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Research article

Optimizing the placement of a number of D-Statcom for improving SARFI$_X$ in the distribution system

Bach Quoc Khanh*

ABSTRACT

While the users only consider solutions for power quality improvement at a single site, utilities concern about solutions for power quality improvement for not only an individual location, but also for the whole system. Therefore, the paper deals with an utilities' systematic solution for power quality mitigation by using simultaneously a number of custom power devices in distribution system. In the paper, a new method is introduced for optimizing the placement of a multiple of Distribution Synchronous Compensation Devices - D-Statcoms for globally mitigating the voltage sags due to faults in distribution systems according to the ``central improvement'' approach. D-Statcom's placement is optimally selected in a distribution system basing on a problem of optimization where the objective function is to minimize the system average rms voltage variation frequency index – SARFIx of the system of interest. The effectiveness for global voltage sag mitigation in a distribution system by the presence of a number of D-Statcoms is newly modeled basing on the method of Thevenin's superimposition in the problem of short-circuit calculation in the distribution system. The presence of D-Statcoms is simulated as the matrix of additionally injected currents to buses for increasing the voltage of all buses throughout the system of interest. The paper considers the case of using a multiple of D-Statcoms with a proposed voltage compensating principle that can be practical for large-size distribution systems. In the paper, the IEEE 33-buses distribution feeder is used as the test system for global voltage sag simulation in the events of short-circuit in the system and various influential parameters to the outcomes of the problem of optimization such as rms voltage threshold and D-Statcom's limited current are considered and discussed.

Key words: Distribution System, Voltage Sag, SARFIX, Distribution Synchronous Compensation – D-Statcom

School of Electrical Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam

Correspondence

Bach Quoc Khanh, School of Electrical Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam

Email: khanh.bachquoc@ hust.edu.vn

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INTRODUCTION

According to IEEE1159[1], voltage sag is a phenomenon of power quality (PQ) in which the rms (root mean square) value of the voltage magnitude drops below 0.9 p.u. in less than 1 minute. The main cause which is account of more than 90% voltage sag events is the short-circuit in the power systems. Solutions for voltage sag mitigation[2,3] have generally been classified as two approaches[4] named "distributed improvement" and "central improvement" (or systematic improvement). The first is mainly considered for protecting a single sensitive load while the latter is introduced for systematically improving PQ in the distribution system that is mainly interested by utilities. Either approaches have recently used custom power devices (CPD)[2] such as inverter-based voltage sources like the distribution static synchronous compensator (D-Statcom) as their cost has gradually decreased.

In reality, researches using D-Statcom for voltage sag mitigation have mainly been introduced for "distributed improvement" approach where dynamic modeling of D-Statcom is developed with main regard to D-Statcom's controller design improvement[5–8] for mitigating PQ issues at a specific load site. The introduction of researches for "central improvement"[4,9–14] that normally deal with the problem of optimizing D-Statcom's location and size are rather limited because of following difficulties:

i. To find steady-state or short-time modeling of D-Statcom for systematic mitigation of PQ issues;

ii. To optimize the use of D-Statcom.

Some researches just deal with voltage quality in steady-state operation and loss reduction[9–11]. Ali (2015) deals with the mitigation of various PQ issues including voltage sag using D-Statcom using the multi-objective optimization approach, but such an optimization can rarely get the best performance for voltage sag mitigation only[12]. Zhang (2010) deals directly with voltage sag mitigation, but the modeling of D-Statcom for short-circuit calculation is still needed to improve[13]. Khanh (2018) introduced a good modeling of a CPD, but it is the case for dynamic voltage

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restorer (DVR) and the optimization of DVR application is just based on voltage sag event index [14]. Khanh (2019) also considers the performance of only one D-Statcom [15].

This paper newly extends the method of estimating the effectiveness of global voltage sag mitigation [15] by the presence of a number of D-Statcoms in the short-circuit of a distribution system. This method optimizes the placement of D-Statcoms basing on minimizing a well-known system voltage sag index – $SARFI_X$ that consider all possible short-circuit events in a system of interest. In solving the problem of optimization, the modeling of a multiple of D-Statcoms simultaneously compensating system voltage sag in short-circuit events is introduced and discussed. The research uses the IEEE 33-bus distribution system as the test system. Short-circuit calculation for the test system as well as the modeling and solution of the problem of optimization are all programmed in Matlab.

For this purpose, the paper is structured as the following parts: section *Method* introduces the new method for modeling of a number of D-Statcoms for system voltage sag mitigation in the problem of short-circuit calculation in distribution system with its presence. Section *Problem definition* introduces the problem of optimization. The results are analysed and discussed in section *Result analysis and discussion*.

METHOD OF MODELING D-STATCOM WITH LIMITED CURRENT FOR SHORT-CIRCUIT CALCULATION IN DISTRIBUTION SYSTEM

D-Statcom's basic modeling for voltage sag mitigation

D-Statcom is a shunt connected FACTS device. The basic steady-state description of a D-Statcom is popularly given as a current source [3] injecting in a bus needed for voltage compensation. For mitigating voltage sag due to fault, the load voltage can be seen as the superposition of the system voltage and the voltage change due to the injected current by D-Statcom (Figure 1).

In the simplest network (Figure 1a) with one load (Load impedance: Z_L) fed by one source (Source voltage: U_S, Source impedance: Z_S), when voltage sag occurs, the load voltage can be boosted to $U_{sag} + \Delta U_L$ as D-Statcom injects the current I_{DS} :

$$\dot{U}_L = \dot{U}_{sag} + \triangle\dot{U}_L = \dot{U}_{sag} + \dot{I}_{DS}.Z_{th} \quad (1)$$

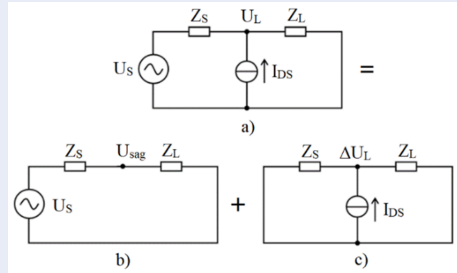

Figure 1: Modeling D-Statcom for voltage sag mitigation.

So, we have

$$\dot{I}_{DS} = \frac{\dot{U}_L - \dot{U}_{sag}}{Z_{th}} \quad (2)$$

where Z_{th} : Thevenin impedance of the system seen from the D-Statcom (equals Z_S in parallel with Z_L).

The typical V-I characteristic of a STATCOM is depicted in Figure 2 showing that the STATCOM's current can be within the range for a stable output voltage. If the STATCOM is connected to the location experiencing a deep sag, it can not boost the voltage up to 1p.u. for a given I_{DSmax}. So, we assume that I_{DS} just takes I_{DSmax}. As the result, the compensated voltage ΔU_L is

$$\left|\triangle\dot{U}_L\right| = \left|\dot{I}_{DS.max} \times Z_{th}\right| = \left|\dot{U}_L - \dot{U}_{sag}\right| < \left|1 - \dot{U}_{sag}\right| \quad (3)$$

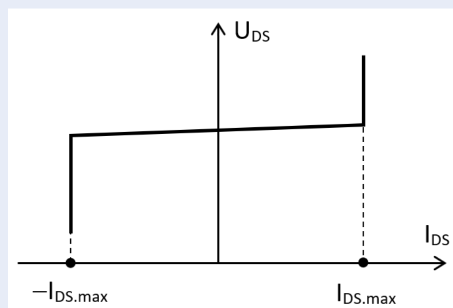

Figure 2: V-I characteristic of a STATCOM

Modeling of a multiple of D-Statcoms for system voltage sag mitigation

Generality

For modeling the effectiveness of a multiple of D-Statcoms for system voltage sag mitigation, Khanh (2018) introduced the application of the superposition principle according to the Thevenin theorem for the problem of short-circuit calculation in distribution system [14]. It's assumed that the initial state of the test system is the short-circuit without the presence of D-Statcoms. However, as the result of the presence of D-Statcoms, the bus voltage equation should be modified in compliance with Thevenin theorem [16] as follows:

$$[U] = [Z_{bus}] \times \left([I^0] + [\triangle I]\right)$$
$$= [Z_{bus}] \times [I^0] + [Z_{bus}] \times [\triangle I]$$
$$= [U^0] + [\triangle U] \quad (4)$$

Where

[Z_{bus}]: System bus impedance matrix calculated from the bus admittance matrix: [Z_{bus}]= [Y_{bus}]$^{-1}$. If the short-circuit is assumed to have fault impedance, we can add the fault impedance to [Z_{bus}].

[U^0]: Initial bus voltage matrix (Voltage sag during power system short-circuit)

[I^0]: Initial injected bus current matrix (Short-circuit current).

$$[U^0] = \begin{bmatrix} \dot{U}_{sag.1} \\ \vdots \\ \dot{U}_{sag\cdot k} \\ \vdots \\ \dot{U}_{sag.n} \end{bmatrix} \quad (5)$$

$$[I^0] = \begin{bmatrix} \dot{I}_{f1} \\ \vdots \\ \dot{I}_{fk} \\ \vdots \\ \dot{I}_{fn} \end{bmatrix} \quad (6)$$

$$[\triangle U] = [Z_{bus}] \times [\triangle I] \quad (7)$$

or
$$\begin{bmatrix} \Delta\dot{U}_1 \\ \vdots \\ \Delta\dot{U}_k \\ \vdots \\ \Delta\dot{U}_n \end{bmatrix} = [Z_{bus}] \times \begin{bmatrix} \Delta\dot{I}_1 \\ \vdots \\ \Delta\dot{I}_k \\ \vdots \\ \Delta\dot{I}_n \end{bmatrix} \quad (8)$$

DU_i : Bus i voltage improvement (i=1÷n) after adding the custom power devices in the system.

DI_i : Additional injected current to the bus i (i=1÷n) after adding the custom power devices like D -Statcom in the system.

However, Khanh (2018) proposed the condition of voltage compensation regardless of the D-Statcom's current limitation [14]. For globally improving the voltage sag caused by short-circuit (using $SARFI_X$ index), we have to deal with all possible fault positions and it's likely that the fault position is close to the D-Statcom's location that requires a big current from it to boost voltage the the required value. This paper proposes another method that bases on a limited current from D-Statcom as follows.

Placing m D-Statcoms in the test system

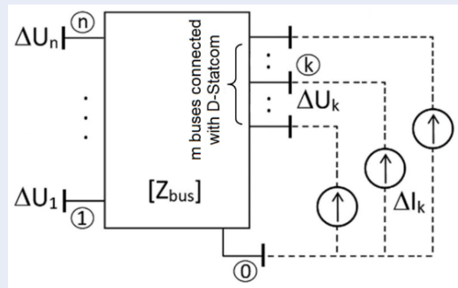

Figure 3: Test system short-circuit modeling using [Zbus] with presence of m D-Statcoms (m<n).

Assume that M is the set of m buses to connect to D-Statcom (Figure 3), so the column matrix of bus injected current [$\triangle I$]in (8) has m non-zero elements and n-m zero elements. From (8), for the bus k, k∈M, we have

$$\triangle\dot{U}_k = Z_{kk} \times \dot{I}_{DS.k} + \sum_{j\in M,\ j\neq k} Z_{jk} \times \dot{I}_{DS.j} \quad (9)$$

If the $I_{DS.k}$ large enough, we assume the initial condition of voltage compensation is similar to the research by Khanh (2018) [14] as follows:

$$\triangle\dot{U}_k = \dot{U}_k - \dot{U}_{sag.k} = 1 - \dot{U}_{sag.k} \quad (10)$$

Replace (10) to (9) we have m equations to calculate m variables $\dot{I}_{DS.k}$of m D-Statcoms. Solve this system of m equations, we get m required values of $I^*_{DS.k}$

However, as above said, there're definitely buses that need large I_{DS} to boost the bus voltage to 1p.u. that is beyond D-Statcom's current limit. Therefore, for a given Statcom's current limit I_{DSmax}

- If $I^*_{DS.k}$is smaller than a given I_{DSmax}, we use the value $I^*_{DS.k}$to calculate the voltage upgrade of n-m buses without connecting to D-Statcoms ($I_{DS.k} = I^*_{DS.k}$).

- If the given I_{DSmax} is smaller than $I^*_{DS.k}$ we use the given value I_{DSmax} as the current the D-Statcom injects in bus k ($I_{DS.k}$ = I_{DSmax}) to calculate the voltage upgrade of n-m buses without connecting to D-Statcoms and system voltage as (11).

$$\triangle\dot{U}_i = \sum_{i=1}^{n} Z_{ik} \times \dot{I}_{DS.k} \quad (11)$$

And finally, the system bus voltages after placeing D-Statcom are calculated as follows:

$$\dot{U}_i = \triangle\dot{U}_i + \dot{U}_i^0 = \triangle\dot{U}_i + \dot{U}_{sag.i} \qquad (12)$$

For better understanding about the above proposed modeling of the D-Statcom's voltage compensation in the short-circuit of distribution system, we consider the cases of using two D-Statcoms as follows.

Placing two D-Statcoms in the test system

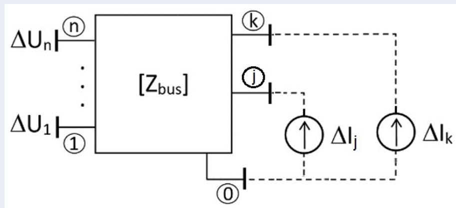

Figure 4: **Test system short-circuit modeling using [Z$_{bus}$] with presence of two D-Statcoms.**

In the case of using two D-Statcoms (Figure 4) assumed to connect to bus j and k (such as k>j), the matrix of additional injected bus current only has two elements at bus j and bus k that do not equal zero ($\Delta I_j = I_{DS.j}$ and $\Delta I_j = I_{DS.k} \neq 0$). Other elements equal zero ($\triangle I_i = 0$for $\forall$ i $\neq$ j,k). Therefore, (8) can be rewritten as follows:

$$\begin{cases} \triangle\dot{U}_j = Z_{jj} \times \dot{I}_{DS.j} + Z_{jk} \times \dot{I}_{DS.k} \\ \triangle\dot{U}_k = Z_{kj} \times \dot{I}_{DS.j} + Z_{kk} \times \dot{I}_{DS.k} \end{cases} \qquad (13)$$

If the injected currents to bus j and bus k are large enough to boost U_j and U_k from $U_j = U_{sag.j}$ and $U_k = U_{sag.k}$ to desired value, say $U_j = U_k = 1$p.u, we have:

$$\begin{cases} \triangle\dot{U}_j = 1 - \dot{U}_{sag.j} \\ \triangle\dot{U}_k = 1 - \dot{U}_{sag.k} \end{cases} \qquad (14)$$

Replace (14) to (13) and solve this system of two equations, we get the required injected current to bus k and j as follows:

$$\begin{cases} I_{DS.k} = I^*_{DS.k} = \dfrac{Z_{kj} \times \left(1 - \dot{U}_{sag.j}\right) - Z_{jj} \times \left(1 - \dot{U}_{sag.k}\right)}{\left(Z_{kj} \times Z_{jk} - Z_{jj} \times Z_{kk}\right)} \\ I_{DS.j} = I^*_{DS.j} = \dfrac{Z_{jk} \times \left(1 - \dot{U}_{sag.k}\right) - Z_{kk} \times \left(1 - \dot{U}_{sag.j}\right)}{\left(Z_{kj} \times Z_{jk} - Z_{jj} \times Z_{kk}\right)} \end{cases} \qquad (15)$$

and other bus voltages are calculated as (11)Equation (11).

For a given I_{DSmax}, If $I^*_{DS.j} > I_{DSmax}$or $I^*_{DS.k} > I_{DSmax}$ we use the given $I_{DS.j} = I_{DSmax}$ or $I_{DS.k} = I_{DSmax}$ to calculate other bus i ($\forall$ i $\neq$ j,k) voltages as follows

$$\triangle\dot{U}_i = Z_{ij} \times \dot{I}_{DS.j} + Z_{ik} \times \dot{I}_{DS.k} \qquad (16)$$

Finally, the voltages at other buses after placing two D-Statcoms at buses j and k are calculated as (12)Equation (12).

PROBLEM DEFINITION

Objective function and constraints

In this paper, D-Statcom's performance for global voltage sag mitigation is estimated basing on the problem of optimizing the location of a number of D-Statcoms in the test system where the objective function is to minimize the system index – $SARFI_X$ [17].

$$f = SARFI_X = \frac{\sum_{i=1}^{N} n_{i.X}}{N} \Rightarrow Min \qquad (17)$$

where

X is a given rms voltage threshold

$n_{i.X}$: The number of voltage sags lower than X% of the load i in the test system.

N: The number of loads in the system.

$SARFI_X$ calculation is described as the block-diagram in Figure 5 for a given fault performance (fault rate distribution) of a given system and a given threshold X.

In this problem of optimization, the main variable is the scenario of positions (buses) where D-Statcoms are connected. We can see each main variable as a string of m bus numbers with D-Statcom connection out of the set of n buses of the test system. Therefore, the total scenarios of D-Statcom placement to be tested is the m-combination of set N (n=33):

$$T_m = C_n^m = \frac{33!}{m! \times (33-m)!} \qquad (18)$$

If we consider the placement of 2 D-Statcom in the test system, we have m=2 and the total scenarios for placing these two D-Statcoms is $T_2 = C_{33}^2 = \frac{33!}{2! \times (33-2)!} = 528$

Each candidate scenario to be tested is a pair of buses number j and k out from 33 buses where the two D-Statcoms are connected (*e.g.* 1,2 ; 1,3;…).

The problem of optimization has no constraint, but an important parameter is be given is the limited current of D-Statcom. The modeling about how D-Statcom with a limited current compensates system voltage sag is introduced in Section ***Method of modeling d-statcom with limited current for short-circuit calculation in distribution system.***

Problem solving

In such a problem of optimization, the objective function which is $SARFI_X$ is always achieved for given preset parameters (X%, number of D-Statcoms m and D-Statcom's limited current). So, we use the method of direct search to test th e whole set of all scenarios of D-Statcom positions T_m. Figure 6 is the block-diagram for solving this problem.

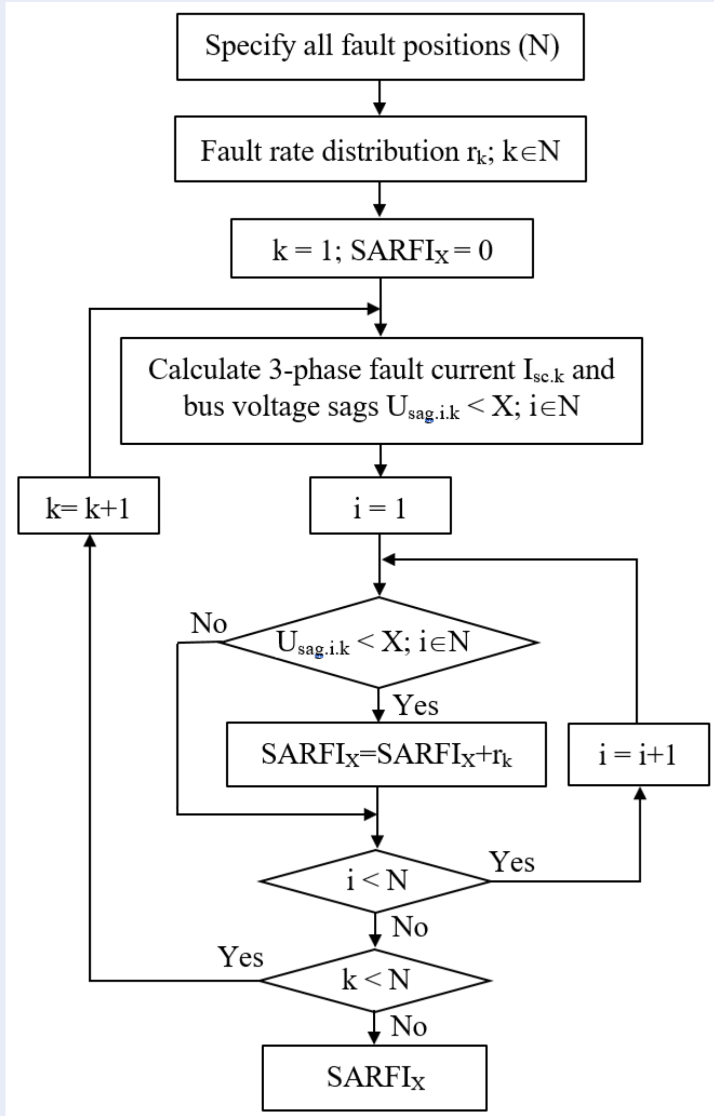

Figure 5: **$SARFI_X$ calculation.**

Each scenario in T_m is determined by counting a combination of m buses connected with D-Statcom out of n buses of the test system. For a certain scenario k, we firstly calculate the I_{DS} of D-Statcom for verifying the D-Statcom's limited current. The revised I_{DS} is then used for calculate bus voltage matrix with the presence of D-Statcoms and finally $SARFI_X$ is calculated. Preset parameters can be seen as input data. "postop" is the intermediate variable that updates the optimal scenario of D-Statcom position corresponding to the minimum $SARFI_X$. The starting solution of objective function (Min $SARFI_{X)}$ is assumed to equals B (*e.g.* B=33) which is big value for initiating the search process. The scenarios for parameters of fault events are also considered.

Short-circuit calculation

To calculate the $SARFI_X$, all possible fault positions in the test system need to be considered. However, with only regard to the introduction of the new method, only three-phase short-circuits are taken into account. Other short-circuit types can also be considered similarly in the model if detailed calculation is needed. The paper uses the method of bus impedance matrix for three-phase short-circuit calculations. The resulting bus voltage sags with and without the presence of D-Statcom can be calculated for different cases of preset parameters as discuss ed in Section Result analysis

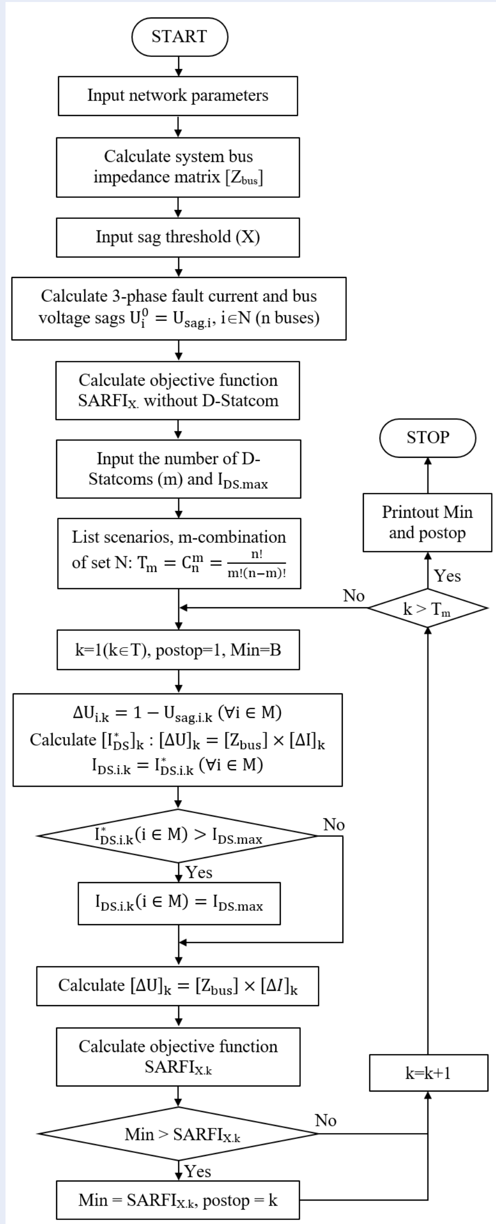

Figure 6: **Block diagram of the problem of optimization.**

and Discussion.

RESULT ANALYSIS AND DISCUSSION

IEEE 33-Bus Distribution System

In the paper, the IEEE 33-bus distribution feeder (Figure 7) is used as the test system because it just features a balanced three-phase distribution system, with three-phase loads and three-phase lines. Following parameters are assumed: Base power is 100MVA, base voltage is 11kV, System voltage is 1pu and system impedance is 0.1pu.

Preset parameters

The research considers the following preset parameters:

- For calculating $SARFI_X$, the paper uses uniform fault distribution [18] and fault rate = 1 time per unit period of time at fault position (each bus) for system component failure.

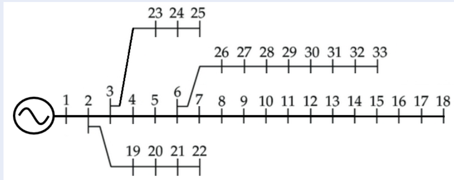

Figure 7: IEEE 33-bus distribution feeder as the test system.

- For rms voltage threshold X, following values are considered: X = 90, 80, 70, 50% of U_n.
- For D-Statcom's limited current, following values are considered: I_{DSmax} = 0.05, 0.1, 0.2p.u.

Result Analysis

The proposed method of modeling the system voltage sag mitigation for the case of using a multiple of D-Statcoms in Section ***Modeling of a multiple of D-Statcoms for system voltage sag mitigation*** can be illustrated for the case of using two D-Statcom. We know that the number of D-Statcoms should be suitable with the system size so that its voltage compensation is economically effective. For such a size of 33-bus test system, two D-Statcoms can be used.

For the case of two D-Statcoms placed in the test system, solving the optimization problem, followings are step-by-step analysis of the results. We start to consider the case with X=80% and I_{DSmax} =0.1p.u. The voltage sag frequency at all system buses are plotted for the case without and with two D-Statcoms in the Figure 8.

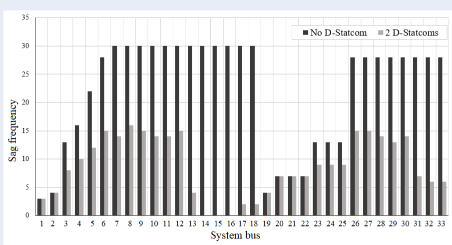

Figure 8: Sag frequency for X=80% at system buses without and with two D-Statcoms, I_{DSmax} = 0.1p.u.

The two D-Statcoms are optimally located at bus 14 and bus 32 and the resulting minimum value of $SARFI_X$ equals 8.7879.

In fact, the optimal placement of two D-Statcoms at buses 14 and 32 is searched from T_2 =528 scenarios. The $SARFI_X$ for X=80% and I_{DSmax} =0.1p.u. is calculated for 528 scenarios as plotted in Figure 9.

A scenario is a point with its ordinates equal to D-Statcom's locations. Also, because we don't consider the permutation for the pair of D-Statcom's location (*e.g.* 1-2 is the same as 2-1), we only consider points on the triangle from the main diagonal of the matrix of scenarios of placement of 2 D-Statcoms. The points in the other triangle of the above said matrix are not considered and thus its objective function is given a high value (e.g. SARFI=33) for searching the minimum of SARFI. However, for better graphical description of $SARFI_X$ as the function of two D-Statcoms placement, in the Figure 9, the positions that are not considered are assigned the $SARFI_X$ to equal zero.

Solving the problem of optimization for other preset parameters, the results are presented as the followings:

• Regarding the relation between $SARFI_X$ and the scenarios of 2 D-Statcom placement, Figure 10 and Figure 11 are presented to have a closer look on the influences of X% to SARFI and I_{DSmax} to SARFI.

• Regarding the effectiveness on sag frequency of all system buses, the results by all preset parameters are described in Figure 12 for X = 80%, I_{DSmax} = 0.05, 0.1, 0.2, 0.3p.u. and Fig. 1 3 for X = 50, 70, 90% and I_{Dsmax} = 0.1p.u.

Figures 9 and 10 and Figure 11 imply the optimal placement in the area of buses of 10-15 and buses of 25-32. Figure 12 shows an obvious influence of X as X is higher, the SARFI is greater, but for X=50%, with two D-Statcoms, the SARFI is very low (about 1.5). We know that for distribution system, the sag duration is defined mainly protection device tripping time and its typical time is 0.1s or greater. With regard to the voltage ride-through curves [16], X should be 50% or greater. For the size of distribution system like the 33-bus, using two D-Statcoms is good enough for mitigating almost voltage sags in the system. That's why the paper takes the scenarios of two D-Statcom placement for modeling a multiple of D-Statcom mitigating system voltage sag for the 33-bus distribution system. Figure 13 also show how the maximum injected current from D-Statcom can improve voltage sag and SARFI. Increases in I_{DSmax} result in big SARFI reduction. For I_{DSmax} = 0.2 and 0.3pu, the SARFI is very small and for some buses it equals zero. That proves for effectiveness of system voltage sag by 2 D-Statcoms for the size of the test system. Remarked results are summarized in the Table 1. For X=50, the SARFI does not improve for I_{DSmax} increasing from 0.2pu to 0.3pu. That also prove again that two D-Statcoms can well mitigate voltage sag for such a size of the test system.

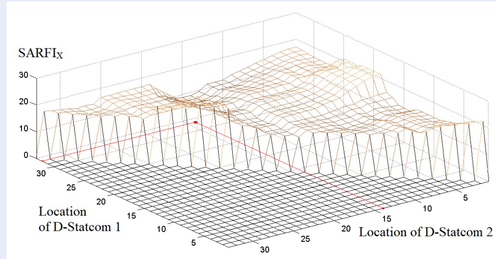

Figure 9: SARFI$_X$ for X=80% and I$_{DSmax}$ = 0.1p.u. as the function of all scenarios of 2 D-Statcom placement.

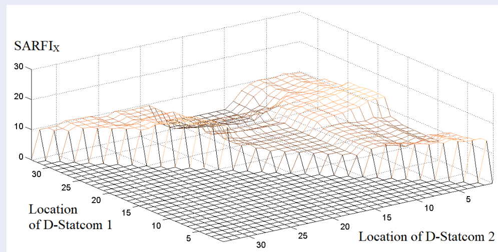

Figure 10: SARFI$_X$ for X=50% and I$_{DSmax}$ = 0.1p.u. as the function of all scenarios of 2 D-Statcom placement.

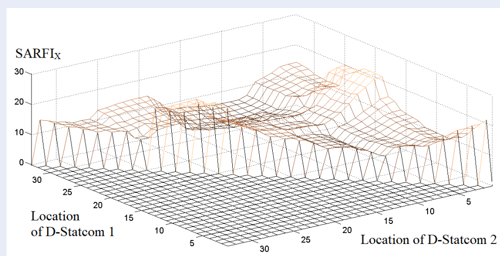

Figure 11: SARFI$_X$ for X=80% and I$_{DSmax}$ = 0.3p.u. as the function of all scenarios of 2 D-Statcom placement.

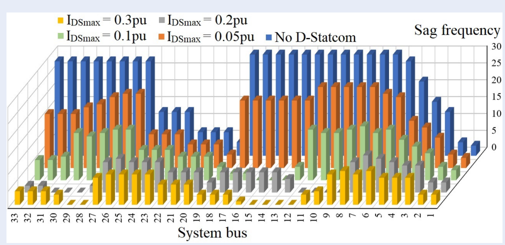

Figure 12: Sag frequency for X=80% at system buses without and with of two D-Statcoms (at optimal placement), for cases of I$_{DSmax}$ = 0.05, 0.1, 0.2, 0.3p.u.

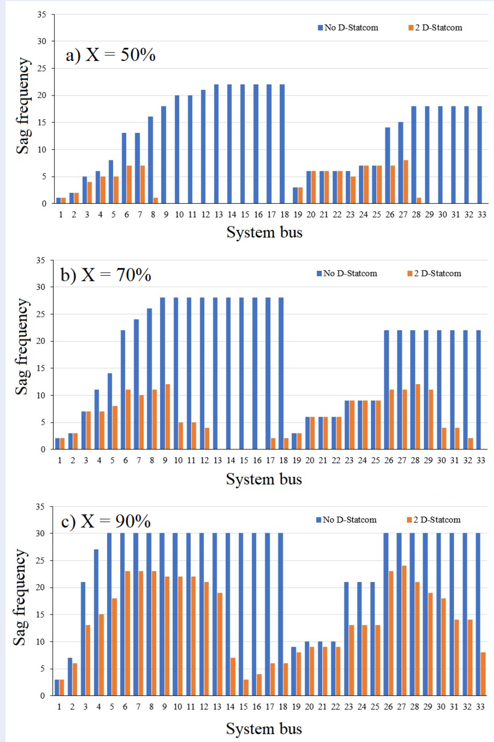

Figure 13: **Sag frequency at system buses for X=50,70,90% without or with 2 D-Statcoms, I_{DSmax} = 0.1p.u. (at optimal placement).**

Table 1: **Results for using 2 D-Statcom**

I_{DSmax} (pu)	0.05	0.1	0.2	0.3
X = 50%				
$minSARFI_X$	7.8485	2.6667	1.5758	1.5758
DS1 Bus	17	13	13	13
DS2 Bus	29	32	28	28
X = 70%				
$minSARFI_X$	12.7273	5.8182	3.3939	3.0303
DS1 Bus	18	13	9	14
DS2 Bus	33	33	28	27
X = 80%				
$minSARFI_X$	16.0606	8.7879	5.0909	4.9091
DS1 Bus	14	14	10	13
DS2 Bus	33	32	30	28
X = 90%				
$minSARFI_X$	20.1818	14.2727	7.2727	7.1212
DS1 Bus	10	15	10	10
DS2 Bus	18	33	29	28

CONCLUSION

This paper introduces a new method for global voltage sag mitigation by a multiple of D-Statcoms in distribution system where the effectiveness of global voltage sag mitigation by a multiple of D-Statcoms for the case of limited maximum current is modeled using Thevenin's superposition theorem in short-circuit calculation of power system. The paper illustrates the method for the case of using two D-Statcom. The results show a better performance of two D-Statcom in comparison with the case of one D-Statcom [15]. It's practical to take the method for a large enough distribution network where a number of D-Statcom can be used.

For the purpose of introducing the method, some assumptions are accompanied like the type of short-circuit and the fault rate distribution. For real application, the method can easily include the real fault rate distribution as well as all types of short-circuit.

ABBREVIATIONS

IEEE: Institute of Electrical and Electronics Engineers

SARFI: System Average Rms variation Frequency Index

PQ: Power Quality

CPD: Custom Power Device

STATCOM: Static Synchronous Compensator

D-Statcom: Distribution Static Synchronous Compensator

DVR: Dynamic Voltage Restorer

FACTS: Flexible Alternating Current Transmission System

COMPETING INTERESTS

The author declares he has no conflicts of interest.

AUTHORS' CONTRIBUTIONS

The author has done all the research work of the article as a sole author.

REFERENCES

1. IEEE Std. 1159-1995, IEEE Recommended Practice for Monitoring Power Quality. 1995;p. 15–18.
2. Ghosh A, Ledwich G. Power quality enhancement using custom power devices. London: Kluwer Academic Publishers; 2002.
3. Math HJ, Bollen. John Wiley& Sons, Inc; 2000.
4. Farhoodnea M, Mohamed A, Shareef H, Zayanderoodi H. A Comprehensive Review of Optimization Techniques Applied for Placement and Sizing of Custom Power Devices in Distribution Networks; 2012. PRZEGLD ELEKTROTECHNICZNY R. 88 NR. 11a.
5. Babaei E, Nazarloo A, Hosseini SH. Application of flexible control methods for D-STATCOM in mitigating voltage sags and swells. Presented at IEEE IPEC 2010 conference. Singapore; 2010.
6. Hamoud F, Doumbia ML, Chriti A; 2017. Available: https://ieeexplore.ieee.org/abstract/document/7935917.
7. Jyotishi P, Deeparamchandani P. Mitigate Voltage Sag/Swell Condition and Power Quality Improvement in Distribution Line Using D-STATCOM. Journal of Engineering Research and Applications. 2013;3:667–674.
8. Tanti DK, Verma MK, Singh B, Mehrotra ON. An ANN Based Approach for Optimal Placement of D-STATCOM for Voltage Sag Mitigation. Int'l Journal of Engineering Science and Technology (IJEST). 2011;3(2):827–835.
9. Yuvaraj T, Devabalaji KR, Ravi K. Optimal placement and sizing of DSTATCOM using Harmony Search algorithm. In: ScienceDirect, Int'l Conf. on Alternative Energy in Developing Countries and Emerging Economies. Elsevier; 2015. Presented at.
10. Taher SA, Afsari SA. Optimal location and sizing of DSTATCOM in distribution systems by immune algorithm. International Journal of Electrical Power & Energy Systems. 2014;60(3):34–44. ScienceDirect.
11. Thangaraj Y. Multi-objective simultaneous placement of DG and DSTATCOM using novel lightning search algorithm. Journal of Applied Research and Technology. 2017;15(5).
12. Ali MA, Fozdar M, Niazi K, Phadke AR. Optimal Placement of Static Compensators for Global Voltage Sag Mitigation and Power System Performance Improvement. Research Journal of Applied Sciences, Engineering and Technology. 2015;10(5):484–494.
13. Zhang Y, Milanovic JV. Global Voltage Sag Mitigation With FACTS-Based Devices. IEEE Transaction on Power Delivery. 2010;25(4):2842–2850.
14. Khanh BQ, Minh NV. Using the Nortons Equivalent Circuit of DVR in Optimizing the Location of DVR for Voltage Sag Mitigation in Distribution System. GMSARN International Journal. 2018;12(3):139–144.
15. Khanh BQ. Preparation A Novel Method for the Improvement of SARFIX of Distribution System Using One D-STATCOM Considering Its Limited Current. GMSARN International Journal. 2019;13(1):52–57.
16. Grainger JJ, Stevenson WD. Power System Analysis. McGraw-Hill, Inc; 1994.
17. 1564-2014 IEEE Guide for Voltage Sag Indices.
18. Khanh BQ, Won DJ, Moon SI. Fault Distribution Modeling Using Stochastic Bivariate Models For Prediction of Voltage Sag in Distribution Systems. IEEE Transaction on Power Delivery. 2008;23(1):347–354.

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Bài Nghiên cứu

Tối ưu hóa vị trí nhiều thiết bị D-Statcom nhằm cải thiện chỉ tiêu SARFI$_X$ trong lưới phân phối

Bạch Quốc Khánh*

TÓM TẮT

Trong khi người sử dụng thường xem xét các giải pháp cải thiện chất lượng điện năng cho một vị trí cụ thể thì phía cấp điện lại quan tâm đến các giải pháp cải thiện chất lượng điện năng không chỉ cho một vị trí cụ thể mà còn cho cả hệ thống điện. Do đó bài báo này liên quan đến một giải pháp cải thiện chất lượng điện năng mang tính hệ thống của phía cấp điện bằng cách sử dụng đồng thời một số thiết bị điều hòa công suất (CPD) trong lưới phân phối. Trong bài báo, một phương pháp mới được giới thiệu nhằm tối ưu hóa vị trí đặt của nhiều thiết bị bù đồng bộ tĩnh D-Statcom nhằm cải thiện tổng thể sụt giảm điện áp ngắn hạn trong lưới phân phối điện theo cách tiếp cận tập trung. Vị trí đặt của D-Statcom sẽ được lựa chọn tối ưu không trong lưới phân phối dựa trên bài toán tối ưu trong đó hàm mục tiêu là tối thiểu hóa chỉ tiêu tần suất sụt giảm điện áp ngắn hạn trung bình SARFI$_X$ của lưới điện đang xét. Hiệu quả của nhiều D-Statcom cải thiện tổng thể sụt giảm điện áp ngắn hạn được mô phỏng mới dựa trên phương pháp xếp chồng Thevenin trong bài toán tính ngắn mạch trong lưới phân phối. Sự xuất hiện của nhiều thiết bị D-Statcom được mô phỏng như là ma trận các nguồn dòng được bơm vào các nút trên lưới làm tăng điện áp trên tất cả các nút trên toàn lưới điện đang xét. Bài toán xét trường hợp sử dụng nhiều D-Statcom với một nguyên tắc bù điện áp thực tế cho các lưới phân phối có kích cỡ lớn. Bài báo sử dụng lưới phân phối mẫu 33 nút của IEEE để mô phỏng tính toán sụt giảm điện áp ngắn hạn khi có ngắn mạch trong lưới phân phối và xem xét các tham số ảnh hưởng đến các kết quả của bài toán tối ưu.

Từ khoá: Lưới phân phối điện, Sụt giảm điện áp ngắn hạn, SARFIX, thiết bị bù đồng bộ tĩnh trong lưới phân phối D-Statcom

Bộ môn Hệ thống điện, Viện Điện, Trường Đại học Bách khoa Hà Nội, Hà Nội, Việt Nam

Liên hệ

Bạch Quốc Khánh, Bộ môn Hệ thống điện, Viện Điện, Trường Đại học Bách khoa Hà Nội, Hà Nội, Việt Nam

Email: khanh.bachquoc@hust.edu.vn

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