OPTIMAL PLACEMENT OF STATIC VAR COMPENSATORS IN POWER SYSTEM

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Abstract :
This paper presents a new method which applies the application of Genetic Algorithm as meta-heuristic optimization method for power system problems in distribution substations. With increase in load, any power system model suffers from disturbances. These disturbances effect the overall stability of the system. Criterias like voltage profile, power flows, losses tell us about the state of the system under study. Load flow analysis under study is capable of providing the insight of the system. Static var compensator is one of the methods and can be applied to obtain a system with least losses, increased power flow and healthy voltage profile. Number, location and size of Static var compensator are the main concerns and they can be optimized to a great extent by Genetic Algorithm. Use of Static var compensator in system has shown considerable increase in voltage profile and power flows while decrease in losses.

Keywords: Static var compensator; distribution system; etap; voltage profile; losses; genetic algorithm.

1. Introduction

As a result of recent environmental legislation, rights of way issues, increase in construction cost and deregulation policies, there is an increasing recognition of the necessity to utilize existing transmission system assets to the maximum extent possible which can be achieved with the help of FACTS devices. The flexible ac transmission system is the result of related developments in electronic devices designed to overcome the limitations of traditional mechanically controlled power transmission systems. By using reliable, high speed electronic controllers, this technology offers opportunity for increased efficiency. The parameters such as transmission line impedances, terminal voltages and voltage angle can be controlled by FACTS devices in an efficient way. The benefits brought about FACTS include improvement of system dynamic behaviour and enhancement of system reliability, voltage profile, and power flows with reduction of losses. SVC, STATCOM, SSSC and TCSC are the few examples of FACTS devices. System instability ,loop flows, high transmission losses, voltage limit violations, inability to utilize transmission line capability up to the thermal limit, cascade tripping and high operational costs has been mentioned as a result of unregulated active and reactive power flows[Acha *et al.*(2004)]. Upgrading existing transmission lines by using FACTS controllers is suggested as a solution to these problems [Gotham and Heydt (1998)]. Facts devices provide new control facilities, both under steady power flow control and Dynamic state. The possibility of controlling power flow in an electric power system without generation rescheduling or topological change can solve the problems of planning engineers to much extent and improve the system performance considerably. By using controllable components such as controllable series capacitors, phase shifters, static VAR compensators (SVC), static compensators (STATCOM), thyristor controlled series compensator (TCSC), static synchronous series compensator (SSSC), unified power flow controllers (UPFC) [Gyugyi *et al.*(1995)] ,line flows can be changed in such a way that thermal limits are not violated, losses are minimized, stability margin are increased and contractual requirements are fulfilled without violating specified power dispatch.

1.1. Static var compensator

A Static Var Compensator (SVC) is a power quality device, which employs power electronics to control the reactive power flow of the system where it is connected [Porate *et al.* (2009)]. As a result, it is able to provide fast-acting reactive power compensation on electrical systems. The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. When SVC is connected to power system to regulate transmission voltage, then called as transmission SVC and when it is connected near large industrial loads to improve power quality, then called industrial SVC. Static var compensators have their output adjusted to exchange inductive or capacitive current in order to control a power system variable such as the bus voltage.SVC is based on thyristors without the gate turn-off capability. It includes separate equipment for leading and lagging vars; the thyristor-controlled or thyristor-switched reactor for absorbing reactive power and thyristor-switched capacitor for supplying the reactive power. It is low cost substitute for STATCOM. Proper placement of static VAR compensator (SVC) and thyristor controlled series compensator (TCSC) reduces transmission losses, increases the available capacity, and improves the voltage profile [Biansoongnern *et al.* (2006)]. The optimal location of SVC is identified by a new index called single contingency voltage sensitivity (SCVS) index [Sundar and Ravikumar (2008)]. Optimal placement of Static VAR Compensator (SVC) controller is suggested to improve voltage profile using a novel hybrid Genetic Algorithm and Sequential Quadratic Programming (GA-SQP) method [Khandani *et al.*(2011)] .The proposed algorithm has used to determine optimal placement of SVC controller and solving optimal power flow (OPF) to improve voltage profile simultaneously. The proposed OPF has used to improve voltage profile within real and reactive power generation limits, line thermal limits, voltage limits and SVC operation limits. A modified artificial immune network algorithm (MAINetA) has used for placement of static var compensators (SVC) in a large-scale power system to improve voltage stability. To enhance voltage stability, the planning problem has formulated as a multiobjective optimization problem for maximizing fuzzy performance indices for bus voltage deviation, system loss and the installation cost [Khaleghi *et al.* (2009)]. Minguez et al addressed the optimal placement of static var compensators (SVCs) in a transmission network in such a manner that its loading margin gets maximized. A multi scenario framework that includes contingencies has also considered in [Minguez *et al.* (2007)].A Simple Connection diagram of SVC has been given in figure 1.

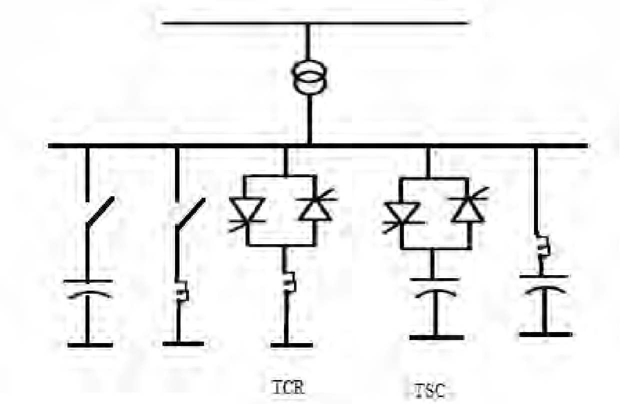

Fig.1. SVC connection to a bus

1.1.1. Types of static var compensator controllers

- Thyristor Controlled Reactor (TCR): In this type of SVC, a reactor with thyristor valves is incorporated in each phase. Reactive Power is varied by controlling the current through the reactor using the thyristor valves. This type of SVC is characterized by smooth and continuous control.
- Thyristor Switched Capacitor (TSC): in this type of SVC, a shunt capacitor bank is divided into an appropriate number of branches. Each branch is individually switched on or off through anti-parallel connected thyristors. The main characteristics of this type of SVC are step and smooth control, no harmonics, low losses and flexibility.
- Fixed Capacitor Thyristor Reactor (FC-TCR): In this type of SVC, a TCR is used in combination with a fixed capacitor bank when reactive power generation is required. This is often the optimum solution for sub-transmission and distribution applications. The main characteristics of this type of SVC are smooth and continuous control, elimination of harmonics by tuning the fixed capacitors and compact design.
- Thyristor Controlled Reactor-Thyristor Switched Capacitor (TCR-TSC): In this type of SVC, the TCR and the TSC is combined to get an optimum solution in many cases. With a TCR-TSC SVC, continuously variable reactive power can be obtained across the entire control range, with full control of both the inductive and the capacitive parts of the compensator. The principal benefit is optimum performance during major disturbances in the system such as line faults and load rejections. This type of svc is characterized by continuous control, elimination of harmonics through TSC control, low losses, redundancy and flexibility.

2. System under Study

A Single line diagram of 33/11 KV Distribution Substation is considered in ETAP [Porate *et al.* (2009)]] with eleven buses (from Bus 1 to Bus11) as shown in figure 2. It consists of two power transformers (T1 and T2), each having capacity of 3 MVA and four distribution transformers (T3, T4, T5 and T6). There are four static loads (from Load 1 to Load 4). There are two out going feeders connected to each of power transformers. Incoming voltage level is 33KV and the distribution voltage level is 11KV. Load receives a voltage of 0.435 KV.

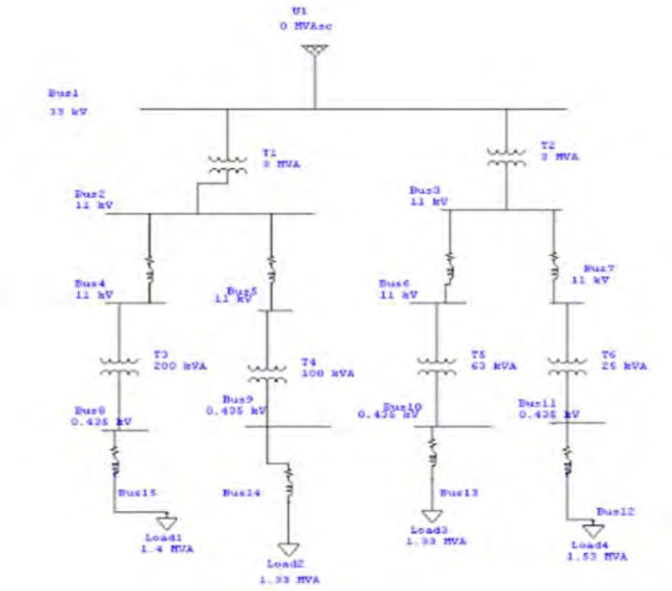

Fig.2 Single line diagram

The values of transmission line parameters and transformer parameters are shown in Table 1 and Table 2.

Table1. Transmission line parameters

From	**To**	**Resistance per Km**	**Reactance per Km**
Bus1	Bus2	0.16	0.32
Bus1	Bus3	0.16	0.32
Bus2	Bus4	0.16	0.32
Bus2	Bus5	0.16	0.32
Bus3	Bus6	0.16	0.32
Bus3	Bus7	0.16	0.32
Bus4	Bus8	0.16	0.32
Bus5	Bus9	0.16	0.32
Bus6	Bus10	0.16	0.32
Bus7	Bus11	0.16	0.32

Table 2. Transformer parameters

Transformer	**Primary voltage (KV)**	**Secondary voltage (KV)**	**MVA**
TI	33	11	3
T2	33	11	3
T3	11	0.435	200
T4	11	0.435	100
T5	11	0.435	63
T6	11	0.435	25

3. Load flow analysis

ETAP Load Flow analysis calculates Bus voltages, Branch Power Factors, Currents and Power Flows throughout the Electrical system in single line diagram. ETAP allows for swings, voltage regulated, unregulated power sources with multiple power grids and generator connections. It is capable of performing on both radial and loop systems. ETAP allows feeding of all these above values in single line diagram for load flow analysis. ETAP provides three load flow calculation methods: Newton-Raphson, Fast-Decoupled, and Accelerated Gauss-Seidel. They possess different convergent characteristics, and sometimes one is more favorable in terms of achieving the best performance. Any one of them is selected depending on system configuration, generation, loading condition, and the initial bus voltage.

3.1. Newton rapson method

The Newton-Raphson method formulates and solves iteratively the load flow equation as shown in Eq. (1)

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}\begin{bmatrix}J_1 & J_2\\ J_3 & J_4\end{bmatrix}=\begin{bmatrix}\Delta\delta\\ \Delta V\end{bmatrix} \qquad (1)$$

Where ΔP and ΔQ are specified bus real and reactive power mismatch vectors between specified value and calculated value, where ΔV and Δδ represents Bus voltage angle and magnitude vectors in an incremental form; and J_1 through J_4 are called Jacobian Matrices. The Newton-Raphson method possesses a unique quadratic convergence characteristic. It usually has a very fast convergence speed compared to other load flow calculation methods. It also has the advantage that the convergence criteria are specified to ensure convergence for bus real power and reactive power mismatches. This criterion gives the direct control of the accuracy to specify for the load flow solution. The convergence criteria for the Newton-Raphson method are typically set to 0.001 MW and Mvar. The Newton-Raphson method is highly dependent on the bus voltage initial values.

4. Genetic Algorithm

Heuristic methods may be used to solve complex optimization problems. Thus, they are able to give a good solution of a certain problem in a reasonable computation time, but they do not assure to reach the global optimum. In case of GAs are global search technique, based on the mechanism of natural selection and genetics; they can search several possible solutions simultaneously. Genetic algorithms (GAs) are based on biological principles of evolution and provide an easy interesting alternative to "classic" gradient-based optimization methods [Alexander and Schreyer *et al.* (2005)]]. They are particularly useful for highly nonlinear problems and models, whose computation time is not a primary concern. The primary usefulness of the GA is that it starts by sampling the entire design space, possibly enabling it to pick points close to a global optimum. It then proceeds to apply changes to the ranked individual design points, which leads to an improvement of the population fitness from one generation to another. To ensure that it doesn't converge on an inferior point, mutation is randomly applied, which perturbates design points and allows for the evaluation and incorporation of remote points. The Fitness Function [Beromi *et al.* (2007)] made in GA, by considering all objectives is given by Eq. (2).

$$f_x = \frac{1}{n}\left[\sum_{all} voltage + \sum_{all} losses + \sum_{all} activepower + \sum_{all} reactivepower\right] \quad (2)$$

5. Results

The graph for fitness function obtained from GA by considering the effect of SVC is shown in figure 3.

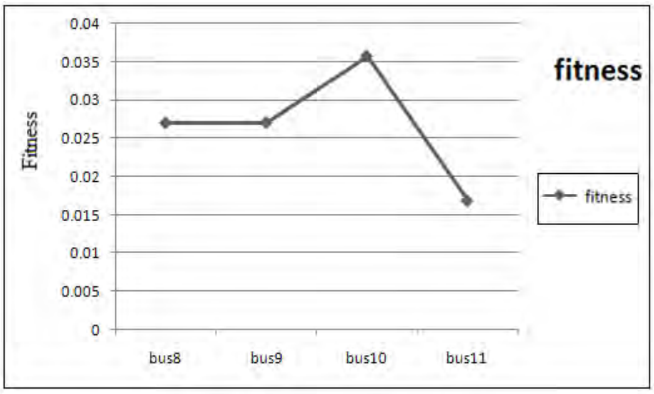

Fig.3. Fitness fuction curve

It can be seen that the value of fitness when single SVC is connected at Bus-10 is high ie.**0.035677**. Therefore, a SVC of inductive rating of 2.5 Mvar and capacitive rating of 5 Mvar must be placed at this location. It is shown that when SVC is connected at Bus-10, we have improved voltage profile and reduction in overall losses. The Average voltage is increased by 1.17272 units i.e. from 94.99273 to 96.16545 and Average losses decreased by 1.48182 units i.e. from 11.88182 to 10.40 as shown in figure 4 and figure 5 respectively.

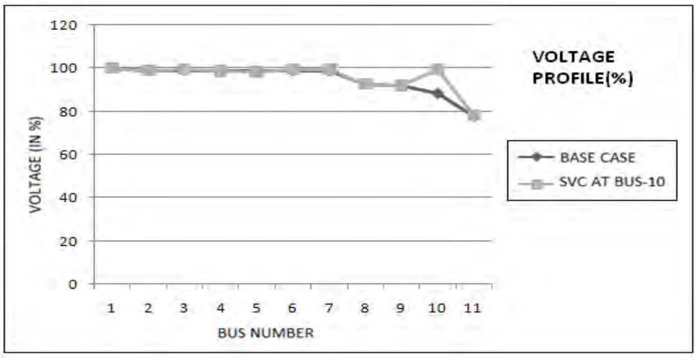

Fig.4. Comparison of voltage profile between base case and SVC at BUS-10

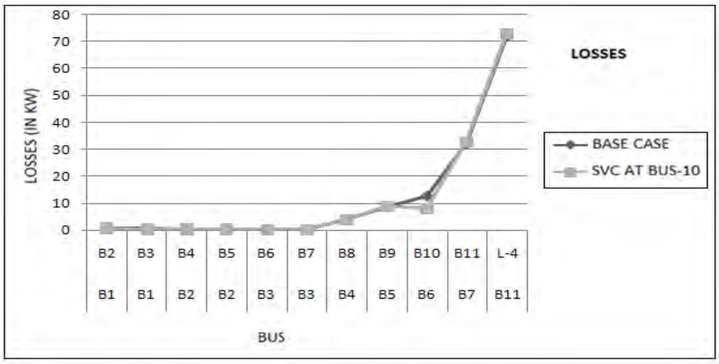

Fig.5. Comparison of losses between base case and SVC at BUS-10

There is also improvement in active power when SVC is used. SVC connection at Bus-10 resulted in increase of average active power from 175.0909 to 184.8182 i.e. increment by 9.7273 units as shown in figure 6.

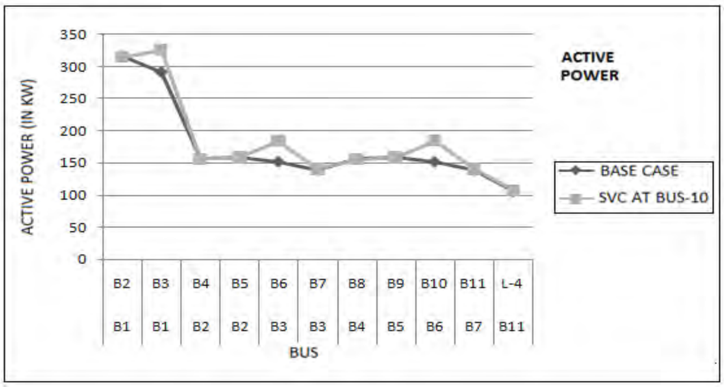

Fig.6. Comparison of active power between base case and SVC at BUS-10

6. Conclusion

This paper presents the potential applications of static var compensator (SVC) as one of the FACTS controllers, using power electronic switching devices in the fields of power transmission systems with increasing the voltage and power flow, and reducing the losses. On the induction of SVC and genetic algorithm to find its location, it has found that SVC installed at all following buses where static load is present, Bus 10 gives us increased voltage profile as shown by figure 4, reduced losses as shown by figure 5 and increased power transfer capability as shown by figure 6. Reduction of losses, increase of power transfer capability and voltage profile can also be optimized by number of other optimization methods and instead of having ETAP as a power system solution, the same system can be simulated and the results of various indices like voltage profile, reactive power, active power and losses can be done with the help of Matlab, PSPICE and PSCAD softwares.

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