Congestion Relief via Intelligent Coordination of TCSC & SVC

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Abstract: - Power systems may not capable of utilizing full transmission capacity. Restructuring of electricity industry produces some management criteria to improve technical as well as economical efficiency. The process of reregulation causes more challenges with regards to technical and trading issues. Under the new scheme of power markets, congestion management is a crucial problem that needed to be considered. Congestion relief can be handled using FACTS devices, where transmission capability will be improved. In this paper, coordination between two different FACTS devices is investigated via implementation of intelligent RGA (Real Genetic Algorithm) technique to increase the capacity of power transfer. Case study and results analysis presents the effectiveness of the proposed methodology, where is tested by applying to modified IEEE 30-bus system.

Key-Words: - Congestion Management, Transmission Capability, RGA Technique, FACTS Devices.

1 Introduction

Electricity industry restructuring and reregulation may dictate maximum power transfer using the existing facilities under transmission open access scheme. Procuring electricity contracts associated with market participants' requirements can cause more challenges regarding energy management systems. Reregulation will impose new necessities to power systems such as transmission open access. Transmission congestion management is an important mechanism in order to solve power transfer bottleneck both in the operation and planning horizons [1]. There are two issues with regards to applying transmission open access that should be considered, the so-called: transmission losses as well as transmission congestion. Congestion is dependent to the network constraints that may show the ultimate transmission capacity, while it can restrict the concurrent electric power contracts [2]. It can be said that, under congestion conditions the price of electricity transfer will be increased. In fact, congestion management is an overall as well as particular systematic way of improving electricity transfer in which power systems planning and operating can be regarded.

Transmission congestion is dealing with some restrictions of electricity transfer via transmission network. These restrictions are increased in the presence of open access considering electricity restructuring environment [3]. Under new conditions of power market, more constraints such as: economical problems, environmental restrictions and transmission rights as financial contracts will be added to technical limitations of transmission capacity [1]. Congestion relief is such a solution to release some blocked capacity of transmission network that are based upon the above mentioned restrictions In literature, there are some techniques suggested to increase the available transfer capability (ATC). In literature among the proposed solutions for ATC enhancement, the use of FACTS devices is reported considerably [4]. It can be said that the application of FACTS devices should be based upon the investigation of capital investment as well as operating costs and the impacts of these devices of ATC improvement [5]. On the other hand, the optimum placement of FACTS devices is an important issue in terms of planning horizon [4], especially considering different types of these devices. While from operating point of view the coordination among these devices is much of interest either researchers or operation engineers.

2 Transmission Congestion Mathematical Modeling

In order to study congestion problem, it is needed to define mathematical statements as a proposed model. Mathematical modeling that is implemented in this paper is based upon a multi-objective optimization problem in which some new constraints are added to a conventional optimization model that can be found in literature. In fact, the model includes different terms for objective function such as: improvement of voltage profile, less transmission losses and

minimum capital investment for FACTS devices incorporating ATC enhancement. The optimum location as well as the capacity of SVC and TCSC as two different types of FACTS devices can be derived considering the duties of these elements.
The study is carried out by implementing a performance index that can be defined as follow:

$$PI = \sum_{m=1}^{N} \frac{W_m}{2n} \left[\frac{Pl_m}{Pl_m^{max}} \right]^{2n} \quad (1)$$

Where: Pl_m is real power transfer in line m , Pl_m^{max} is the maximum transfer capacity of line m, N is the number of lines in the network. W_m is a non-negative real number to show the importance of m^{th} transmission line that can be defined as weighting factor and n is defined as an operating index that is usually less that one. When all transmission lines are working at their permissible conditions (non-congestion situation) PI is very low, while if one or more lines are congested this term will be increased considerably. To calculate the real power transfer in line m, DC power flow is applied that is shown in the following relationship:

$$Pl_m = \left\{ \begin{array}{l} \sum_{n=1, n \neq s}^{N} S_{mn} P_n \; : m \neq k \\ \sum_{n=1, n \neq s}^{N} S_{mn} P_n + P_j \; : m = k \end{array} \right\} \quad (2)$$

The coefficients of S_{mn} is the mn^{th} component of matrix S that is used in DC power flow and P_n is the real power injected at bus n [6,7].

2.1 TCSC / SVC Mathematical Models

2.1.1 SVC Model

In steady state an SVC can be treated as a reactive power injection source, which can be presented as the following mathematical statement:

$$Q_{SVC} = V_t (V_t - V_{ref}) X_{SL} \quad (3)$$

Where: X_{SL} is the slope of voltage control characteristic, V_t is the terminal voltage of SVC and V_{ref} is the reference voltage. Doing some calculation the Equation (3) can be rewritten as:

$$Q_{SVC} = B_{SVC} \times V_{ref}^{\;2} \quad (4)$$

The value of B_{SVC} can be varied between minimum and maximum susceptance the so-called capacitive susceptance and inductive susceptance, where the desired reactive power can be maintained [8].

2.1.2 TCSC Model

Generally, TCSC is a series compensator as a capacitive as well as an inductive element that can be added to a transmission line. Based upon the adding a TCSC to a transmission line the admittance matrix of the system should be modified. The difference between the susceptance and conductance of transmission line before and after including TCSC can be considered using Equation (5):

$$\Delta y_{ij} = y_{ij}' - y_{ij} = (g_{ij}' + jb_{ij}') - (g_{ij} + b_{ij}) \quad (5)$$

In which:

$$g_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}} ,$$

$$b_{ij} = -\frac{x_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}} \quad g_{ij}' = \frac{r_{ij}}{\sqrt{r_{ij}^2 + (x_{ij} + x_c)^2}} , \quad (6)$$

$$b_{ij}' = -\frac{x_{ij} + x_c}{\sqrt{r_{ij}^2 + (x_{ij} + x_c)^2}}$$

A multi-objective optimization model is represented as a compact form of Equation (7) [8].

$$\min \frac{P_{ij}}{P_{ijmax}} \quad \text{Subject to the followings:}$$

$$P_{gi} - P_{li} - \sum_{j=1}^{n} |V_i||V_j| (G_{ij-FACTS} \cos\delta_{ij} + B_{ij-FACTS} \sin\delta_{ij}) = 0$$

$$Q_{gi} - Q_{li} - \sum_{j=1}^{n} |V_i||V_j| (G_{ij-FACTS} \sin\delta_{ij} - B_{ij-FACTS} \cos\delta_{ij}) = 0$$

$$|V_i|_{min} \le |V_i| \le |V_i|_{max}$$

$$P_{ij} \le 0.8 P_{ijmax}$$

$$P_{k,gi\,min} \le P_{k,gi} \le P_{k,gi\,max}$$

$$P_{SVC} = 0 \quad (7)$$

$$Q_{gimin} \le Q_{gi} \le Q_{gimax}$$

$$Q_{SVC_{min}} \le Q_{SVC} \le Q_{SVC_{max}}$$

$$-0.5 X_{mn} \le X_{TCSC} \le 0.6 X_{mn}$$

Where: P_{ij} is the real power flow through transmission line ij; P_{ijmax} is the maximum capacity of line ij; P_{li} is the actual real load supply at bus i; N is bus number of the system; P_{gi} is the real power generation at bus i; Q_{gi} is the reactive power generation at bus i; Q_{li} is the actual reactive load supply at bus i; $|V_i|$ is the voltage magnitude at bus i; $G_{ij-FACTS}, B_{ij-FACTS}$ are the real/reactive part of the ij^{th} element of the admittance matrix, which may be a function of the reactance of TCSC; δ_{ij} is the angle difference between the voltage at bus i and that at bus j; $Q_{gi\min}, Q_{gi\max}$ are the minimum/maximum reactive power generation at generation busi ; $|V_i|_{\min}, |V_i|_{\max}$ are the minimum/maximum voltage magnitude at bus I; X_{TCSC} is the reactance of TCSC; X_{mn} is the reactance of the line where TCSC has been installed; P_{SVC} is the real power generation of SVC; $Q_{SVC\min}, Q_{SVC\max}$ are the minimum/maximum reactive power generation of SVC [9].

3 Solution Algorithm

In order to solve such a multi-optimization model, different techniques can be implemented either using conventional or heuristic criteria. In this paper a combinatorial heuristic criterion is suggested that can be used for such an optimization problem significantly. The proposed hybrid methodology consists of real genetic algorithm (RGA) incorporating an intelligent valuing mechanism to include the merit as well as the importance of different terms in the objective function. The combination of AHP (analytical hierarchy process) and a valuing method for making dimensional similarization can create a significant collaborated methodology for solving multi-objective optimization problem.

3.1 Dimensional Serialization Valuing Mechanism

The valuing process that is used in this paper is based upon a L row vector with the dimension equal to the number of population in GA. As it is shown in Figure (1) the measure of each component of L is linearly decreasing as the row index increases, while the sum of these measures are equal to one. Determination of chromosome merit is applied for reproduction of new populations via n multi-process, where n is the number of constraints associated with the objective function. In the first stage all chromosomes are sorted in a descending order based upon the first constraints [10].

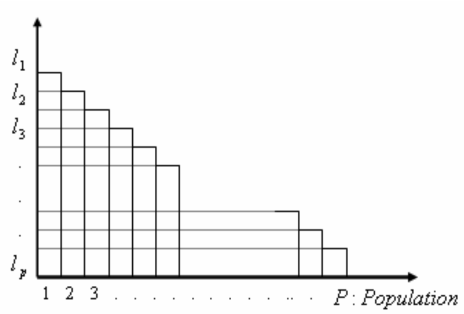

Fig 1- Linearly Merit Arrangement Values

The vector of a_1L, in which a_1 can be considered as the importance of the first constraint, is directly dependent on the merit arrangement and will be allocated to each individual chromosome. For the second stage, chromosomes are arranged in terms of the second constraint in a descending fashion and the vector a_2L will be added to a_1L correspondingly. This process will be continued to reach such a merit order chromosomes arrangement with regards to applying the RGA for optimization [11,12]. In this paper an AHP [13] technique is applied to derive the importance of constraints, in which a pair-wise comparison is employed associated with the relative importance.

4 Case Study and Results Analysis

A modified IEEE 30-bus system including 6 generators and 21 loads is selected to implement the proposed methodology for congestion management. This system is simulated using Power World software, where the base MVA and base voltage are assumed to be 100 MVA and 135 KV respectively. In order to enhance power transfer in the congested line, firstly the best location of FACTS devices is derived and control parameters of the allocated devices are then adjusted.

4.1 IEEE 30-Bus System Without Congestion

As it can be seen in Figure (2), under normal condition having no congestion, maximum real power is transferred through line 6-8 by amount of 77.87% of the permissible line capacity.

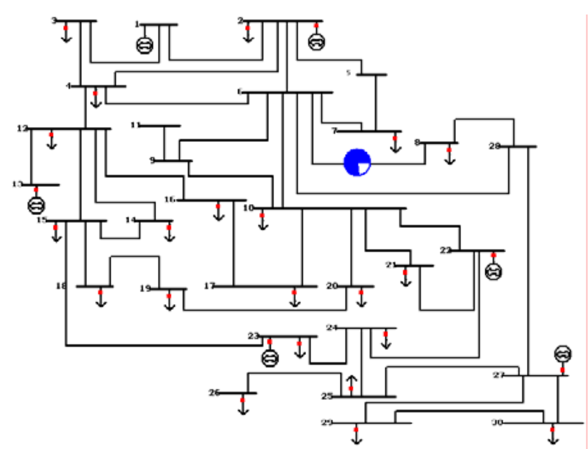

Fig 2-Modified IEEE 30-Bus System

Voltage profile of modified IEEE 30-bus system is shown in Figure (3), where at bus 25 and 26 the magnitude of bus voltages are 0.925 pu and 0.905 pu respectively. Congestion can be taken into account if real power transfer increases 80% of the line thermal capacity [14]. By considering congestion condition, it can be said that from congestion point of view there is no security violation while from voltage profile point of view this system needed to be compensated.

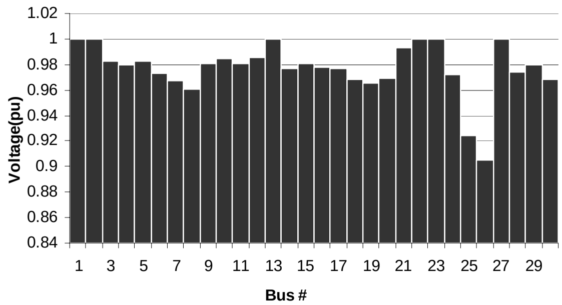

Fig 3- Buses Voltage Profile without Congestion

4.2 IEEE 30-Bus System with Congestion

The simulation results of this case is illustrated in Figure (4), in which by increasing load at bus 28 by 5 MW and increasing total demand by 5%, the congestion is going to be happened in line 6-8 reaching to 85%. Congestion can be taken into account if real power transfer increases 80% of the line thermal capacity [14]. By considering congestion condition, it can be said that from congestion point of view there is no security violation while from voltage profile point of view this system needed to be compensated. As it can be seen in Figure (4) by increasing 5 MW load at bus #28, congestion is going to be happened at line 6-8. In this case real power transfer from line 6-8 reaches to 27.5 MW. In this case the increment of PI is 20.1%, which indicates the congestion in the transmission network.

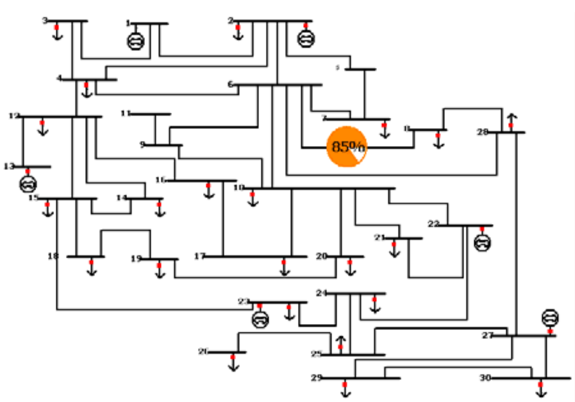

Fig 4-Modified IEEE 30-Bus System With Congestion

Voltage profile is depicted in figure (5). This figure is shown the minimum voltages are 0.92 pu & 0.9 pu at buses 25 and 26 respectively under congestion pressure.

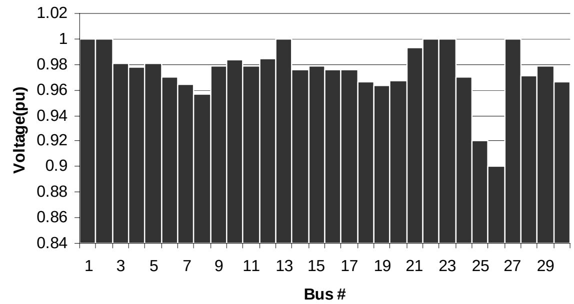

Fig 5- Buses Voltage Profile with Congestion

4.3 Voltage Profile Improvement and Congestion Relief Using SVC/TCSC

In the case of having congestion SVC & TCSC can be used to improve voltage profile as well as to relieve congestion associated with reducing transmission losses. To derive the importance of constraints in the objective function, AHP technique is applied where weighting matrix is presented by equation (8) with regards to three variables: voltage, congestion and losses.

$$P = \begin{bmatrix} 1 & \frac{1}{3} & 7 \\ 3 & 1 & 9 \\ \frac{1}{7} & \frac{1}{9} & 1 \end{bmatrix} \qquad (8)$$

Where:

$W = E_n = [\ 0.4032\ \ 0.9119\ \ 0.0764\ ]^T$

$A = [a_1\ \ a_2\ \ a_3] = [\ 0.2897\ \ 0.6554\ \ 0.0549\ ]^T$

Maximum eigenvalue of this matrix is λ_{max} =3.0803 which is approximately equals to the number of three variables. Weighting vector (W) and the normalized importance vector (A) can then be derived. Implementing RGA with the recombination rate of 76%, mutation rate of 3% and regeneration of 21% considering ellipsis is applied as it is depicted in Figures(6) and(7). These figures show that with congestion, after 47 generation the algorithm is converged wile the best solution is obtained after 60 generation. But voltage profile improvement is converged again after 46 generation, reaching the best profile after 60 generations. It can be realized that line 8-28 is the candidate for TCSC and bus 26 is candidate for SVC locations. In this regards the best capacity of those FACTS devices are 52.6% of line reactance which is equal to 0.10586 pu and 15.61 MVAr for SVC respectively.

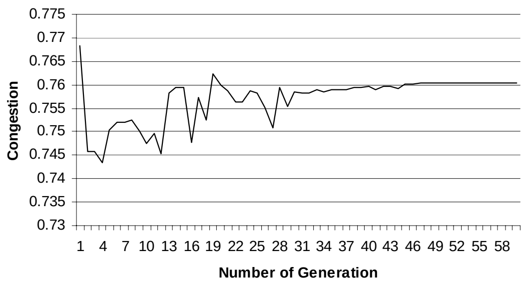

Fig 6-Congestion Variations versus Number of RGA Generation

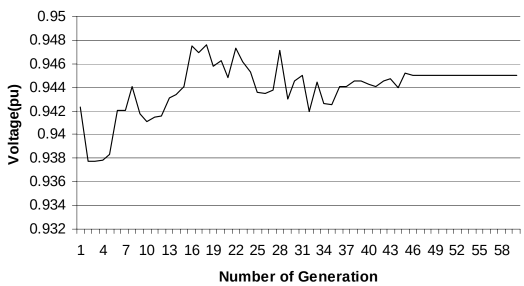

Fig 7-Voltage Variations versus Number of RGA Generation

The performance index of real power transfer in the network having TCSC shows the minimum amount that justifies the best location of TCSC (figure (8)).

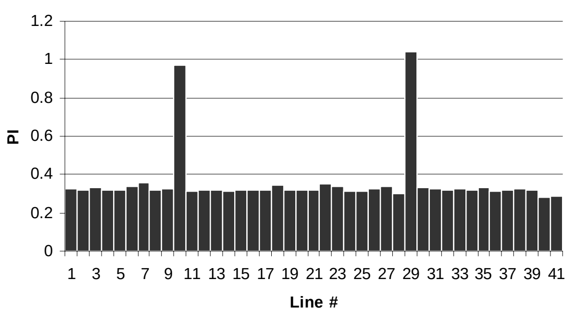

Fig 8-The Performance Index Diagram

By installing TCSC and SVC at their locations, power transfer at line 6-8 decreases to 76% of its maximum capacity and the worst voltage is 0.945 which belongs to bus 25, while it is improved significantly. Figure (9) illustrates the improvement of voltage profile as well as congestion relief in the system by applying the proposed criterion.

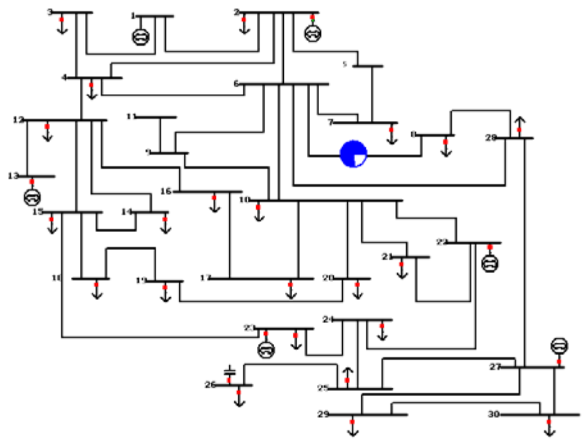

Fig 9-Modified IEEE 30-Bus System Using proposed TCSC & SVC

Figure (10) shows bus voltage profile using the allocated FACTS devices.

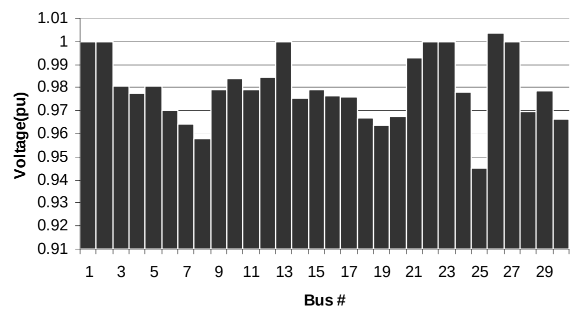

Fig10- Buses Voltage Profile Using proposed TCSC & SVC

As these results show that by using FACTS devices in their optimal location, it can help the modified IEEE 30-bus system to facilitate more transmission capacity. Using TCSC and SVC as FACTS devices procure system congestion relief and voltage profile improvement simultaneously. This feature increases transmission capability as well as voltage security margin of power systems.

5 Conclusions

Congestion management is an important issue in the reregulated environment of power systems. Congestion should be relieved in order to use the maximum capacity of transmission networks, It is well known that FACTS technology can control voltage magnitude, phase angle and circuit reactance clearly. Using these devices may redistribute the load

flow associated with regulating bus voltages. Therefore, it is worthwhile to investigate the effects of FACTS controllers on the congestion management.
SVC and TCSC are the main commercially available FACTS controllers. This paper presents an implementation of the AHP associated with RGA to determine the location and capacity of these devices. The proposed methodology is employed incorporating dimensional serialization valuing mechanism. Case studies and the obtained results show the effectiveness of the suggested criteria significantly.

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