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Optimal Placement Model of TCSC in Power System Network Considering the Budget Available

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***Abstract* — This paper presents an optimal placement of TCSC which is a FACTS (*Flexible Alternative Current transmission Systems*) controller in order to increase the loadbility of the system. The optimization problem is solved using the genetic algorithm. In this study the availablity of the budget is taken in consideration. The result show that the increase in loadability can be restricted by the availability of budget and also that beyond a certain budget there will not be any further increase in loadability. Also beyond a certain number of TCSC there will be no further increase in system loadability.**

Keywords—TCSC; budget; genetic algorithm; optimal; loadabilty

I. Introduction

Economic growth comes with heavy requirement on the power system network, there is always a need to increase the capacity of the network. It is not always possible to increase the capacity by building new infrastructure and this is as a result of environmental and financial constraints. Flexible Alternative Current transmission Systems (FACTS) device can assist in increasing the loadability of the network without building a new infrastructure. FACTS devices are able to alter the characteristics of the network and as a results increase loadability of the network. FACTS devices have the ability to re-direct power in the network. There are different types of FACTS devices which affect different characteristics of the network and the following are some of the FACTS devices

- Thyristor controlled phase angle regulator (TCPST),
- Unified power flow controller (UPFC)
- Thyristor controlled series compensator (TCSC),
- Static VAR Compensator (SVC),
- Static compensator (STATCOM).

The FACTS device of interest in this paper is the TCSC. The TCSC operate the same way as the series capacitor with the advantage of being fast. The utilization of TCSC in power system network can result in the following benefits [1]

- Increase in the system loadability and enhanced power flow
- Rapid power flow control in transmission lines,
- Increase the sensitivity and the responsiveness of the transmission lines

The study in [2] utilizes the TCSC to identify the highly sensitive lines for outages. In [3] the particle swarm optimization (PSO) is used to optimally located TCSC with the aim of maximizing the system loadability while minimizing the investment cost. In [4] TCSC is utilized together with other FACTS devices for congestion relief and voltage stability in a market-based power system. The enhancement of the total transfer capacity (TTC) of a power system is determined by using different combination of FACTS devices with TCSC being one of them [5]. To determine the optimal size and the location of TCSC or any FACTS device is a complex optimization problem. There are different methods that can be employed to solve such problems, the methods can be categorized into heuristic optimization algorithms and analytical techniques [6]

The most employed method is heuristic optimization algorithm tabu search (TA) is used in [7],[8]. Studies in [9]-[12] solves the problem using particle swarm optimization (PSO). There are few studies that employ simulated annealing (SA) [7]. The popular heusistic method used is the genetic algorithm [13]-[17].

This paper proposes an optimal placement of TCSC in a power system network with the objective to increase system loadability given a certain budget. The current research in this area focus on optimization of the location while considering cost of installation of TCSC. This research assumes an infinite budget which is not realistic[3],[19]. The research in this paper addresses the problem by taking into account the budget constraints, the reason being there is no any utility company or organization with infinite budget. The paper answers the problem were the power utility company have a certain amount of money and want to determine how much it can increase the loadability with the money in disposal.

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After giving the introduction in section 1 the paper is further organized as follows, The influence of TCSC on the power flow is explained in section 2. The formulation and modelling of the problem is given Section 3. The case study is presented in section 4. The results are given in section 5 and the discussion of the result is given in section 6. The paper ends by conclusion which is given in section 7.

II. TCSC INFLUENCE ON POWER FLOW

The influence of TCSC on the power flow on transmission line between bus i and k can illustrated by the active and reactive power equations 1 and 2

$$P_{ik} = -P_{ki} = \frac{V_i V_k}{x_{ik}} \sin(\theta_i - \theta_k) \quad (1)$$

$$Q_{ik} = \frac{1}{x_{ik}} [V^2{}_i - V_i V_k \cos(\theta_i - \theta_k)] \quad (2)$$

Where,

V_i and V_k voltage at bus i and k

X_{ik} is the reactance of the line

$\theta_i - \theta_k = \theta_{ik}$ is the angle between the phasors V_i and V_k

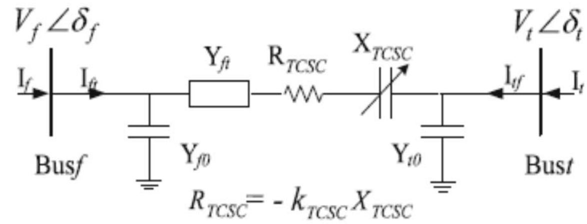

Fig. 1. The influence of TCSC in a transmission line [20]

III. PROBLEM FORMULATION AND MODELLING

The modelling of the optimal placement of TCSC problem is considered in this section. The optimization model will choose the location where the TCSC should be placed and the setting of that TCSC which will be represented by the reactance. The model will select both the location and setting based on the budget available. The objective of this is to determine the optimal setting, location and number of TCSCs that can be installed in a network in order to maximize the system loadability (L) given a certain budget.

Thus, mathematically, the problem is modelled as follows;

$$J = Max\{L(x_{ik}, u_{ik})\} \quad (3)$$

$$\forall_i = 1, \ldots \ldots \ldots \ldots \ldots \ldots \ldots . . N_{bus}$$

$$\forall_k = 1, \ldots \ldots \ldots \ldots \ldots \ldots \ldots . . N_{branches}$$

Where N_{bus} is the number of buses and $N_{branches}$ is the number of branches in the network.

$$S_i \le S_{lmax} \quad (4)$$

$$|\Delta V_{bi}| \le 0.05 \quad (5)$$

$$IC(Q_{ik}) \le \beta \quad (6)$$

$$\theta_{ik(\min)} \ge \theta_{ik} \ge \theta_{ik(\max)} \quad (7)$$

Where;

S_i is power carrying capacity of the line

V_{bi} is the bus voltage of individual buses

$IC(Q_{ik})$ is the total investment cost the TCSC

β is the budget available

$$OVL_{ik(\min)} = \begin{cases} 1 & if\ S_l \le S_{l,max} \\ Pvol\left(\left|1 - \frac{S_l}{S_{l,max}}\right|\right) & if\ S_l > S_{l,max} \end{cases} \quad (8)$$

$$VBL_{ik(\min)} = \begin{cases} 1 & if\ \ |\Delta V_{bi}| \le 0.05 \\ Pbus(|0.05 - \Delta V_{bi}|) & if\ \ |\Delta V_{bi}| > 0.05 \end{cases} \quad (9)$$

$$u_i = \begin{cases} 1; & if\ there\ is\ TCSC\ in\ branch\ i \\ 0; & if\ there\ is\ no\ TCSC\ in\ branch\ i \end{cases} \quad (10)$$

$$N_\emptyset = \sum_{i=0}^{N_b} u_i \le N_b \quad (11)$$

Where $N_\emptyset$ in equation 11 is the number of TCSC installed and while N_b gives an upper limit on how many TCSCs you can install in this network

The cost of installing a TCSC is given by the equation that follows

$$IC = C(Q_{ik}) \times R \times 1000 \quad (12)$$

Where

C represent the cost of TCSC in US$/KVAR

R is the operating range of the TCSC in MVAR

The bus voltage constraints (VBL), line loading limits (OVL) and budget constraints are implemented in a form of a fitness function;

$$Fit = 2 - (OVL + VBL) + Bud \quad (13)$$

Where Bud is a penalty function defined by;

$$Bud = \begin{cases} 0; & if\ \ IC(Q_{ik}) \le \beta \\ 1x10^8; & if\ \ IC(Q_{ik}) \le \beta \end{cases} \quad (14)$$

As is already mentioned in [13]-[19] the most popular heuristic optimization model used to solve these kinds of problems is GAs, The GA is also applied to solve the optimal placement problem presented in this paper. There are several steps that are followed in GA and the steps are as follows (and are depicted in figure 2)

Step 0: The first step is to create a random population which will be called the initial population. This population must be of a certain size and the size is determined by the user. This population represent the possible solution of the problem posed in (3). These solutions are referred to as individuals. The size of the population is selected to be 100 in this paper.

Step 1: In this step the possible solutions created in step 1 are evaluated to check their fitness. The solutions are then ranked accordingly and checked if there is an optimal solution. The termination of the algorithm will occur if there is an optimal solution or a condition of termination is met.

Step 2: If there is no optimal solution from step 1, then out of the ranked solutions (individuals), the two individuals on top of the list are selected and these two will serve as parents.

Step 3: In this step mating will occur between the individuals selected in step 2. New population will be formed by the offsprings of this process. This population represent new solutions.

Step 4: The mutation of the population takes places in this step, some of the individual's genes are altered and this create also a new population.

Step 5: The algorithm terminates in this step if the conditions for termination are met and if not the algorithm will repeat the process all over again by returning to step 2.

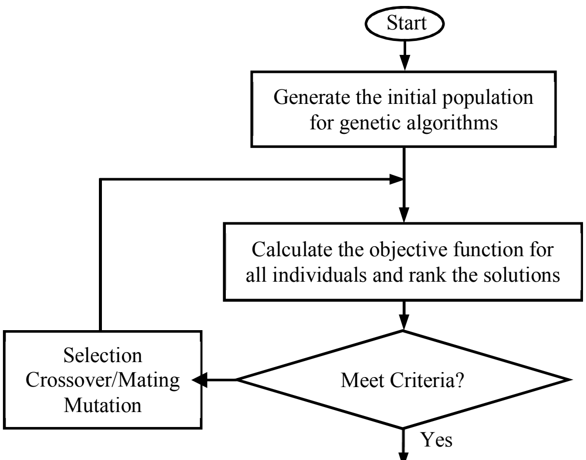

Fig. 2 Genetic Algorithm-Flow Chart

IV. CASE STUDY

To illustrate the efficiency of the optimization model, the model will be applied on a modified IEEE 14-bus test system. The values of the line parameters are altered to be the same with lines that are utilized in one power utility company in South Africa. Figure 3 is the modified IEEE 14 bus test system. The transmission line parameters are given in Table 1 and the transformer parameters are given in Table 2.

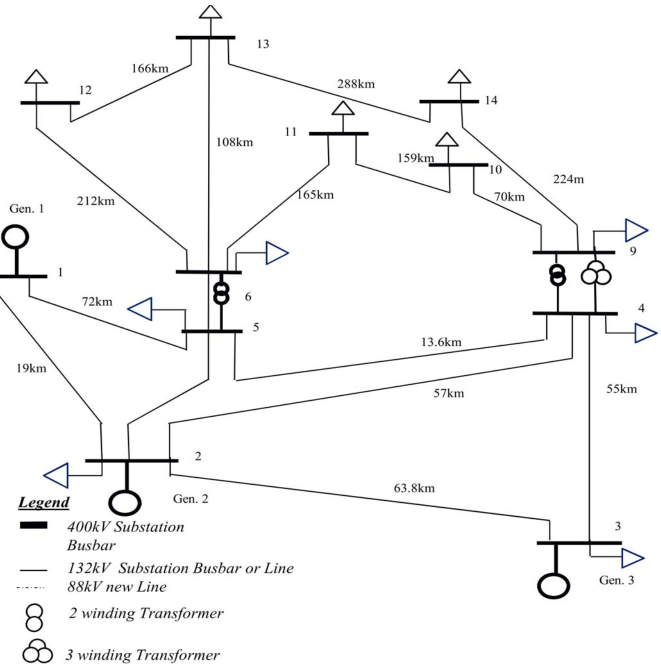

Fig. 3: A modified IEEE 14 bus system.

TABLE I. TRANSMISSION LINE PARAMETERS

Bus Number		Line		
From	To	R	X	Charging B
1	2	0.000576676	0.001760677	1.774417139
1	5	0.001608037	0.006636834	1.653434152
2	3	0.001398246	0.005890845	1.471959672
2	4	0.001729136	0.005246622	1.256878807
2	5	0.001694618	0.005174017	1.142617097
3	4	0.001993966	0.005089211	1.54589372
4	5	0.000397246	0.001253036	0.430161731
6	11	0.001038108	0.002173928	0
6	12	0.001343376	0.00279594	0
6	13	0.000723003	0.001423819	0
7	8	0	0.001925276	0
7	9	0	0.001202382	0
9	10	0.000347675	0.000923564	0
9	14	0.001389281	0.002955186	0
10	11	0.008967862	0.002099277	0
12	13	0.002414601	0.002184639	0

TABLE II. TRANSFORMER PARAMETERS

Bus Number		Line			
From	To	R	X	Charging B	Tap ratio
4	7	0	0.00228563	0	
4	9	0	0.00607891	0	
5	6	0	0.002754516	0	

V. RESULTS

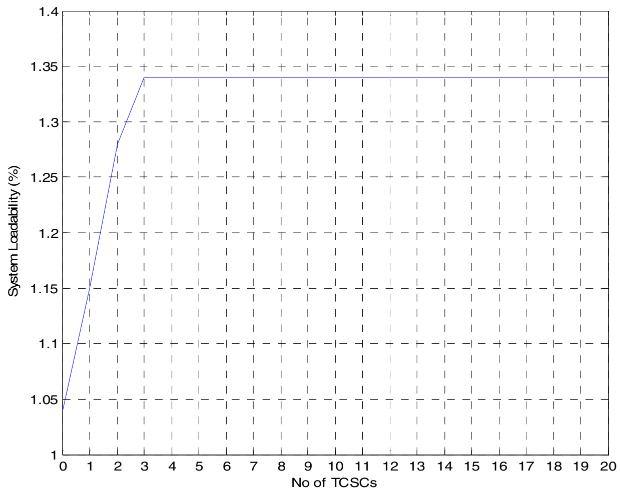

Fig. 4: Influence of number of TCSCs on total system loadability

TABLE III. THE IMPACT OF ONE TCSC ON SYSTEM LOADABILITY

No of TCSC = 1	
System loadability	1.15
System loadability increase	(15%-4%) = 11%
Location	10
Reactance	0.1901

TABLE IV. THE IMPACT OF TWO TCSC ON SYSTEM LOADABILITY

No of TCSC = 2		
System loadability	1.29	
System loadability increase	(29%-4%) = 25%	
Location	2	5
Reactance	-0.5314	-0.7979

TABLE V. THE IMPACT OF THREE TCSC ON SYSTEM LOADABILITY

No of TCSC = 3			
System loadability	1.34		
System loadability increase	(34%-4%) = 30%		
Location	2	4	5
Reactance	-0.470	-0.1534	-0.6544

TABLE VI. THE IMPACT OF 15 MILLIONS BUDGET ON SYSTEM LOADABILITY

Budget of $8 million			
System loadability	1.18		
System loadability increase (%)	(18%-4%) = 14%		
Actual Money spent (Million)	7.5		
Location	2	14	17
Reactance	-0.437	-0.2794	-0.7335

TABLE VII. THE IMPACT OF 25 MILLIONS BUDGET ON SYSTEM LOADABILITY

Budget of $12 million			
System loadability	1.22		
System loadability increase (%)	(22%-4%) = 18%		
Actual Money spent (Million)	11.5		
Location	2	7	19
Reactance	-0.422	-0.724	-0.554

TABLE VIII. THE IMPACT OF 35 MILLIONS BUDGET ON SYSTEM LOADABILITY

Budget of $18 million			
System loadability	1.30		
System loadability increase(%)	(30%-4%) = 26%		
Actual Money spent (Million)	17.6		
Location	2	4	5
Reactance	-0.736	-0.7877	0.122

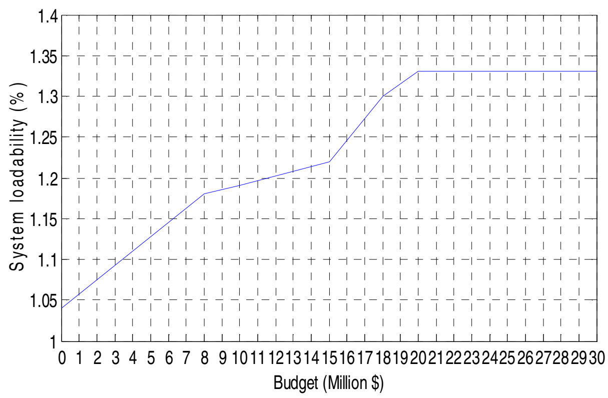

Fig. 5: Influence of budget on the total system loadability

VI. Discussion of the Results

The graph in figure 4 shows the influence of the number of TCSCs on the loadability of the system. The loadability of the system increases as the number of TCSCs increases up until to a certain point. In this case there is no loadability improvement beyond three TCSCs. Table 3 , 4 and 5 gives the system loadability as the result of installing the TCSCs and also the increase in system loadability. The tables also gives the locations on which the TCSCs are placed. The locations are the branch numbers which are shown on figure 3, the modified IEEE 14 bus system. The loadability of the system can be improved by 30% which is achieved by installing 3 TCSCs at the optimal places. By installing 1 TCSCs you can improve the loadability by up 10%, while installing 2 TCSCs the system can achieve the loadability of up to 25%.

The graph in figure 5 shows the influence of the budget on the loadability of the system. To illustrate the influence of the budget on the system loadability, a system with 3 TCSCs is used because it gives you maximum loadability. Table 6, 7 and 8 shows the influences of budget on system loadability and loadability increase. These tables also gives the budget and the actual money spent in contrast to the previous tables. Table 6 illustrate the case were there is budget of $8 million available the system loadability can be increased by up to 14%. With the budget of $12 millions avaible the loadability can be increased to 18% and 26% increase in loadability can be achieved if there is a budget of $18 millions.

VII. Conclusion

The optimal placement of TCSCs in the power system network is formulated while taking into consideration the budget constraint. The result shows a non linear relationship between the increase in the number of TCSCs and the increase in system loadability, this is also true for the increase in budget and the increase in system loadability.

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