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Research Article

Transmission Line Congestion Management by Specifying Optimal Placement of FACTS Devices Using Artificial Bee Colony Optimization

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Abstract: An evolutionary based approach is proposed to congestion management of transmission lines in a restructured market environment by optimizing the Flexible Alternating Current Transmission System (FACTS) devices. The specification and readjustment of electricity markets has enhanced competition and electricity may be generated and used in amounts that would make the transmission system to act beyond transfer limits. Therefore, congestion management is a primary transmission management crisis. Considering to the worldwide exestuation of congestion management methods, different schemes can be described. The different international execution suggests that there is no specific congestion management system. In this study, we attempted to improve an OPF solution incorporating FACTS devices in a given market mode. FACTS devices facilitate the power grid owners to enhance existing transmission network capacity while preserving the operating margins necessary for grid stability. Consequently, extra power can achieve consumers with a minimum impact on the environment, after significantly shorter project implementation times and at lower assessment costs-all compared to the alternative of building new transmission lines or power generation facilities. FACTS devices are controlled in a mode so as to guarantee that the formal obligations are implemented as far as possible by minimizing line congestion. Different optimization approaches available in the literature have been used to solve OPF problem. For optimizing the FACTS devices placement in the market, Artificial Bee Colony (ABC) algorithm is utilized and compared with GA base optimizing. The proposed methods are tested on the standard IEEE9 bus reliability test systems.

Keywords: Artificial bee colony optimization, congestion management, FACTS devices, genetic algorithm, optimal location, power flow, power world software

INTRODUCTION

The electricity markets specialization and deregulation has a vast impression on about the total power systems around the world. Electricity markets Competition consists of complex systems with many partners who purchase and sell the electricity. A major complexity derives from the basic transmission systems limitations and the fact that producers and consumers must be in balance at all times. System security represents a substantial role in competitive market discussions. When the demand and supply of electric energy have tendency to produce and consume in quantities which would cause the transmission system to operate at or beyond one or more transfer limits, the system is said to be congested (Goncalves and Vale, 2003). Congestion management contains the control of the transmission system to makes transfer limits considerable and is perhaps the most fundamental transmission management problem (Liangzhong *et al*., 2005). Congestion before readjusting was acted in steady-state security condition and the main purpose was to control the generators' output so that system stayed secure at the lowest cost as seen by the reciprocal agreeing vertically integrated utilities (Srivastava and Kumar, 2000a). Readjusting makes congestion to get a term in combination with power systems and competition. There are several techniques to the congestion management. One of these techniques is capacitance auction (Kumar and Srivastava, 2000). Independent system operator auctions are some of the specified transmission commonly or partially in a short time and typically are transmissions which happens congestion to them. In the pool markets congestion management is utilized by load flow and LMP (Henry *et al*., 2003). The role of the Independent System Operator (ISO) between several sellers and buyers is to maintain system safety and perform congestion management. In this study, an optimal placement of Multi-Distributed Generation for load ability enhancement is applied by using Artificial Bee Colony (ABC) algorithm.

Artificial Bee Colony (ABC) algorithm is one of the most recently optimizing algorithms which simulate the behavior of a honeybee swarm. Comparison the results obtained with GA illustrates the superiority of

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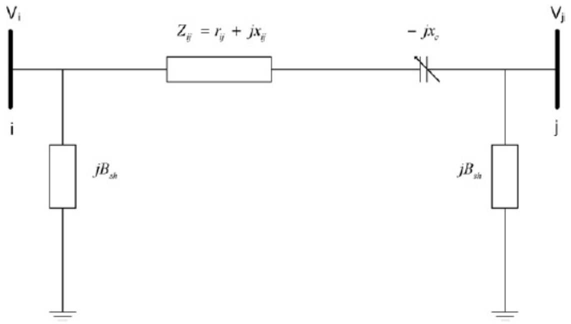

Fig. 1: A model of TCSC connected transmission line

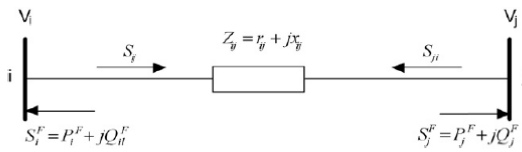

Fig. 2: The static power injection model of TCSC

the ABC algorithm. Examined systems are then simulated by using the Power World software (Power World, 2008). The main contribution of this study is to use an optimization algorithm in order to develop a formulization for fitting FACTS device controllers and demand responses to get a minimum cost congestion management. In addition, the social welfare term is added to the existing mathematical model of TSCR to control and minimize the generation cost of FACTS device.

METHODOLOGY

Thyristor Controlled Series compensator (TCSR) modeling: TCSCs are a type of FACTS devices which utilize in power transmission line which can improves the transportability and the stability of system and lessen the system loss considerably. Because of the static application in this study, a static Power Injection Model (PIM) of the TCSC has been used (Xia *et al*., 2002); TCSCs (as a series FACTS device) can control the power flow (Srivastava and Verma, 2000b). They can also use as series FACTS devices.

The congestion management purpose is also considered and formulated as a steady state problem. In the injection model, we consider the FACTS as devices that inject a specified amount of active and reactive power to a node for demonstrating a FACTS device as PQ elements. The π-equivalent model of transmission line with a TCSC connected (which is between two buses) is shown in Fig. 1. The TCSC can be considered as a reactance ($-jx_c$) in a steady manner. The controllable reactance (x_c) is directly used as a regulator in the power flow process.

In the steady state manner, the TCSC can be modeled as a reactance ($-jx_c$). The controllable reactance (x_c) can be directly utilized for power flow equations. The PIM model of TCSC is shown Fig. 2:

The injected powers of the series capacitors at nodes i and j are:

$$P_i^F = V_i^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos(\delta_i - \delta_j) + \Delta B_{ij} \sin(\delta_i - \delta_j)] \quad (1)$$

$$Q_i^F = -V_i^2 \Delta B_{ij} - V_i V_j [\Delta G_{ij} \sin(\delta_i - \delta_j) - \Delta B_{ij} \cos(\delta_i - \delta_j)] \quad (2)$$

$$P_j^F = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos(\delta_i - \delta_j) - \Delta B_{ij} \sin(\delta_i - \delta_j)] \quad (3)$$

$$Q_j^F = -V_j^2 \Delta B_{ij} + V_i V_j [\Delta G_{ij} \sin(\delta_i - \delta_j) + \Delta B_{ij} \cos(\delta_i - \delta_j)] \quad (4)$$

where,

$$\Delta G_{ij} = \frac{x_c r_{ij} (x_c - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)\left(r_{ij}^2 + (x_{ij} - x_c)^2\right)} \quad (5)$$

$$\Delta B_{ij} = -\frac{x_c r_{ij} (x_c - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)\left(r_{ij}^2 + (x_{ij} - x_c)^2\right)} \quad (6)$$

The presented equations are modeled in the optimal power flow.

TCSC size and location: One of the most important categories in FACTS devises is to determine the size and location of them, which can impress the prices and also effect the interests of some generators and loads (Srivastava and Verma, 2000b). One mechanism to specify these parameters is to locate and size the FACTS devices such that the social welfare is maximized. This approach is well-known objective for pricing energy in deregulated electricity markets (Shrestha and Wang, 2005).

The first step in the optimal location of TCSC installation is to form a priority table based on the magnitude of congestion rent share of individual line segment (Acharya and Mithulananthan, 2007). After that, the TCSC is located on each line in the priority table; the best place attains with a location where by placing TCSC, the overall social welfare is maximized. Interconnecting TCSC in the OPF results the optimal setting of the TCSC (Lehmkoster, 2002). The OPF solutions also give the optimum recovery level of the TCSC which maximizes the total social welfare.

OPF formulation: Recently, Optimal Power Flow (OPF) has been illustrated as widely used and widely studied nonlinear optimization problems. Deregulated electricity markets are also utilized in many pool based systems to calculate the generation dispatch and load schedule, to price the energy and also to congestion management in the systems. In this study, the main objective is to maximize the social welfare (or to minimize the generation cost if loads are uncompromising). In the centralized pool based markets, for maximizing the total social welfare, the central dispatcher optimally dispatches the generators while satisfying the operational and security relevant constraints. The mathematical formulation of such approach can be stated as:

$$\min\left(\sum_{i\in S_G^{PL}} C_i^{PL}(P_{Gi}^{PL}) - \sum_{i\in S_D^{PL}} B_i^{PL}(P_{Di}^{PL})\right) \tag{7}$$

And the constraints are:

$$P_i(\theta,V) - P_{Gi}^{PL} + P_{Di}^{PL} - \sum_{k\in K} P_{GK,i}^{M} + \sum_{k\in K} P_{DK,i}^{M} = 0 \tag{8}$$

$$Q_i(\theta,V) - Q_{Gi}^{PL} + Q_{Di}^{PL} = 0 \tag{9}$$

The illustrated equations are well-known as power balance equations. After TCSC location, the achieved equations are:

$$P_i(\theta,V) - P_{Gi}^{PL} + P_{Di}^{PL} - \sum_{k\in K} P_{GK,i}^{M} + \sum_{k\in K} P_{DK,i}^{M} + P_i^F = 0 \tag{10}$$

$$Q_i(\theta,V) - Q_{Gi}^{PL} + Q_{Di}^{PL} + Q_i^F = 0 \tag{11}$$

Which P^F_i and Q^F_i are the injected active and reactive powers of TCSC to the bus *i*. The other constraints are presented in below:

$$V_{i,\min} \le V_i \le V_{i,\max} \tag{12}$$

$$X_{c,\min} \le X_c \le X_{c,\max} \tag{13}$$

where superscripts *k is* the bilateral transaction index; *i* and *j* the bus indices, *PL* and *M* signify pool transaction and bilateral (or multilateral) transaction, P^{PL}_{Gi} and P^{PL}_{Di} show the pool real power generation and demand at bus *i*, $P^{M}_{GK,i}$ and $P^{M}_{DK,i}$ are the bilateral injection and extraction of agent *k* at bus *i*, Q^{PL}_{Gi} and Q^{PL}_{Di} are the pool reactive power generation and load at bus *i*, $V_{i,max}$ and $V_{i,min}$ are the upper and lower limits of voltage at bus *i* and finally $X_{c,max}$ and $X_{c,min}$ are the upper and lower limits of capacitive reactance of TCSC respectively.

Genetic Algorithm (GA): The Genetic Algorithm (GA) is an approach for solving both constrained and unconstrained optimization problems which is based on natural selection, the process that drives biological evolution. The GA algorithm can be illustrated as below (Kazemi *et al*., 2011):

- Select a random number as the initial generation of *pop* chromosomes with *f* genes each one.
- Continue the process while the number of generations *gen* is not reached:
  - **Fitness:** Calculating the fitness of every chromosome.
  - **Selection:** Select *pop*/2 chromosomes from the better regulated chromosomes.
  - **Crossover:** Cross those *pop*/2 selected chromosomes in pairs, producing two new chromosomes by pair.
  - Turnover the *pop*/2 non-crossed chromosomes by the new ones generated by the crossover process.
  - **Mutation:** Randomly mutate the population.
- After reaching the *gen*, return the best chromosome.

Artificial bee colony algorithm (ABC): Recently using swarm intelligence algorithms for optimization the problems has been increased. Artificial Bee Colony (ABC) Algorithm is an optimization algorithm that is inspired by the behavior of honeybee swarms. A developed version of the ABC algorithm was then presented to apply constrained optimization problems. ABC algorithm has been illustrated to accomplish well for most number of static problems. The colony of artificial bees includes of three essential steps: onlookers, employed and scout bees; the Employed Bees (*Eb*) randomly explore for food-source locations (solutions). After location exploring, the employed bees assign the nectar contents (solutions qualities) of the food sources and their location information with the Onlooker bees (*Ob*) on the dance area (Karaboga and Basturk, 2007). Onlooker bees watch several dances to find a nectar amount by means of the information given by the employed bee; this process is accomplished in order to their nectar amount probability.

In this case, she generates an improvement on the position in her memory and tests the nectar amount of the candidate source. If the new nectar has a higher amount rather than the previous one, the bee preserves the new position and passes the old one up. The probability p_i of the chosen food source (by onlooker bees) can be demonstrated as:

$$p_i = \frac{fitness_i}{\sum_{i=1}^{Eb} fitness_i} \tag{14}$$

where,

$fitness_i$: The cost function of the solution *i*
Eb : The number of nectar source positions and is equal to the half of *CS*

In order to determine a neighboring nectar source position, the ABC algorithm modifies a random parameter and keeps the other parameters fixed as below:

$$x_{ij}^{new} = x_{ij}^{old} + u\left(x_{ij}^{old} - x_{kj}\right) \quad (15)$$

where,
$k \neq i$: And both are in the interval [1, 2, …, Eb]
u : A random number between [-1, 1]
j : Selects randomly in the interval [1, 2, …, D]
x_{ij} : The j^{th} parameter of a solution x_i is selected to be corrected

When the nectar source position has been single, the employed bee joined with it modifies to a scout. The scout produces a quiet new nectar source position as:

$$x_i^{j(new)} = \min x_i^j + u\left(\max x_i^j - \min x_i^j\right) \quad (16)$$

Employed and onlooker bees select new nectar sources in the vicinity of the prior one belonging on visual information based on the comparison of nectar source positions (Killingworth and Krstic, 2006). Table 1 shows the pseudo-code of the ABC algorithm.

EXPERIMENTAL RESULTS

In this section, IEEE9 bus system by 3 generator units, 3 customers (loads) and 6 transmission lines is analyzed. The related values of the 9-bus system (transmission lines, system buses, generators and loads) are presented in Table 2 to 6.

Simulation results of 9 bus system using Power World software shows that. Table 7 and 8 indicate the line flow in the 9-bus system before and after congestion management.

From the Table 9, we can result that the achieved welfare social index after congestion management by ABC algorithm has a definite excellence toward the congestion management by GA algorithm.

Table 10 illustrates the results from power flow on the 9-bus system.

And the generated power of each bus is presented in Table 11.

Table 1: The pseudo-code of the ABC algorithm

- Initialize the population of solutions
- Evaluate the population
- Apply selection criterion
- Repeat (cycle)
- Produce new solutions
- Allow the employed bees to assign the food information with onlooker bees
- Allow the onlooker bees to select the best food source based on the probability calculation
- Apply the greedy selection
- Check the abundant solution and (if exists) replace it with a new nectar source position. Otherwise, follow the next step
- Memorize best solution so far
- Until stopping criteria

Table 2: 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 3: Related data for transmission lines system

From	To	R (p.u.)	X (p.u.)	Line rating (MVA)
4	5	0.0100	0.0850	50
4	6	0.0270	0.0920	100
5	7	0.0320	0.0160	150
6	9	0.0390	0.1700	150
7	8	0.0850	0.0720	250
8	9	0.0119	0.1008	150

Table 4: Related data for buses system

Bus no.	Bus type[a]	Area	V_{max} (p.u.)	V_{min} (p.u.)
1	3	1	1.1	0.9
2	2	1	1.1	0.9
3	2	1	1.1	0.9
4	1	1	1.1	0.9
5	1	1	1.1	0.9
6	1	1	1.1	0.9
7	1	1	1.1	0.9
8	1	1	1.1	0.9
9	1	1	1.1	0.9

Table 5: Related data for generators system

Generator no.	Bus no.	Q_{max} (Mvar)	Q_{min} (Mvar)	P_{min} (MW)	P_{min} (MW)
1	1	100	-100	100	0
2	2	100	-100	200	0
3	3	100	-100	150	0

Table 6: Related data for loads system

Load no.	Bus no.	Power factor logging	Pd_{max} (MW)	Pd_{min} (MW)
1	5	0.9	125	0
2	8	0.9	100	0
3	6	0.9	90	0

Table 7: Social welfare index before congestion management

	ABC		GA	
Generators	Output (Gen (MW))	Cost ($)	Output (Gen (MW))	Cost ($)
Gen. 1	99.4404	1363.0130	135.2253	1659.546
Gen. 2	69.0995	906.6087	137.1308	1512.093
Gen. 3	132.9711	1223	77.6439	725.879
Total cost for generators	350	3492.6210	350	3897.536
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 ($)	19238.3790		18833.4640	

Table 8: 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	109.15	150	128.9
2	18.41	100	20.3
3	55.32	50	45.4
4	147.58	150	138.2
5	215.20	250	195.8
6	42.30	150	40.5

Table 9: Simulation results for 9 bus system

	Algorithm					
	ABC			GA		
Generator no.	Gen. 1	Gen. 2	Gen. 3	Gen. 1	Gen. 2	Gen. 3
Output generators without congestion management (MW)	99.4404	69.0995	132.9711	135.2253	137.1308	77.6439
Output generators with congestion management (MW)	110.5620	48.6400	146.2500	173.4200	114.8600	145.5900
Curtailed output (MW)	11.1216	-20.4595	13.2289	38.1974	-22.2708	67.9461
Total cost for generators ($)	969.4603			1628.2455		
Total benefit for customers ($)	22731			22731		
Social welfare ($)	21761.5397			21102.7545		

Table 10: The result of power flow for 9 bus system

			Load		Generator		
Bus no.	Voltage (Pu)	Angle (degree)	MW	Mvar	MW	Mvar	Injection reactive power (Mvar)
1	1.040	0	0	0	73.63	26.38	0
2	1.025	9.29	0	0	163	6.71	0
3	1.025	4.68	0	0	85	-10.15	0
4	1.026	-2.22	0	0	0	0	0
5	0.995	-3.99	125	50	0	0	0
6	1.010	-3.66	90	30	0	0	0
7	1.025	3.73	0	0	0	0	0
8	1.015	0.74	100	35	0	0	0
9	1.031	1.98	0	0	0	0	0
Sum			315	115	321.63	22.94	0

Table 11: The value of power generators for GA and ABC algorithm

	Bus no.					
	1		2		3	
Method	GA	ABC	GA	ABC	GA	ABC
Generator (MW)	73.48	73.93	163	163	85	85

Table 12: The optimal size and location of series capacitor for congestion management using ABC algorithm

Sending bus no.	8
Inception bus no.	9
Reactance series capacitor (Pu)	-0.09136

Table 13: The optimal size and location of series capacitor for congestion management using GA algorithm

Sending bus no.	4
Inception bus no.	6
Reactance series capacitor (Pu)	-0.2148

Table 14: The result of power flow for 9 bus systems after location series capacitor using ABC algorithm

	Voltage (Pu)		Angle (degree)	
Bus no.	GA	ABC	GA	ABC
1	1.0400	1.0400	0	0
2	1.0250	1.0250	11.40	11.40
3	1.0250	1.0250	3.73	3.73
4	1.0260	1.0290	-2.26	-2.26
5	0.9833	0.9873	-2.65	-2.65
6	1.0379	1.0080	-4.05	-4.05
7	1.0230	1.0390	5.55	5.55
8	1.0160	1.0530	2.87	2.87
9	1.0360	1.0178	0.99	0.99
Sum of generation (MW)			321.31	

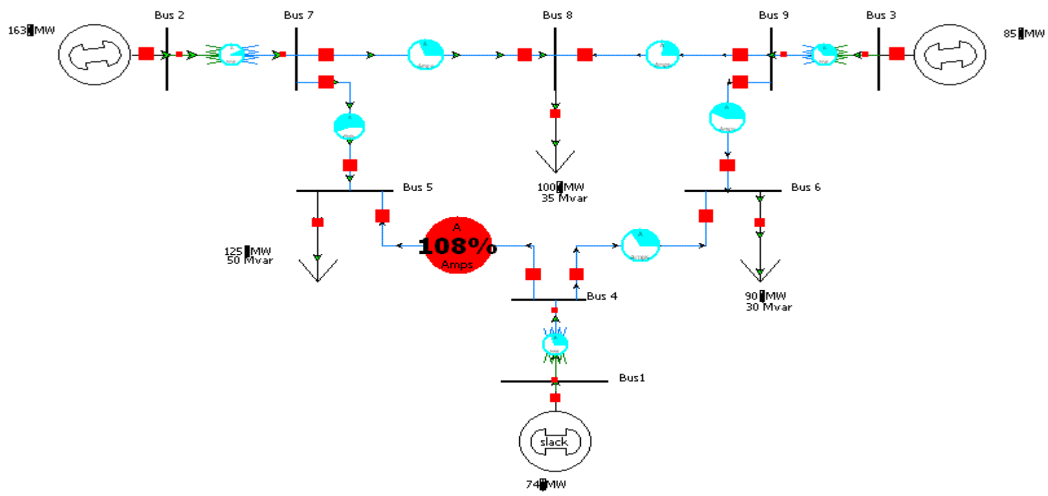

Fig. 3: Mimic diagram of 9 bus system and power flow before congestion management-power world software

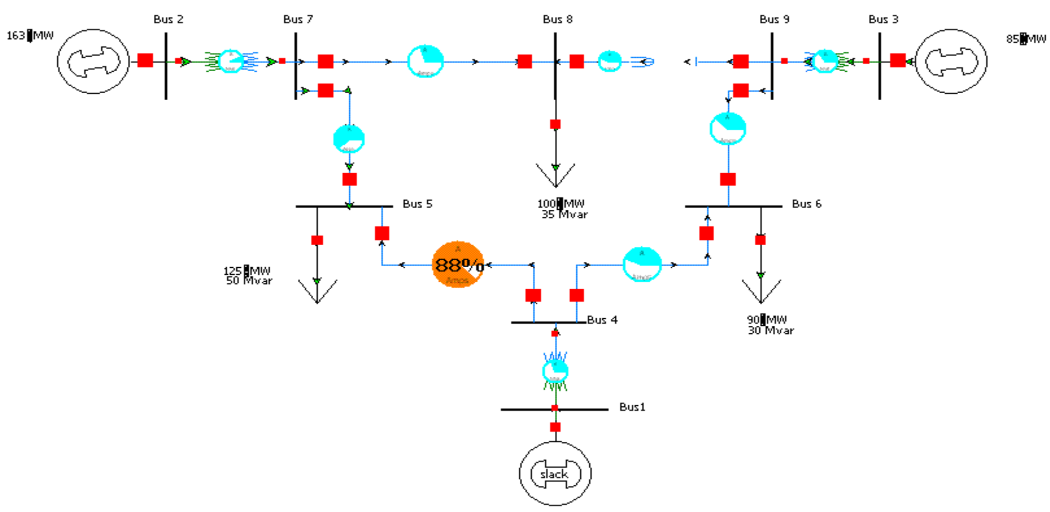

Fig. 4: Mimic diagram of 9 bus system and power flow after congestion management using ABC method-power world software

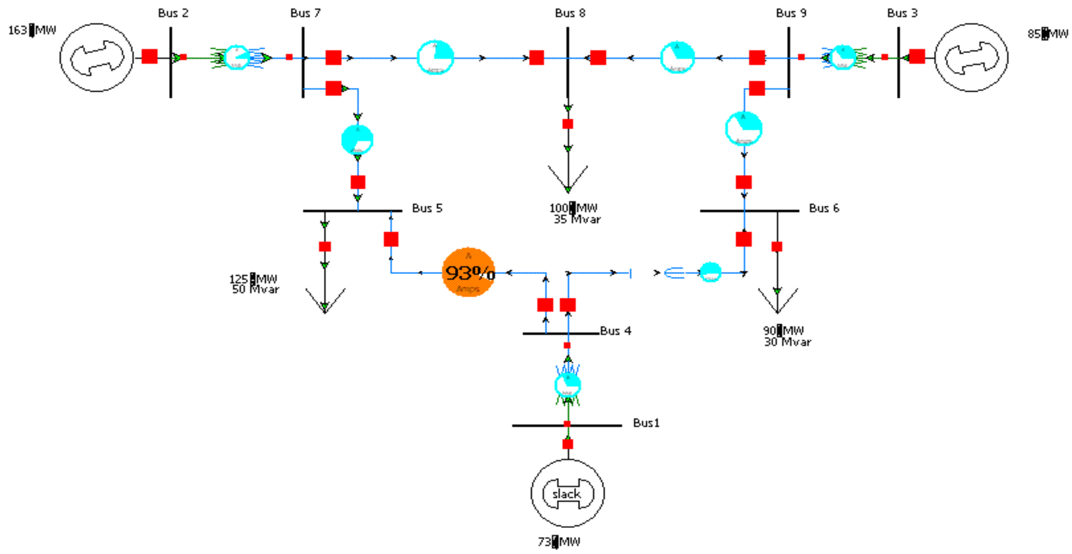

Fig. 5: Mimic diagram of 9 bus system and power flow after congestion management using GA method-power world software

And finally, size and location of the series capacitor is presented Table 12 and 13.

And the result of power flow for 9 bus system after location is presented Table 14 and Fig. 3 to 5.

With regarding to Fig. 4, it can be seen that the transmission line between bus4 and bus5 gets congested; in this case it is clear that by using a series capacitor in transmission lines, the congestion between the defined busses gets decreased. In the final evaluation, congestion management increased the welfare social index.

CONCLUSION

Congestion management is an important subject in deregulated power systems. In this study, a new algorithm has been proposed to optimal location of *TCSC* in power systems and the results has been compared by GA; this process is accomplished to find the global optimal generation scheme for maximizing the social welfare index. Final results show that the output power of generators and also social welfare indexes in our approach have more performance than the GA. Analysis is carried out by assuming two types of FACTS devices. In order to have a more realistic boundaries and too problems of power flow execution by Newton-Raphson and Gauss-Sidel methods, power world software is applied. Above method is tested on IEEE9 bus system and it can be readily developed to any practical system.

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