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Voltage Stability Index Improvement in RDS Using DSTATCOM

[a] Muhammad Danish[1], Mahesh Kumar[2], Zubair Ahmed Memon[3]
[a] Mehran University of Engineering and Technology Jamshoro
Corresponding author e-mail: (danish.muet@gmail.com)
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***Abstract* - Interconnected radial distribution system consists of the large number of the nodes and branch es to meet the required load demands. In case of Pakistan, rising demand of electricity causes the exceeding burden on radial distribution system which primarily affect the performance of whole network that could leads to voltage collapse, so it is desired to maintain the voltage at every bus within permissible limits. Various methods like DSTATCOM and other shunt connected devices are employed to overcome voltage stability index issues, but proper sizing and placement is also a major challenge in the network. This paper presents Particle Swarm Optimization algorithm that identifies voltage stability index for the weakest bus in the system and determines the proper location and size of DSTATCOM to be installed on the real time HESCO feeder. Results show that the placement of DSTATCOM at proper location has improved the VSI, reduced the total power loss and enhanced the voltage profile.**

***Index Terms*— radial distribution system, DSTATCOM, voltage stability index, voltage profile, power losses, HESCO**

I. INTRODUCTION

In electrical power system, electricity to end consumer is supplied through distribution system. Generally, there are three types of distribution system. Widely used is the radial distribution system. Radial distribution system is used in whole world because of technical benefits. Distribution system is usually unbalanced and have high resistance to reactance ratio (R/X) which results in immense power losses and stability of power system is greatly affected. Generally, RDS is responsible for approximately thirteen (13%) losses [1]. Due to inductive nature of the loads lines losses are increased because the major household and industrial loads are inductive in nature. Therefore, it is of paramount importance to add the or counterbalancing devices in the system which is distribution to decrease the power loss and improve the voltages profile across the buses as well improving the voltage stability of individual busses and overall system. In the current analysis, DSTATCOM units are installed in a radial distribution solution to enhance the voltage stability index, minimize real and reactive power losses and strengthen the voltage stability.

STATCOM was generally designed and integrated in transmission systems to maintain the voltage profile by providing the reactive power compensation and controlling the power factor; research were conducted to developed the same process for distribution systems [7, 8]. DSTATCOM is incorporated in distribution system to enhance the voltage stability index, reduce the loss and enhance the voltage profile. The **D-STATCOM** is a PE based reactive power compensation device that is connected in shunt at a specific bus in the electrical distribution system [9]. DSTATCOM is a rapid compensation mechanism that increases the voltage profile and eliminates power losses by introducing countervailing current into grid. It is recommended that DSTATCOM devices is positioned at an optimum position with an optimum scale in order to achieve the greatest value of the system. Inappropriate positioning of DSTATCOM devices can lead to the downfall and potentially harm the overall operation of the equipment [11].

Enough analysis is performed to effectively refine the challenges of positioning and scale of DSTATCOM with conventional and artificial intelligence approaches. Foremost, least research work has been voltage stability index improvement using DSTATCOM in the radial distribution networks. Hence this work is based on optimal size and location DSTATCOM and placement within real time HESCO radial distribution feeder. The current study is aimed to design a fast and non-traditional technique to calculate the best optimized location and sizing of DSTATCOM for improvement of voltage stability index, minimizing the power losses and enhancing voltage profile. DSTATCOM can be calculated using LSF and VSI, respectively. The optimal best size of DSTATCOM can be determined by using Particle Swarm Optimization (PSO). The main difference of this work is implementing an integrated approach of LSF and VSI with PSO to determine the optimal location and sizing of DSTATCOM for the sake of enhancement of VSI, reduction of power losses and increasing voltage profile. It has been applied on Real Time HESCO Feeder.

II. PROBLEM FORMULATION

The main purpose of study is VSI improvement of the system to avoid the voltage collapse and determine the bus with weak stability index and improve its index. Other than VSI, the main two objectives have been improved in this study which are foremost important in improving the power quality. Voltage profile and total power loss play greater role in any distribution system. This study also focus to improve the overall voltage profile along by reducing the active and reactive power losses.

A. Voltage Stability Index

Voltage Stability Index calculates the operator to monitor how close the system is to collapse. The systems weakest node which is most sensitive for voltage collapse is determined by VSI. The problem of voltage stability & voltage collapse has increased because of the increased loading, exploitation and improved optimization operation of power system. Voltage stability index helps in determining the node, which is most sensitive to voltage collapse. Formula for calculation of Voltage Stability Index is given in equation 1.0

$$VSI(n) = \{|V(n_0)^4 - 4.0\{(Pn_1) * X(k) - Q(n_1) * R(k)\}^2 - 4.0\{P(n_1) * R(k) + Q(n_1) * X(k)\}|V(n_0)|^2 \quad (1.0)$$

B. Power loss reduction

Many research papers have discussed and proved that the distribution system incurred the many losses which are approximately 13% of the entire losses which also affect the performance of overall power system but importantly the major distribution system. Addition of other devices may affect the power system and increase the power losses but this study is done in such a way these losses would also be taken into consideration and are thereby reduced that previously calculated loss. Power loss has with addition to VSI is also improved in this study. **Fig. 1** shows two nodes of RDS connected via k branch where nodes are denoted as G & L.

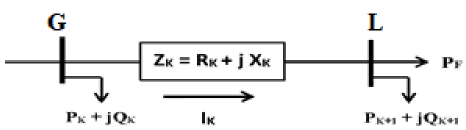

Fig. 1. Two bus RDN

At node L Voltage is given by Eq. (1.1)

$$V(L) = V_G - I_G * (R_G + jX_G \quad (1.1)$$

Equation (2) give the value of line current

$$I_K = \left(\frac{P_K + Q_K}{V_K}\right) \quad (1.2)$$

Active and reactive power loss is determined with Eqs. (1.3) and (1.4)

$$P_{kloss} = \left(\frac{P_{K+1}^2 + Q_{K+1}^2}{|V_{K+1}^2|}\right) \times R_K \quad (1.3)$$

$$Q_{kloss} = \left(\frac{P_{K+1}^2 + Q_{K+1}^2}{|V_K^2|}\right) \times X_K \quad (1.4)$$

Total power loss of the entire can be determined by sectionally calculating the real and reactive losses which is given by equation (1.5)

$$T_{loss} = \sum_{K=1}^{nb} P_{kloss} + j\sum_{K=1}^{nb} Q_{kloss} \quad (1.5)$$

C. Voltage Profile Improvement:

Consumers are directly linked with the distributive network. The customers vary and their load is also varied in nature from capacitive load to inductive load. Hence when load is inductive in nature there are many issues arises from under voltage to over voltage and dips and sags This study has also taken this voltage profile into consideration so that when VSI is improved voltage profile of any bus must not be degraded and there should not be any voltage sag or other voltage issues. Voltage profile of the system in this study has also been improved which remains helpful in maintaining the performance of the power network(system).

The constraints

A. Power balance:

The overall amount of power supplied to DSTATCOMs both by distribution transformer is indeed the total amount of power loss and maximum load added to the distribution network

$$P_{substation} + \sum P_{DSTATCOM} = \sum P_{loss} + \sum P_{load} \quad (1.6)$$

$$Q_{substation} + \sum Q_{DSTATCOM} = \sum Q_{loss} + \sum Q_{load} \quad (1.7)$$

Where $P_{substation}$ and $Q_{substation}$ the active as well as reactive power delivered respectively. The DSTATCOM supplies power which is given as $P_{DSTATCOM}$ and $Q_{DSTASTCOM.}$ The total summation of total real power loss and reactive power loss is given by $\sum P_{loss}$ and $\sum Q_{loss}$ respectively.

B. Placement of DSTATCOM

DSTATCOM can not be integrated at bus 1 as it is reference bus.

$$2 \leq D_{STATCOM} \leq N_{buses} \quad (1.8)$$

C. DSTATCOM sizing

The scale of DSTATCOM cannot exceed the connected load in the distribution network.

$$\sum P_{STATCOM} \leq P_{load} \quad (1.9)$$

D. Voltage profile limitation

For each node the permissible voltage limit is ±5%. Thus, variation in base value varies 0.95 to 1.05 pu.

$$V_{min} \leq V \leq V_{max} \quad (1.10)$$

III. METHODLOGY

A. PSO AI Algorithm

Kennedy and Eberhart partnered a PSO algorithm that was dependent on a population-based stochastic algorithm in 1995. (Kennedy, 2010). This algorithm has a group of swarms that are randomized triggered, so each particle moves in a N dimensional search space via an irrational created velocity. Across all implementations of Particle Swarm Optimization, the two leading values are recorded for each of particles. The first is regarded as a fitness (best) approach, has been acquired to date and is saved. Such a value is expressed as the pbest value. The 2nd most popular considered as global optimum or gbest and is evaluated by PSO compiler via monitoring through pbest values and then it sets both the values, the velocity of this particle is varied by using Equation. (1.11)

$$V_{M,N}^{new} = V_{M,N}^{old} + \alpha \times randn\,k + \beta \times \left(P_{M,N}^{global\ best} - P_{M,N}^{old}\right) \quad (1.11)$$

Here randn is a randomized variable having value 0 to 1 and α and β constants of acceleration.

position is updated by Eq. (1.13) if desired values are not found.

$$P_{M,N}^{new} = P_{M,N}^{old} + V_{M,N}^{new} \quad (1.12)$$

Where M = 1,2, 3…, y and N = 1, 2, 3…, z
In order to minimize the error, more iterations are needed such that the location could be in a single stage.

$$P_{M,N}^{new} = (1 - \beta) \times P_{M,N}^{old} + \beta \times P_{M,N}^{global\ best} + \alpha \times randn\,k \quad (1.13)$$

α ranges from 0.1 to 0.5 and β ranges 0.1 to 0.7.

B. PSO Implementation

PSO Algorithm steps for placement of DSTATCOM are given as follows:
I. Bus and Branch data is collected and used as in input
II. Load Flow has been done for the calculation of Voltage of each branch and for each bus VSI is calculated using equation.
III. Number of iterations required, number of particles and w1,w2 and c1 and c2 values.
IV. Population is generated arbitrarily for the velocity and position .
V. Voltage Stability Index of each bus is calculated using equation no
VI. Evaluate the constraints of system used.
VII. Comparison of the objective function for the best individual particle .
VIII. Choose the particle which has lowest pbest value and set is as gbest.
IX. Velocity of particle to be updated by the equation number
X. Particle's position is updated based on the equation
XI. Find if the iteration number is achieved to final value, if it is, then go to next step. Else go back to step 6.
XII. Print the best solutions. It will be the best solution to place DSTATCOM for Voltage Stability Index improvement in RDS for weak bus.

C. Load Flow Analysis

The Forward/Backward Sweep Power-flow technique used in this study. The impedance of a feeder branch is computed by the specified resistance and reactance of the conductors used in the branch construction. The Forward/Backward Sweep Power-flow method consist two steps (i) backward sweep and (ii) forward sweep.
Backward sweep: In this step, the load current of each node of a distribution network is calculated.
Forward sweep: This step is used after the backward sweep so as to determine the voltage at each node of a distribution network

D. Feeder Description

Real time HESCO Feeder has been used for the analysis. Line and Load data taken from the specification of mentioned feeder. Feeder has 51 buses with and has load of 4.214kWatts.

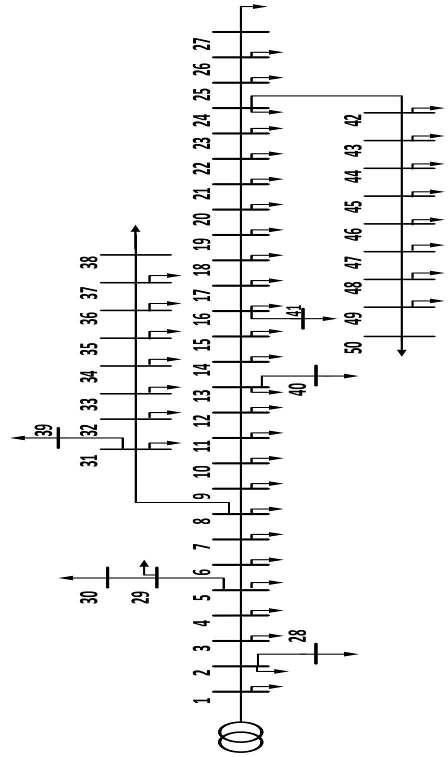

Fig 2. One-line diagram of 11kV Sarfaraz HESCO Feeder

Following for the methodology steps are given as:

Step 1: Data is inputed and simulation of system is carried out in MATLAB.
Step 2: Load flow analysis is carried out with the Backward/Forward sweep method using MATLAB software.
Step 3: PSO algorithm is used for finding out the weakest bus for placement of DSTATCOM.
Step 4: Specific bus for placement of DSTATCOM is obtained by PSO algorithm.
Step 5. Values obtained through step 4 are used to evaluate VSI of the weakest bus.
Step 6: Results after placement of DSTATCOM are obtained.

IV. RESULTS AND DISCUSSIONS

This research work is done for real time HESCO feeder based in Qasimabad Hyderabad, Sindh. It is aimed to observe the improvement of Voltage Stability Index with the optimal placement and sizing of DSTATCOM. Feeder has 51 buses with and has load of 4.214kWatts. MATLAB version 2016a and on a Windows 10, and laptop configuration is Core m3 processor with 8gb Ram

A. Load Profile of Feeder

Load Data were collected physically and designed in the MATLAB 2016a accordingly.

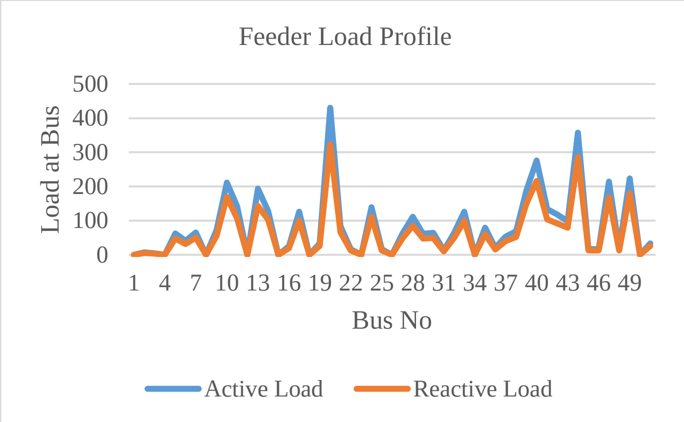

Fig 3. Load Profile of Feeder

Case 1. Voltage Stability Index improvement

VSI is the main objective of this study and DSTATCOM is to be installed to determine the weakest bus in the distribution system to avoid collapse. Maximum and minimum bounds for voltage stability index are as 1.00 and 0.65 respectively. Slack bus is one bus number 1 in the system. Voltage for Slack bus is 1 and by default system is 11kV MVA.

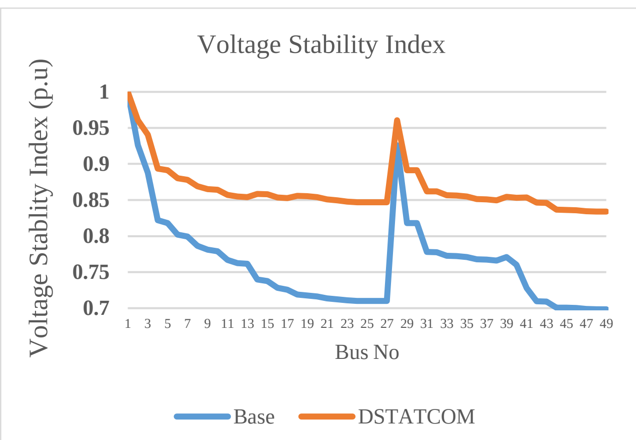

Fig 4. Voltage Stability Index Comparison

Above figure depicts the Voltage Stability Index for real time 11kV HESCO Sarfaraz feeder Qasimabad Hyderabad, Sindh. It can be seen from graph that DSTATCOM placement has major impact on the system and the voltage stability index of the system is improved at all the buses. Moreover, the table shown below compares the bus voltage within the constraints limit.

TABLE 1. Voltage Stability Index Comparison

Voltage Stability Index (p.u)			
Base Case		After DSTATCOM Placement	
Minimum	Maximum	Minimum	Maximum
0.699 at Bus No. 48	1.00 at Bus No. 1	0.834 at Bus No. 48	1.00 at Bus No. 1

Minimum Voltage Stability Index prior to DSTATCOM allocation was 0.699 p.u. However, allocation of DSTATCOM has greatly improved the VSI to 0.834pu.

Voltage Stability Index is the principal objective of this study to enhance the voltage stability index of the realtime Sarfaraz Feeder by allocation of DSTACOM by Particle Swarm Optimization AI technique. The table below described the extent of enhancement of VSI of all the buses. Optimal placement and size of DSTACOM has been calculated as 2.42MVAR at bus no 19.

Case 2. Reduction of total Power Loss

Power loss is main while considering improve the voltage stability index. This part of the paper shows the comparison the total power losses including Active and Reactive Power of the system. Active and Reactive power after DSTACOM allocation in the real time distribution system has been reduced.

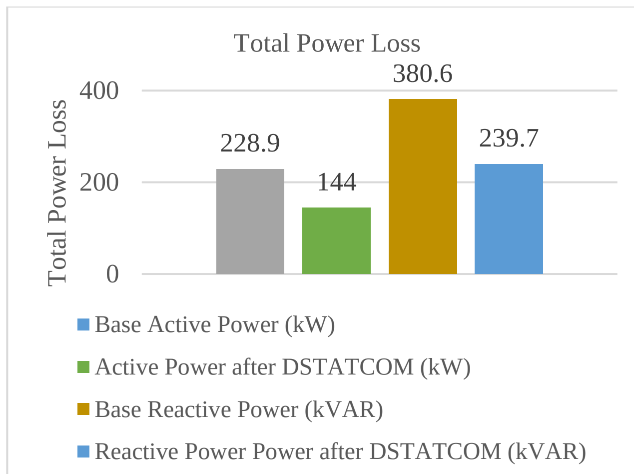

Fig 5. Total Power Losses Comparison

Power Loss reduction is another consideration for this study in the real time feeder by allocation of DSTATCOM. From above figure it can be assured that there is huge reduction in the total power losses ie Active Power (kW) and Reactive Power (kVAR) losses.

Case 3. Voltage Profile Improvement

Voltage profile is main, that also needed attention while improving the Voltage Stability Index. In this study, after the DSTATCOM allocation in the system, Voltage Profile is greatly improved of the buses.

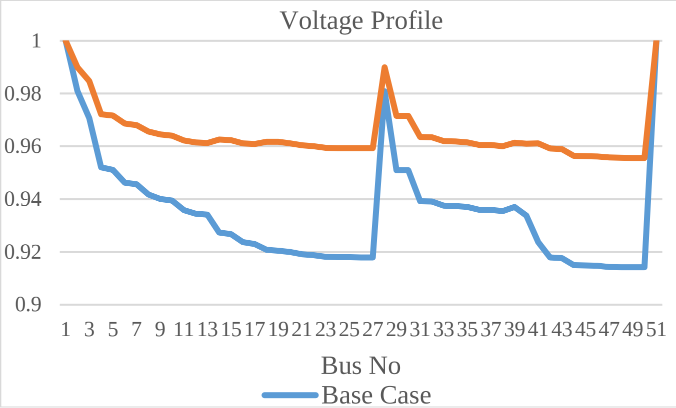

Fig 6. Voltage Profile Comparison

Above figure shows the base case voltage profile and Voltage Profile after DSTACOM placement. It can noted from the above figure that there is also a good improvement in voltage profile of the system beside Voltage Stability Index improvement in Power Losses reduction.

Overall Analysis. There is major improvement in voltage stability index, overall voltage profile, active and reactive power of the real time HESCO Feeder. Before placing DSTATCOM on network the VSI, Power Loss and Voltage Profile was least but after placing DSTATCOM of sizes respectively improved the voltage stability index of that bus and also there is major improvement has been noted in voltage profile and greater reduction in power less. In comparison with the base case, this is incredibly clear that the enormous rise in VSI, the voltage profile, and effective reduction in real and reactive power losses, is achieved after placement of DSTATCOM on bus number 19. Hence it is recommended to DSTATCOM in the network to improve the performance of network.

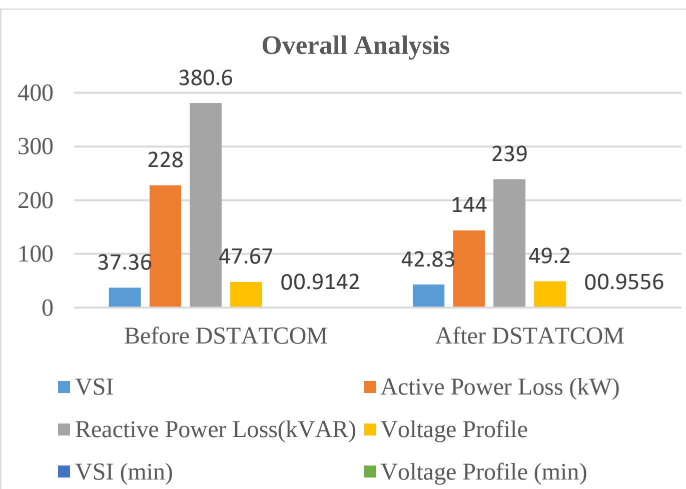

Fig 5. Overall Analysis

V. Conclusion

This study illustrated the modern technique to improve the voltage stability index along with the reduction in power losses and improving the voltage profile of the real time distribution system. Particle Swarm Optimization Algorithm as fast and highly attentive algorithm has been used to find the optimum location and size of DSTACOM to be allocated in the system. The main objective of this study was to focus on improving the voltage stability of the weak bus so that the system is saved from the major collapse which affect the performance and entire consumer connected within the feeder location. Results proved the allocation of DSTACOM on the system not only improved the Voltage Stability Index but also it improved the voltage profile and reduced the power losses of the system. Besides that simulation results affirms that technique has good convergence. However, results also assure that effectiveness of this method for VSI improvement, voltage profile enhancement and reduction of total power losses.

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