
Customer 1	$110d_1-0.18\ (d_1)^2$	150 (MW)	
Customer 2	$120d_2-0.16\ (d_2)^2$	60 (MW)	

At the first, transmission lines before congestion assumed and the relative analysis on the 5 bus system implemented. Afterwards, congestion also implemented and the analysis executed on the system again. Bid values and attaining cost using GA and IWO are described in Table 2 and the results show a higher performance for IWO algorithm toward GA (Mehrabian and Yousefi-Koma, 2007; Biskas *et al*., 2007).

Table 3 shows the line flows before and after congestion management at bus 5. From Table 3, in line 5, the line flow is about 6 MW more than the limited value which is decreased to 45 MW after congestion management.

From the Table 3 it is observed that after bidding strategy, line 5 has found some over loads. Simulation results show that in order to remove the congestion, the output power of generator 3 is decreased. In brief generators in bus 2 for consumption load ensuring are faced to genesis growing. Also the acquired social welfare index in the IWO is desirable rather than the GA. Notice that transmission lines losses are also calculated in this analysis. Table 4 shows the simulation results.

Simulation results for 5 bus system: Simulation results of 5 bus system using Power World software shows that the line transmission 5 (the line that is between bus 2 and bus 4) has over loaded which by

Table 2: Social welfare index before congestion management

Algorithm	IWO		GA	
Generators	Output (Gen(MW))	Cost ($)	Output (Gen(MW))	Cost ($)
Gen. 1	92.3274	1330.3303	115.6827	1513.0573
Gen. 2	64.8405	776.90370	43.97480	640.90880
Gen. 3	52.8310	490.41520	50.34000	472.48440
Total cost for generators	210 (MW)	2597.6492 ($)	210 (MW)	2626.4505 ($)
Customers				
Cust. 1	150 (MW)	16095	150(MW)	16095
Cust. 2	60 (MW)	6624	60(MW)	6624
Total benefit for customers	210 (MW)	22719 ($)	210 (MW)	22719 ($)
Social welfare ($)	20121.35		20092.54	

Table 3: Line flow before and after congestion management

Line number	Line flow after bidding strategy (MW)	Line flow limit (MW)	Line flow after congestion management (MW)
1	46.60	50	43.40
2	24.10	150	13.30
3	19.90	50	17
4	21.60	100	20.70
5	55.90	50	44.90
6	128.4	150	129.3

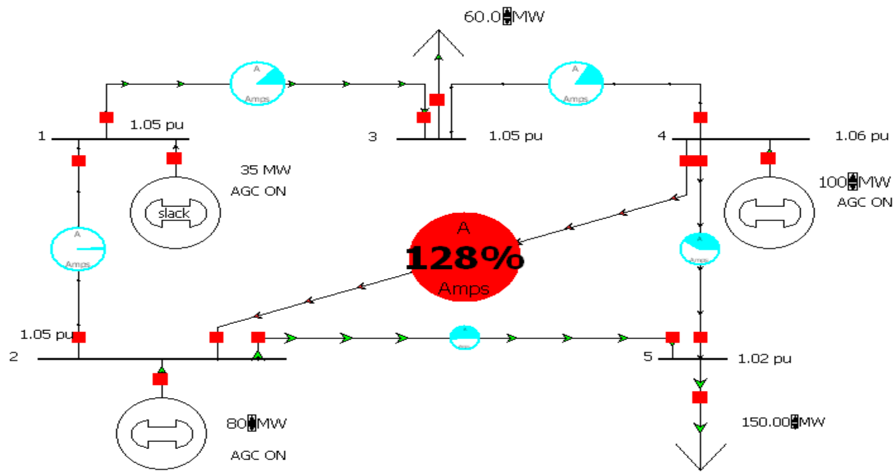

Fig. 2: Mimic diagram of 5 bus system and power flow before congestion management-power world software

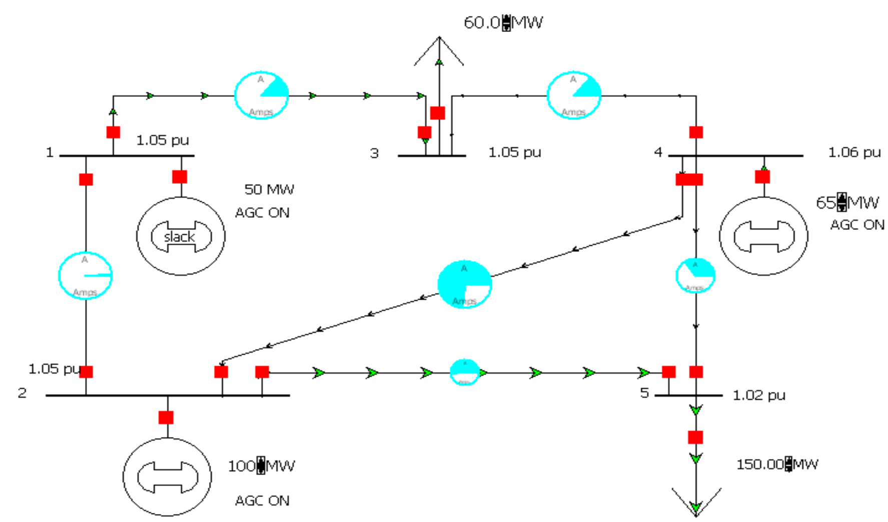

Fig. 3: Mimic diagram of 5 bus system and power flow after congestion management-power world software

declining the value of generated power on generator 3 (to 65 MW) and increasing the generated power of generator 2, congestion of line 5 (using the sensitivity decreasing method) is decreased (rather than the flow power of transmission lines). Figure 2 and 3 show the results.

As you can see in Fig. 3, by increasing the output power of generator 2 into 100 MW congestion in transmission line, (the line which is between bus 2 and bus 4) is decreased. And the output power value on generator 3 is raised for the consumption load security.

Case B. 9 bus system:

Bidding strategy model after congestion management: Since the electricity market has been deregulated the participants have a variety of choices to improve their standing in the market. A set of different bidding strategies may be adopted by the participants in order to maximize their profit. In this system Assessment, by spot the losses in the load flow is advised and is as:

$$MinF = \frac{1}{F_L . F_G} \tag{14}$$

$$F_L = \prod_{i=1}^{k} F_{lineflow} \tag{15}$$

$$F_G = \prod_{q-1}^{p} F_{generatiopower} \tag{16}$$

where, the requirement power of consumption loads vector is described by consumption loads power differences, and k is the number of transmission line and p is the number of generators in the 9 bus system (Kazemi *et al*., 2011).

Table 4: Simulation results

Algorithm	IWO			GA		
Generator No.	Gen. 1	Gen. 2	Gen. 3	Gen. 1	Gen. 2	Gen. 3
Output generators without congestion management (MW)	92.3274	64.8405	52.8310	115.6827	43.9748	50.3400
Output generators with congestion management (MW)	30.5743	90.8562	80.1937	35.54700	95.4652	85.2842
Curtailed output (MW)	-61.7531	26.0100	27.3627	-80.3570	51.4904	34.9392
Total cost for generators ($)		2502.88			2608.40	
Total benefit for customers ($)		22719			22719	
Social welfare ($)		20216.12			20110.6	

Table 5: Related data for 9 bus system

Generators	Cost function	p_j^{min}	p_j^{max}
Genco. 1	$0.001562\ (p_1)^2+7.92p_1+560$	0 (MW)	200 (MW)
Genco. 2	$0.00194\ (p_2)^2+8.5p_2+310$	0 (MW)	150 (MW)
Genco. 3	$0.00482\ (p_3)^2+7.97p_3+78$	0 (MW)	150 (MW)
Loads	Profit function	Peak load	
Customer 1	$100d_1-0.175\ (d_1)^2$	125 (MW)	
Customer 2	$110d_2-0.15\ (d_2)^2$	100 (MW)	
Customer 3	$90d_3-0.14\ (d_3)^2$	90 (MW)	

Table 6: Social welfare index before congestion management

Algorithm	IWO		GA	
Generators	Output (Gen(MW))	Cost ($)	Output (Gen(MW))	Cost ($)
Gen. 1	151.4101	1794.97	136.1708	1667.4361
Gen. 2	110.1704	1198.38	135.9245	1412.8500
Gen. 3	88.41950	820.380	77.90470	728.15000
Total cost for generators	350	2734.73	350	3808.4300
Customers				
Cust. 1	125 (MW)	9765	125 (MW)	9765
Cust. 2	100 (MW)	6000	100 (MW)	6000
Cust. 3	90 (MW)	6966	90 (MW)	6966
Total benefit for customers	315 (MW)	22731	315 (MW)	22731
Social welfare ($)	19996.27		18922.57	

Table 7: Line flow before and after congestion management

Line No.	Line flow after bidding strategy (MW)	Line flow limit (MW)	Line flow after congestion management (MW)
1	105	150	123.6
2	17.70	50	19.40
3	52.90	50	47.60
4	146.3	150	135.9
5	204.2	250	197.1
6	48.20	150	42

Table 8: Simulation results for 9 bus system

Algorithm	IWO			GA		
Generator No.	Gen. 1	Gen. 2	Gen. 3	Gen. 1	Gen. 2	Gen. 3
Output generators without congestion management (MW)	151.4101	110.1704	88.4195	136.1708	135.9245	77.9047
Output generators with congestion management (MW)	166.3720	50.2500	150	177.4300	62.5600	148.260
Curtailed output (MW)	14.96190	-59.9204	61.5805	41.2592	-73.3645	70.3553
Total cost for generators ($)	2615.360			2783.54		
Total benefit for customers ($)	22731			22731		
Social welfare ($)	20115.64			19947.46		

9 bus system data: In this study a 9 bus system by 3 generator units, 3 customers (loads) and 6 transmission lines is analyzed. Cost functions and profits to the presented system are described in Table 5. For a suitable analysis on the costs, two different states are demonstrated to the system (Power World, 2008; Viond *et al*., 2010).

At the first, transmission lines before congestion assumed and the relative analysis on the 9 bus system implemented. Afterwards, congestion also implemented and the analysis executed on the system again. Bid values and attaining cost using GA and IWO are described in Table 6 and the results show a higher performance for IWO algorithm toward GA (Sun *et al*., 2003; Daalader *et al*., 2005).

In Table 7 the line flows before and after congestion management at 9 bus system. From Table 3, in line 3, the line flow is about 2.9 MW more than the limited value which is decreased to 47.6 MW after congestion management.

From the Table 7 it is observed that after bidding strategy, line 3 has found some over loads. Simulation results show that in order to remove the congestion, the output of generator 2 is decreased. In brief generators in bus 3 for consumption load ensuring are faced to genesis growing. Also the acquired social welfare index in the IWO is desirable rather than the GA. Notice that transmission lines losses are also calculated in this analysis. Table 8 shows the simulation results for 9 bus system.

Simulation results for 9 bus system: Simulation results of 9 bus system using Power World software shows that the line transmission 3 (the line that is

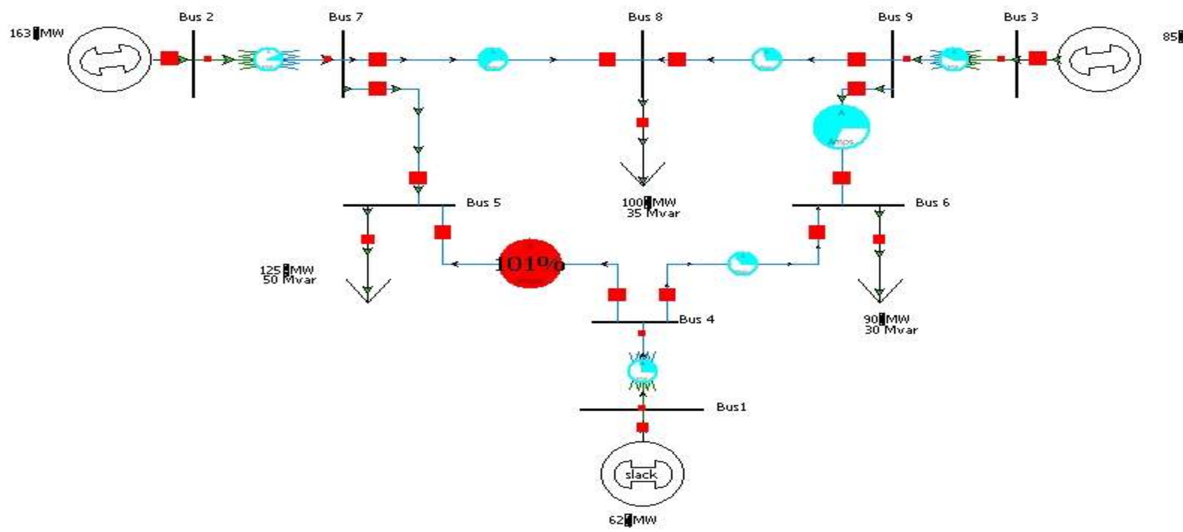

Fig. 4: Mimic diagram of 9 bus system and power flow before congestion management-power world software

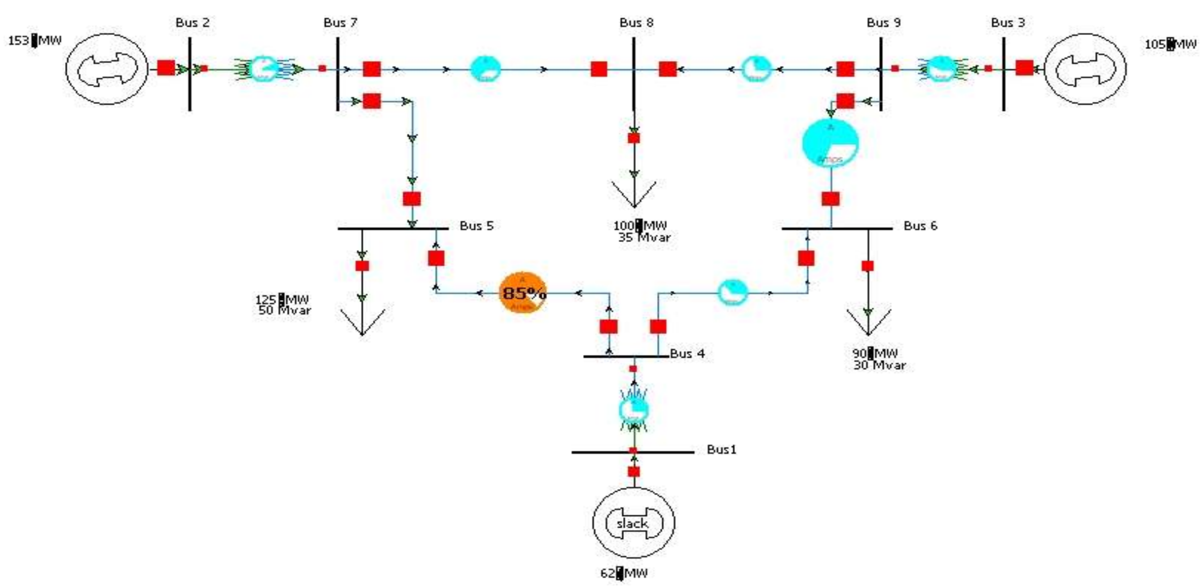

Fig. 5: Mimic diagram of 9 bus system and power flow after congestion management-power world software

between bus 4 and bus 5) has over load which by declining the value of generated power on generator 2 (to 153 MW) and increasing the generated power of generator 3, congestion of line 3 (using the sensitivity decreasing method) is decreased (rather than the flow power of transmission lines). Figure 4 and 5 show the analysis.

As you can see in Fig. 4, by increasing the output power of generator 3 of 85 to 105 MW congestion in transmission line, (the line which is between bus 4 and bus 5) is decreased and the output power value on generator 3 is raised for the consumption load security.

CONCLUSION

Depending on the structure and objectives of the electricity market, different congestion management methods are put into practice. Effective congestion management will help mitigate the effects of market power in electricity markets. In this study, the application of the Invasive Weed Optimization algorithm (IWO) is presented to congestion management in bidding strategy; experimental results are compared by the Genetic Algorithm (GA). It is considered that in IWO, the output power of generators and also social welfare indexes have more performance than the GA. These two algorithms are implemented on 5 and 9 bus systems and transmission line losses are envisaged. With regard to more boundaries and too problems of power flow implementation by Gauss-Sidel and Newton-Rap son methods, power world software is used. The OPF in Power World simulator provides the ability to optimally dispatch the generation in an area or group of areas while enforcing the transmission line limits. Final results show that using IWO in power flow systems and for congestion management purpose is a proper technique.

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