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Optimum Placement of STATCOM in Distribution Network to Improve Uptime of DER using Sensitivity Index

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***Abstract* - In recent years, with increasing development in power networks, the economical operation of power system is more considered . Distributed energy resources (DER) have emerged as a promising option to meet growing customer needs for electric power with an emphasis on reliability and power quality. Due to increase in load demand, need DER increases. The fault occurrence make the DERs to disconnect due to large time taken for clearance of it. If the voltage is not proper the DERs may be disconnected from the line. This may cause demand to rise and the generation to be less. To eliminate this problem a static synchronous compensator(STATCOM) is used to reduce the settling time. STATCOM is one of the new generation flexible AC transmission systems(FACTS) devices with a promising future application . So optimal placement of STATCOM is essential to improve the uptime of DER and sensitivity index method is chosen for optimal location of STATCOM.**

Index Terms - Sensitivity Index, capacitor placement, Tabu Search, FACTS placement.

I. INTRODUCTION

Today's electric system is expected to bring high-quality and reliable power to customer loads. More than a century of development has led to a large, interconnected system that brings power from central-station generators via transmission and distribution to end-use customers. Although this system can provide relatively inexpensive power, issues remain such as increasing fuel costs, reducing power plant emissions, and increasing customer needs for higher reliability power. One potential solution to these issues is the use of distributed and renewable energy sources at the distribution level.

DER have emerged as a promising option to meet growing customer needs for electric power with an emphasis on reliability and power quality.DER system sizes typically range from five kilowatts (5 kW), which is the approximate demand for a typical residential customer to up to 10 megawatts (10 MW) for large commercial or medium industrial installations. Government incentives and lowering cost of renewable DER are some of the driving forces for the steeper growth in DER installations. DERs are commonly connected near the load in electric power distribution systems and include renewable energy such as wind , Landfill gas, Combined heat and power (CHP, or cogeneration)and solar, fossil-fuel based generation like micro turbines, and other distributed energy storage elements[1].

Due to increase in load demand, need of DER increases. The fault occurrence make the DERs to disconnect due to large time taken for clearance of it. All the DERs are connected and controlled by voltage control technique. So it takes time to settle the voltage at the line. If the voltage is not proper the DERs may be disconnected from the line. This may cause demand to rise and the generation to be less. To eliminate this problem a static synchronous compensator is used to reduce the settling time. Tripping of small DER units due to slow voltage recovery is avoided. Here a new index is formulated to make the voltage recovery time faster. The STATCOM is one of the new generation FACTS devices with a promising future application, which is recognized to be one of the key advanced technologies of future power system. The performance is checked by two steps, they are, calculating the index value and finding the optimal location of STATCOM and making a dynamic simulation and checking the transient stability [2]. The IEEE 16 bus system is considered for case study. These analyses are carried out using MATLAB R2011b.

II. PROBLEM FORMULATION

STATCOM placement at optimal location will lead to quick recovery of voltage at all buses of interest and improve the uptime of DER units. The optimal location of STATCOM is the optimization problem with non linear objective function with the corresponding constraints like voltage limit etc.
Here, the objective function [2] is mathematically formulated as the following equation.

$$[\Delta V/\Delta I_R] = \left[\sum_{i\in n_j} |Y_{ji}|(1/\sin(\emptyset_j - \emptyset_i - \theta_{ji})\right]^{-1} \qquad (1)$$

Where

$\Delta V/\Delta I_R$ is the sensitivity index

$\emptyset_j$=phase angle of voltage at jth bus

$\emptyset_i$ == phase angle of voltage at ith bus

θ_{ji} =angle of the element in Y bus matrix connected between jth and ith bus

$|Y_{ji}|$=magnitude of the element in Y bus matrix

n_j is the set of branches connected to bus j.

III. OPTIMAL CAPACITOR PLACEMENT

Capacitors are often installed in distribution system for reactive power compensation to carry out power and energy loss reduction, voltage regulation, system security improvement, and system capacity release. Economic benefits of the capacitor depends mainly on where and how many capacities of the capacitor are installed and proper control schemes of the capacitors at different load levels in the distribution system.

A variety of methods have been devoted to solving the capacitor placement problem. In the early work, most of the researchers used conventional analytical method in conjunction with some heuristics. Tabu search(TS) is a strategy for solving combinatorial optimization problem. The TS strategy has been applied in various fields, and the capability of the TS to obtain high quality solutions within reasonable computing time has been verified. The TS method is built upon a descent mechanism of a search process. The descent mechanism biases the search toward points with lower objective function values, while special features are added to avoid being trapped in the local minima[9,10].

In this section, a step by step TS based solution algorithm for the capacitor placement problem is presented.

Step 1: Input system data. network data and parameter setting (e.g., lower and upper bounds on operating voltage, tabu list size, etc.)..

Step 2: Generate an initial feasible solution state.
1) Randomly select a solution state from the solution space and initialize Sbest variable (Sbest stores the best solutions).

Step 3: check the stopping criteria (Iteration count < maximum iteration) if it is satisfied go to step 4 otherwise Output the optimal solution state. Output of the solution algorithm includes the optimal locations and sizes of capacitors to be installed.

Step 4: Generate the neighbor solutions by satisfying aspiration criterion.

Step 5: Identify the best candidate from candidate list and evaluate the best candidates.

***Step* 6:** Update the Sbest by comparing with Cbest (candidate best).

Step 7: Update the tabu list by Sbest.

Step 8: Update the iteration counter and continue the tabu search procedure criteria until the stopping criteria is satisfied.

I. STATCOM PLACEMENT

The key steps developed to secure a voltage profile throughout a distribution system for all operating conditions (steady state and postfault) are depicted in Fig. 2. Inclusion of DER unit results in reduction of real power intake from the utility grid. Steady state voltage requirement (as in Table I) at the load end as well as the DER connection point is maintained by following an optimal capacitor placement algorithm. VAR optimization and planning is associated with a non differentiable objective function, which leads to a heuristic algorithm for the solution. In the present work, Tabu search-based optimization has been chosen to obtain optimal location and sizes of fixed capacitor banks.

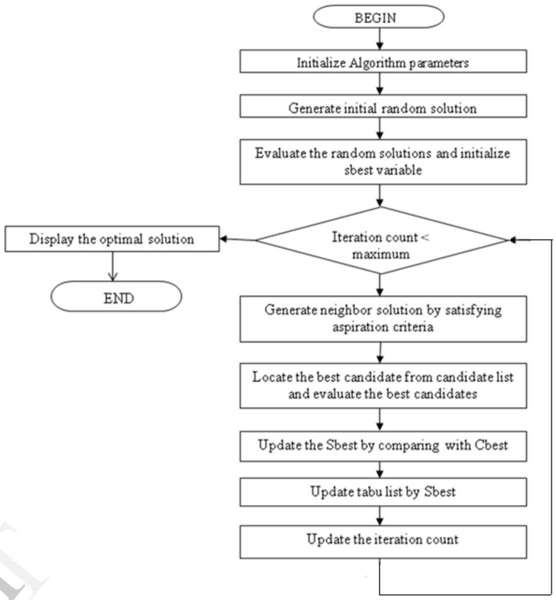

Fig 1. Flowchart for capacitor placement

With the application of various faults such as single line to ground faults and three-phase faults in the system, time domain simulations can be carried out to check the dynamic voltage restoring capability of the generator and load bus. As a three phase fault is the most severe contingency, the present study concentrates on voltage recovery with a three-phase fault near to the generator bus, which makes the proposed methodology applicable for all other faults.

Placement of STATCOM is considered only when the static compensator (capacitor bank) fails to maintain the required voltage profile under post fault conditions. For the placement of STATCOM, the proposed sensitivity index along with its direction is used to find out the single best location. The bus having the highest negative indicates the necessity of inductive current injection by STATCOM at that bus. The optimal capacitor on that bus is replaced by STATCOM of the same reactive power set point and voltage recovery time is obtained with the help of time domain simulation for the generator buses. If the first STATCOM fails to support recovery within an allowed time frame, with the first STATCOM in place the bus with the second most negative sensitivity index is searched .This leads to the placement of a second STATCOM.

The procedure is repeated until the voltage excursion of all buses concerned fall within the boundary specified by the standard/grid code. The proposed index utilizes an inherent feature of STATCOM, which allows reactive current injection even at diminishing terminal voltage Index calculated with frequent snapshots, allows capturing fast dynamics Performance of in choosing the best place for STATCOM is compared with an existing sensitivity index. Effectiveness of the index and the methodology based on this index has been verified through time domain simulations.

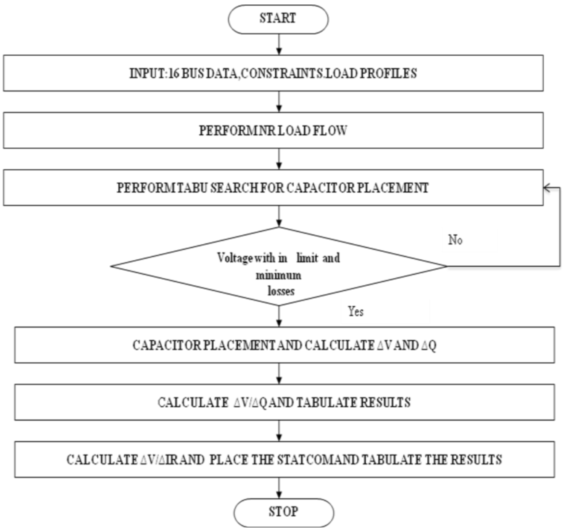

Fig 2. Flowchart for STATCOM placement

II. RESULTS AND DISCUSSION

A. TEST DISTRIBUTION SYSTEM

The proposed method is tested on 16 -bus Distribution system. The base case results and results obtained after capacitor placements and graphs indicating the system voltage are also described. The SI(sensitivity index) is calculated to know that whether system is inductive if yes then the STATCOM's are placed in those buses which are inductive in nature, this is known by the presence of negative values in SI. The calculations will be performed on the IEEE 16-bus system.

The test system is simulated in MATLAB and the proposed methodology has been tested, whose results are shown in below. The test distribution system as shown in figure (3) consists of 16 buses .The total load in the test system is 28.7 MW a 17.3 MVR.. The minimum and maximum voltages are set at 0.95 and 1.05p.u. respectively.The distribution system characteristics are Number of buses= 16, Number of lines=15, Slack bus no=1, base voltage= 11 kV, base MVA= 100

B .DER UNITS AND THEIR CAPACITY

DER units in this study are conventional synchronous generators. The location of DER units are chosen at bus 3 and 6(locations are chosen from mp).DER connection details are presented in Table I.

C.CAPACITOR PLACEMENT AND SENSITIVITY INDEX VALUES

Tabu search technique is used to find out the feasible locations and sizes of capacitors in the system. The maximum number of iterations is set as stopping criteria for this algorithm. Table II summarizes the results for optimal capacitor places for 16 bus system.

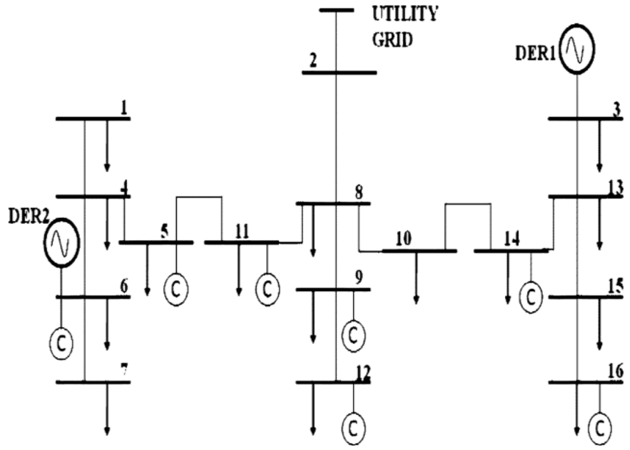

Fig 3.Single line diagram:16 bus system

TABLE I
DER units capacity and location

DER units	16 bus system	
	DER 1	DER 2
Location bus	3	6
MVA rating	10	20
Power factor	1	1

TABLE II
Optimal capacitor solution for 16 bus system

Optimal Bus	Capacitor Size(MVAr)	Sensitivity index ΔV/Δ Q (Vp.u/MVAr)
7	3.6	0.0005
5	1.6	0.016
9	1.8	0.0032
15	1.2	0.0020
3	1.8	0.0017

.D.VOLTAGE RECOVERY AND STATCOM PLACEMENT

According to [2], the voltage at the DER terminal must come back to 88%of its normal operating voltage within 2 s after initiation of an abnormal condition. STATCOM has been introduced to provide dynamic reactive power support in the test system under such conditions. Instead of going for additional locations, the best possible bus for placing STATCOM has been decided within the optimal buses, which were chosen by the optimal capacitor placement algorithm. Sensitivity indices are calculated for optimal capacitor buses and listed in Tables II and III.

The static rating of STATCOM for each system is chosen based on the optimal capacitor size found from Tables II and III.

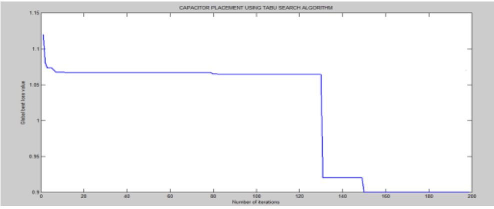

Fig 4. Graph of loss versus number of iterations

TABLE III
Sensitivity Index values for 16 bus system for STATCOM placement.

Optimal bus	Sensitivity index $\Delta V/\Delta I_R$ (Vp.u/Ip.u)
7	-0.00915336(inductive)
5	0.138578
9	0.030427
15	0.0093905
3	0.0889023

As shown in Table III , the most negative value of is found at bus 7, whereas the most positive value is found at bus 5. As STATCOM can absorb as well as inject I_R(shunt reactive current) , the value of $\Delta V/\Delta I_R$ can be both positive and negative. A positive value of the index indicates the requirement of supplying I_R , whereas a negative value stands for the necessity of inductive current at the connection bus of STATCOM. Therefore, a large value of $\Delta V/\Delta I_R$ for a particular bus in system indicates high voltage sensitivity with injection/absorption of reactive current from/by STATCOM..

In order to check the voltage profile under abnormal conditions, the 16 bus system is subjected to a three-phase fault near the generator bus. The following test cases are investigated.

Case 1) without capacitors;

Case 2) with capacitors at optimal locations;

Case 3) with STATCOM at a bus with the highest $\Delta V/\Delta I_R$ (for both inductive, i.e., negative and capacitive, i.e., positive values).

The STATCOM is placed at bus 5 and bus 7.. The time domain simulation for 16 bus system with three phase fault at bus 7, bus 3 is shown in Fig 5, 6 respectively. The STATCOM placed at highest Sensitivity Index recovers the voltage faster than the capacitors

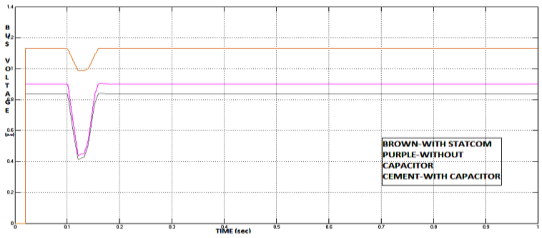

Fig 5. Voltage at bus 7 with three phase fault

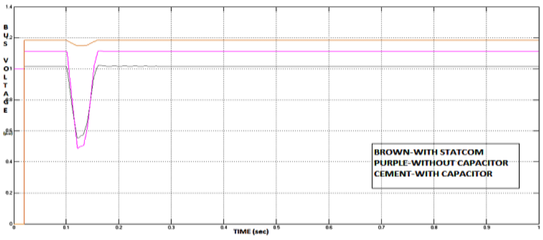

Fig 6. Voltage at bus 3 with three phase fault

VI.CONCLUSION

The optimal location of STATCOM is found by sensitivity index. STATCOM ensures fast voltage recovery at all buses of interest. The exposure of DER units to the problem of slow voltage recovery for contingencies like faults is minimized .Simulation results prove that the presence of STATCOM at a bus with highest negative value ensures a fast voltage recovery at all buses of interest. The simulation is demonstrated in MATLAB/Simulink on IEEE 16 bus system..

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IX. BIOGRAPHIES

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