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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 6 (7): 1095-1099, 2007
ISSN 1812-5638

Optimal Placement of Static VAR Compensator in Algerian Network

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Abstract: Power systems must be carefully controlled in order to maintain an acceptable power supply quality. Advances in power electronics and control technology have introduced powerful tools to power utilities and more recently, the concept thyristor-controlled Static VAR Compensator (SVC). This study presents a based approach to determine optimal placement of Static VAR compensator SVC for voltage security enhancement, the proposed method has been applied the Algerian distribution system. The SVC placement problem considers practical operating constraints of SVC, the upper and lower bound constraints of voltage at different load levels which minimize the system loss. A sensitivity analysis method is used to select the candidate installation location of the SVC. SVC is integrated into OPF program. More specifically the problem of low voltage profile in Eastern Algerian system is investigated. The effectiveness of the proposed project of SVC placement has been validated on a practical 71-bus Algerian system with respect of the dynamic voltage margins.

Key words: Generalized reduced gradient method, static VAR compensator placement, sensitivity coefficient, voltage violation, reactive power control

INTRODUCTION

As deregulation of the electricity system becomes an important issue in many countries, Flexible AC transmission System (FACTS) devices become more and more commonly used. They may be used to improve the transient responses of power system and can also control the power flow (both active and reactive power). The main advantage of FACTS are enhancing system flexibility and increasing the loadability.

In addition to this, due to deregulation and reconstruction of the electric power industry, the need arises to transport large blocks of power between areas through defined corridors. Furthermore the voltage is profile of the remote buses of systems in necessary to be kept within a pre-specified range. Thus the need arises to install modern devices, such as SVC, into power systems.

Static VAR Compensators (SVC) are devices that control the reactive power injection at a bus using power electronics switching components.

Those SVC devices can be used to improve the performance of the electric power system by providing voltage support; improving the power factor and power system damping.

The problem of VAR sources planning has received considerable attention in recent years, where different optimization methods are used to solve the problem. A new technique based on sensitivity method is used to determine the location and size of the VAR sources to be installed.

The proposed method is to use the sensitivity of voltages to reactive power injections at the different system buses as indicators of the locations that are more effective in controlling the voltage in the system.

SVC is installed in distribution system for reactive power compensation to carry out power loss reduction and voltage regulation system security improvement.

In this study, a model of the Algerian power system representing its current state under peak load condition will be analyzed using the enhancement OPF program. More specifically the problem of low voltage profile in the Eastern area of Algerian system is investigated. (Benzergua, 2006).

Optimal Power Flow (OPF) problem is one of the major issues in operation of power systems. This problem can be divided into two sub problems, MVar dispatch or Optimal Reactive Power Flow (ORPF) and MW dispatch (Martinez Ramos, 1995).

Computer simulation results are promising and they indicate that the proposed method yield large annual savings (Berrizzi *et al*., 1999; Leung and Chung, 2000; John and Vlachogiannis, 2000; Barzadeh, 2004).

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PROBLEM FORMULATION

SVC placement problem considered in this study is to determine the locations, numbers and sizes of SVC to be installed in a electrical distribution system.

The objective is aimed to retain the voltage magnitudes of the system within prescribed maximum and minimum allowable values for different loads levels.

The Static Var Compensator (SVC) equipment is composed by capacitors, thyristors and inductance. There are two ways for modelling these devices. The first model considers SVC as variable impedance, which is adapted automatically to achieve the voltage control. This is called the passive model and its main disadvantage is the changing of nodal admittance matrix whenever there is a variation in the operation conditions of the power grid.

The second model, called active model, represents SVC as a nodal power injection.

In this study SVC is modelled as an ideal reactive power injection at bus I. The injected power at bus I is: Q_{svc}.

Distribution system accounts for a major portion of power system SVC are used widely to accommodate voltage regulation and VAR supply, could also reduce the distribution system losses.

For SVC devices placement, general considerations are:

- The number and location;
- The size
- The placement of SVC has been considered at load buses only.

Sensitivity factors are used to determine at which nodes additional SVC will have greatest effect in controlling the voltage limits.

The linearized system of power flow equation is solved by Generalized Reduced Gradient Power Flow (GRGPF) method.

The power flow equations and security constraints are as follows:

$$\text{Min PI } (Vi, \theta i) \qquad \text{(Objective function)} \tag{1}$$

$$P_L = \sum_i^n \sum_j^m -G_{ij}(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}) = 0 \tag{2}$$

$$P_{gi} - P_{li} - V_i\sum_{k=1}^{n} V_k(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) = 0 \tag{3}$$

$$Q_{gi} - Q_{li} - V_i\sum_{k=1}^{n} V_k(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) = 0 \tag{4}$$

$$j = 2,\ldots\ldots\ldots,N \qquad Q_i^{gmin} \le Q_i^g \le Q_i^{max} \qquad i = 2,\ldots\ldots,Ng \tag{5}$$

$$V_i^{max} \le V_i \le V_i^{max} \qquad i = 1,2,\ldots\ldots,N \tag{6}$$

$$\text{Tmin} \le \text{T} \le \text{Tmax} \tag{7}$$

Where:

PL : Total power loss of transmission lines.
N : No. of buses
Ng : No. of generators

The adjustment of the reactive power balance at the network nodes may be more complex because the network itself may be a source of reactive power. Therefore, in order to facilitate this adjustment, at those nodes where a difficulty might occur, we shall put in generating variable instead of the voltage variable. This allows to find easily an initial acceptable voltage profile.

The solution of this problem by the Generalized Reduced Gradient GRG method requires the creation of the Lagrangian as shown below:

$$L = P_L + \left[\lambda_1, \ldots\ldots, \lambda_{2(n-1)}\right]\begin{bmatrix}\Delta P_2\\ \Delta Q_2\\ \\ \Delta P_n\\ \Delta Q_n\end{bmatrix} \tag{8}$$

And the conditions of optimization are:

$$\begin{cases}\dfrac{\partial L}{\partial\theta_i} = \dfrac{\partial P_L}{\partial\theta_i} + \sum_{k=2}^{n}(\lambda_k\left[\dfrac{\partial P_k}{\partial\theta_i}\right] + \left[\dfrac{\partial Q_k}{\partial\theta_i}\right]) = 0\\ \dfrac{\partial L}{\partial v_i} = \dfrac{\partial P_L}{\partial v_i} + \sum_{k=2}^{n}(\lambda_k\left[\dfrac{\partial P_k}{\partial v_i}\right] + \lambda_k\left[\dfrac{\partial Q_k}{\partial v_i}\right]) = 0\end{cases} \tag{9}$$

$$\left[\frac{\partial L}{\partial Q_i^g}\right]0 + \left[\frac{\partial \Delta Q_i}{\partial Q_i^g}\right][\lambda_i] \tag{10}$$

And:

$$\frac{\partial L}{\partial\lambda_i} = 0 \rightarrow \Delta P_i = 0 \text{ and } \Delta Q_i = 0 \tag{11}$$

From the Eq. 8 we can obtain the values of the vector $[\lambda_i]$ which will be used to calculate the values of the vector $\left[\frac{\partial L}{\partial Q_i^g}\right]$ After that we calculate the new values of the reactive power generate:

$$Q_i^{g(k+1)} = Q_i^{g(k)} - \frac{\partial L}{\partial Q_i^g} \tag{12}$$

This new values Q_i^g calculated by the GRG method will be injected in the FDLF algorithm to found the new values of power losses in our network.

BUS VOLTAGE SENSITIVITY FACTORS

A sensitivity analysis is employed to select the candidate location for placing SVC in distribution system (Verma and Srivastava, 2005).

In earlier studies heuristics and engineering judgment have been employed to select the locations. The sensitivity analysis is a systematic procedure to select location that regulate voltages between there limits when we place SVC at those locations,

$$S_i = \frac{\Delta V_i}{\Delta Q_j} \tag{13}$$

In OPF formulation, the SVC has been considered as a reactive power source with above reactive power limits.

The matrix S_i of all the PQ nodes of the system, can be obtained from the Eq. 14:

$$S_i = \frac{\Delta V_i}{\Delta Q_j} = (B'')^{-1} \tag{14}$$

The matrix S_i can be computed from the inverse of B''.

$$S_i = (B'')^{-1}. \tag{15}$$

B'': The imaginary part of the nodal admittance matrix (Ching-tzong *et al*., 1999; Sing and David, 2001).

SOLUTION METHODOLOGY

The proposed optimal SVC device placement method uses sensitivity factors to rank the feeder nodes in order to control the voltage limits and reduce the power losses.

The voltage along the feeder are required to remain within upper and lower limits (typically, within ±5% of the rated feeder voltage) prior to, or after, the addition of the SVC on the feeder.

Sensitivity factors are evaluated at each node every time a change occurs in the feeder such as the addition of the SVC. The nodes are ranked in descending order of the values of their sensitivity factors. The top ranked nodes in there priority list are the first to be considered in generating alternatives in the optimization process.

For the next iteration, the sensitivity factors are recalculated and the nodes are again ranked with the modification described in the previous section, The nodes with permanently assigned SVC additions during previous iterations occupy the highest positions in the priority list (Leung and Chung, 2000).

ALGORITHM

For the base case condition and for each alternative SVC placement generated, a power flow solution is obtained. The Generalized Reduced Gradient power flow method is used because of its reliability and speed of convergence.

However in these algorithms, once a node has been selected and a SVC device has been placed, a load flow is performed to ensure that no voltage constraints have been violated. In the proposed method, an ideal candidate node for SVC placement will be choosed. Thus, the likelihood of voltage violations accruing after the installation of the SVC is reduced.

Each node voltage magnitude is checked against its upper and lower limits. If a node voltage is not within limits, the particular alternative is rejected. If no constraint violation occurs the peak power loss, total energy loss and released SVC are computed.

The proposed algorithm is summarized by the following steps:

- Perform the optimal load flow program to calculate bus voltages using the Generalized Reduced Gradient method.
- Calculated the sensitivity factors.
- On the first iteration, arrange the nodes in a priority list in descending order of the value of their sensitivity factors
- Identify the candidate location as the bus with larges sensitivity factors.
- In the next iterations, place the nodes with permanent SVC additions at the top of the list and the remainder of the nodes in descending order of their sensitivity factors
- Add Q_{svc} at bus k and perform the load flow to find new bus voltages. Exit if there is no voltage violation, otherwise go to step (1).

Terminate the procedure when the maximum numbers of SVC additions have been allocated, or if no better solution can be found (Bala, 1995; Thurkaram and Lomi, 2000).

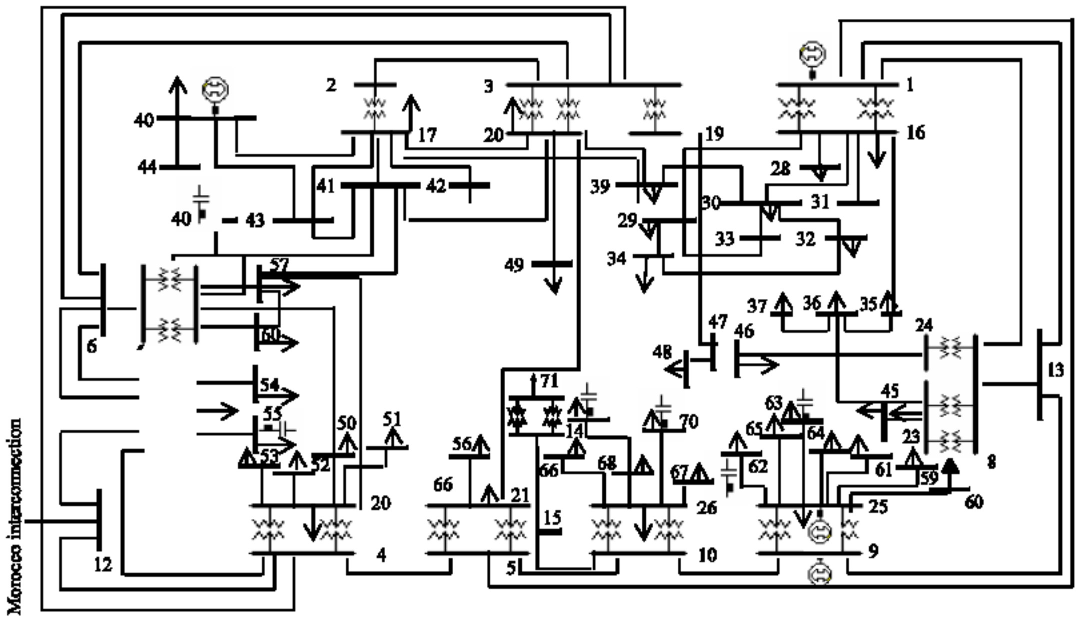

Fig. 1: Algerian 220/60 KV transmission/sub-transmission system

NUMERICAL RESULTS

The assumption being tested is that the largest sensitivity coefficients indicate the buses at which reactive power injection is more effective in order to control the voltage limits. The purpose of the tests is not to study the economy of the reactive power injection. It may happen that the required Q_{svc} injection at a bus to force the bus voltage outside the acceptable range and at the same time minimize the P_{Loss} with that objective in mind.

The proposed method has been applied to practical Algerian transmission/Subtransmission system 220/60 KV (Fig. 1). Its main data and operational limits are summarized in Table 1 and 2. This system has 64 load nodes and 4 generators nodes.

The inequality constraints for optimal Static VAR Compensator placement are the quality of service considerations and equipment limitations utility through company's experiences. Such example a voltage magnitude ratings.

Voltage magnitude, $|V_i|$, constraints are expressed as:

$|V_{i,min}| \leq |V_i| \leq |V_{i,min}|$

$|V_{min}|$ and $|V_{max}|$ are the specified acceptable viltage magnitude limits

The adopted maximum and minimum tolerance have been defined in such a way that the allowed voltage interval is reduced to 0.95 <Vi <1.1 pu for all buses i.

A large value of $|V_{min}|$ and $|V_{max}|$ indicates that one or more of the system buses has a voltage magnitude outside the desired limits.

Table 1 Main data of the Western Algerian system

Main data of the western algerian system	
Load buses	67
Generator buses	4
Lines	80
Transformers	12
Shunt capacitors	5

Table 2: Limits of control variables and bus voltages

Magnitude	Lower	Upper
220 KV voltage	0.99	1.11
60 KV voltage	0.95	1.10
Taps (20steps)	0.9	1.1
Q_{Shunt} (2 steps)	0	10 MVAR
Q_1^g	-250 MVAR	500 MVAR
Q_9^g	-90 MVAR	180 MVAR
Q_{23}^g	-15 MVAR	35 MVAR
Q_{36}^g	-20 MVAR	36 MVAR

Table 3: The violated voltage after the first load flow

Nodes	Vi	ΔVi
48	0.83181	0.118
70	0.84320	0.107
62	0.84710	0.103
69	0.87640	0.077
55	0.93760	0.012
47	0.94023	0.009
37	0.94514	0.005

GRG method is employed both during the line search process and is updating the state before the next iteration.

Table 3 shows the 7 buses whose voltage is initially bellow the lower limit.

After the calculation of the sensitivities, the recommendations at this phase consist to introduce a SVC of 20 MVAR at the bus 48. This first correction could correct the voltages of buses 47 and 48.On the other hand

Table 4: The violated voltage after the first correction

Nodes	Vi	ΔVi
70	0.82720	0.1228
62	0.82815	0.1218
69	0.88131	0.0687
55	0.94118	0.0088
37	0.94712	0.0028

Table 5: violated voltage after he second correction

Nodes	Vi	ΔVi
62	0.8612	0.0888
69	0.9301	0.0199
55	0.9340	0.0160
37	0.9469	0.0031

the voltage at bus 62 has not changed and buses 55, 62, 69, 70 always remain out the limits but with other less novel violations, as shown in Table 4.

New sensitivities are calculated for each bus and tested respecting the given algorithm.

The required reactive injection from SVC correction calculated by the system is 10 MVAR in bus 70.

This correction eliminated the violation from voltage 70 and improved the voltage of node 69(0.9301 been able) without eliminating the violation in this bus, as shown in Table 5.

The third correction suggested by the system is place an SVC of 20 MVAR to bus 62, this injection eliminates all violations and all voltages are acceptable. All voltages are maintained between 0.95 and 1.1 pu, with active power losses of 21.68.

It is noticed that after each correction of the voltage the active powers generated by the generator of the bus assessment decreased, which justifies that the correction of the tension in the network decreases the active losses in this one.

CONCLUSION

In this study, we have proposed a sensitivity based solution methodology to determine the installed locations of SVC devices, number and sizes.The SVC devices should be placed on the most sensitive bus. With the loss sensitivity indices computed for each bus.

The effectiveness of the sensitivity method to solve the combinatorial optimization problem of SVC placement has been demonstrated through the numerical examples capable of handling modern power markets structures.
Results show the impact in transmission Losses using SVC technologies in real networks.

From the results obtained in this work following conclusions can be made:

New sensitivity indices can be effectively used for the optimal placement of SVC devices. In general, the buses having top priority ranked according to their sensitivity indices corresponding to the day-load condition can be selected for optimal placement of the devices.

Table 6: The network active losses before and after the incorporation of SVCs

Parameters	Basic case (without SVC)	1st correction SVC (bus 46)	2nd correction SVC (bus68)	3rd correction SVC (bus 60)
Losses	27.11	23.52	23.45	21.68
Reduction		3.59	3.66	5.43
Reduction (%)		13.24	13.50	20.03

The system with SVC devices improves the voltage profile of the system.

Including SVC devices in the complete load flow problem, reduces in total power loss in the system (Table 6).

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