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Restoration of a new age power distribution system

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ABSTRACT

The new age transformed distribution system became the most popular content in the literature. In that regard a simulation is attempted for the load flow with dynamically changing system data. Any topic of interest like electrical vehicle, distributed generators, FACTS devices were generalized and considered as an element and placed at different possible locations to observe their effect. The outcomes of the work were generalized to re-consider on site. As the power industry is undergoing a drastic change throughout the world. Restoration of a distribution system along with switching sequence has become a challenging task. In the last half of the twentieth century, analysis of transmission system was the prime concern and faced many challenges to power engineers. The chosen equivalent IEEE 33-bus electric power distribution system has been considered to analyze the system properties such as its maximum capacity, operating limits, restoration issues. The placement of static var compensator (SVC) was experimented for each and every bus. Considering the minimization of total power loss as a prime objective, the best location was found. This analysis also suggested a ranking of different buses and can be helpful in deciding the switching sequence, provided in case of fault, weak area clustering is done. So, congestion is managed in this distribution system.

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1. INTRODUCTION

The problem of switching sequence to restore a distribution system after a fault occurs, is still under analysis, in the literature, and is considered a novel and one of the most appropriate areas related to the efficient operation of radial distribution power systems. In this context, the main objective is to refurbish the largest number of out-of-service areas in an efficient way. In order to isolate a fault, switching operations are performed to de-energize a certain portion of the electrical system and tie-lines are switched-on. The main objective in this connection is to restore the largest number of disconnected loads in such a way so that the constraints of electrical distribution system operation are not violated. These constraints include the restrictions of load flow related to Kirchhoff's laws, current capacity of feeders, voltage limits of nodes and capacity of substations.

With the advent of metaverse, electrical engineers are trying to find some job in the newly created world with their simulations. But we should not forget that the ultimate power is in our hands in terms of real power and reactive power. Placement of SVC at different buses is a very simple example to illustrate the reactive power dependence of any system considered. Binary digital world is having only two digits zero and one which created everything. Similarly, we have real power and reactive power which can create a different world with different language. Placement of SVC at different buses to control reactive power and hence voltage stability control is something like an upgrading for the above discussed technology.

Curcic *et al.* [1] presents a review of the main characteristics of the key publications up to 1996. The authors have shown that there are two fundamental objectives of the restoration problem. The first one is to restore the maximum possible demand of the fault effected region and the second one is to implement the restoration process at the earliest. In most of the earlier works loss minimization and load balancing between feeders are not considered in the restoration process and that makes this work a novel attempt.

Romeno *et al.* [2] presented a comprehensive mathematical model has been proposed for the solution of restoration problem in balanced radial distribution system. The authors have shown that the mixed integer second-order conic model can be solved proficiently using commercial solved and the proposed model and proposed solution can be used offline or online, depending upon time needed to solve the problem. But they pointed out that the problem of verdict the sequence of switching operation is still under investigation.
A direct approach for unbalanced three phase distribution load flow solution is proposed in reference [3]. The authors have developed two matrices from the topological characteristics of distribution system and these two matrices are combined to form a direct approach for answering load flow problems. The authors have also shown that the proposed method is suitable for large-scale distribution systems. Suliman [4] discussed voltage profile enhancement in distribution network using static synchronous compensator STATCOM.

An efficient hybrid approach for volt/var control in distribution system with switching limits on tap a shunt has been presented in reference [5]. The approach mentioned combines the strengths of a gradient technique and a metaheuristic technique. It has been shown that the proposed method is 30-35 times faster and is more accurate than the conventional genetic algorithm. But all distribution transformers are not provided with tap setting facility hence in order to avoid the confusion applying SVC is a better alternative.

Arya *et al.* [6] present an algorithm for rescheduling reactive power control variable so as to have an adequate load capability margin for current operating point has been described. The coordinated aggregation-based particle swarm optimization technique has been used to minimize the total reactive power loss. The control variables are similar as in the reference [5] therefore this paper helps in understanding the loss minimization issue. But a mathematical approach is always more consistent than a soft computing. Hence in the projected work a mathematical approach is adopted for SVC placement. Zabaiou *et al.* [7] given the idea of preventive control approach for voltage stability improvement using voltage stability constrained optimal power flow based on static line voltage stability indices. Patil and Karajgi [8] developed a technique for an optimal placement of multiple FACTS devices using PSO and CSA algorithms. Abdullah *et al*. [9] enhanced the stability of power system using optimal location of FACTS devices. Gupta *et al*. [10] presented mitigation of congestion in a power system and role of FACTS devices, in [11] application of voltage stability index for congestion management is discussed whereas [12] presents a comparative analysis of different power delivery systems using voltage stability index.

Dolatabadi [13] presented an enhanced IEEE 33 bus benchmark test system for distribution system studies where presence of electrical vehicle is taken into consideration. Distributed coordination of electric vehicle providing v2g regulation services [14], [15]. Hatziargyriou [16] presented a guest editorial special section on microgrids for sustainable energy system. A multiagent system for controlled charging of a large population of electric [17], Dilek *et al.* [18] presented a simultaneous phase balancing at substations and switches with time varying load patterns. Lin *et al.* [19], reported an expert system for three phase balancing of distribution feeder, Tewari *et al.* [20] gave the concepts of coordinated control of OLTC and energy storage for voltage regulation in distribution network with high PV penetration, Lotfi *et al.* [21] studied the impact of feeder reconfiguration on automated distribution network with respect to resilience concept, Ansari *et al*. [22] discussed the planning for distribution system with grey wolf optimization method, Bhatt and Chandel [23] presented an intelligent water drop approach for simultaneous reconfiguration and DG integration in distribution system, Kim *et al.* [24] presented an advanced power distribution system configuration for smart grid. Ghadban *et al.* [25] purposed an assessment of voltage stability based on power transfer stability index using computational intelligence models. Hinda and Khiat [26] gave the idea of real-time simulation of static synchronous condenser (STATCOM) for compensation of reactive power, whereas a study of reconfiguration of power distribution systems considering reliability and power loss was discussed by Amanulla *et al.* [27]. After reviewing the relevant literature, it is observed that there is no proposal for switching sequence for restoration. Solving it using static var compensator (SVC) is a noble attempt. It can be easily adopted to the restoration problem.

2. POWER FLOW WITH SVC

Reactance of SVC can be adjusted either by using firing angle limits or reactance limits. With the help of SVC non-linear power equations and the linearized equations, used in Teng's method is derived. The current drawn by SVC can be written as (1).

$$I_{SVC} = jB_{SVC}V_K \tag{1}$$

The reactive power drawn and injected at the bus is (2).

$$Q_{SVC} = Q_K = -V_K^2 B_{SVC} \tag{2}$$

The linearized equation is given as (3).

$$\begin{bmatrix} \Delta P_K \\ \Delta Q_K \end{bmatrix}^{(i)} = \begin{bmatrix} 0 & 0 \\ 0 & Q_K \end{bmatrix}^{(i)} \begin{bmatrix} \Delta Q_K \\ \Delta B_{SVC}/B_{SVC} \end{bmatrix}^{(i)} \tag{3}$$

Where the equivalent susceptanceB_SVC is susceptance and is taken to be state variable. The variable shunt susceptanceB_SVC is updated accordingly, at the end of (1) iteration.

$$B_{SVC}^{(i)} = B_{SVc}^{(i-1)} + \left(\frac{\Delta B_{SVC}}{B_{SVC}}\right)^{(i)} B_{SVC}^{(i-1)} \tag{4}$$

It is compulsory to maintain the magnitude of nodal voltage at the specified value. Here, the changing susceptance represents the total SVC susceptance. When the level of compensation has been determined, the firing angle of the thyristor can be calculated. The SVC susceptance and thyristor firing angle are non-linearly related. Hence, the additional calculation requires an iterative solution.

Standard IEEE 33-bus radial distribution system is considered for the analysis. Figure 1. Shows the single line diagram of the system chosen. This system is radial type distribution feeder having the base voltage 12 kV-66 kV and base apparent power 100 MVA. It consists of 32 distribution lines and one slack bus. Figure 2 shows the same IEEE 33-busradial distribution system without all tie-lines provided and Figure 3 shows the same IEEE 33-busradial distribution system with all tie-lines provided. Five different tie lines provided are 22-12, 21-8, 9-15, 25-29 and 33-18. These tie-lines can be connected in case of fault according to the type and condition of the fault. Representation of simulation of two buses is shown below in Figure 1 for illustration purpose, which can be integrated up to 33 bus system as shown in Figure 2 and Figure 3. A direct approach for distribution system load flow proposed by Teng [3] is used in this work. This power flow method is robust for distribution system because of its fast convergence.

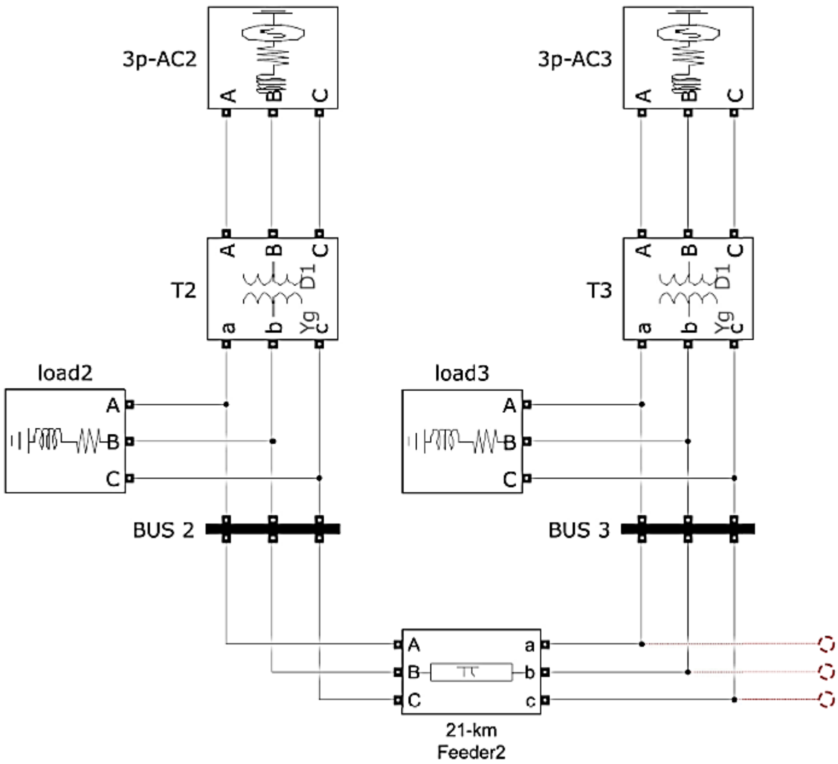

Figure 1. Simulation of radial distribution system with two buses

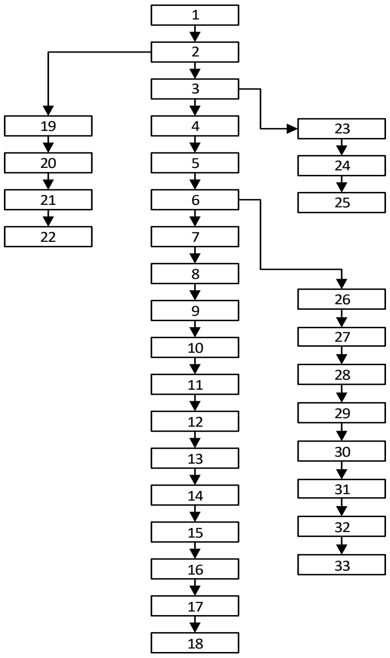

Figure 2. Single line diagram of IEEE 33-bus radial distribution system without tie-line

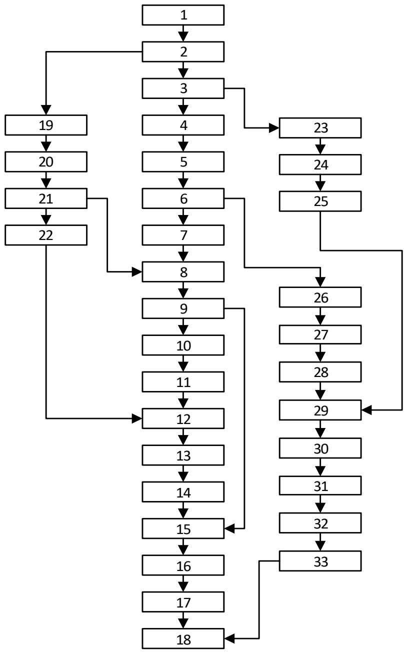

Figure 3. Single line diagram of IEEE 33-bus radial distribution system with tie-line

3. RESULTS AND DISCUSSION

SVC was placed at one bus and total power loss was calculated. During research, the location of SVC was changed throughout all buses and corresponding power losses were tabulated. In Table 1, when SVC was placed at bus-2 of the IEEE 33-bus radial distribution test system, the total power loss of the complete system was $2.8282 - i1.8880$. Similarly, when SVC was placed at the bus-2the total power loss of the system was $2.8176 - i1.8824$. This way total power loss was calculated for all the different positions of SVC.

In Table 2 only reactive power loss i.e. the imaginary part of total power loss is considered. The total reactive power loss is arranged in ascending order and corresponding location of SVC is tabulated in column-2 of Table 2. It is well known that voltage stability is directly related to reactive power of a system. Hence, if total reactive power loss is more, the voltage stability will be less. This way Table 2 provides a ranking among different buses. From Table 2 it is clear, that if SVC is placed at 19th bus, the total reactive power loss is maximum and voltage stability rank is minimum or system will be more unstable. Similarly, if SVC is placed at bus number 30, the total reactive power loss is minimum, hence system is more stable as far as voltage stability is concerned.

If total reactive power loss is minimum after SVC placement at any bus, then voltage stability will be maximum after SVC placement. But before SVC placement corresponding bus-30 was surely the weakest bus to put SVC in order to increase voltage stability, i.e, Corresponding bus was weakest and therefore Placement of SVC is more justified. This way Table 2 represents the ranking of buses. 30th bus is weakest and 19th bus is strongest or healthy bus. Now a healthy bus should provide power supply in case of any fault or contingency. It can suggest therefore, a switching sequence therefore. In the system chosen, five tie-lines are provided, respectively 22-12, 21-8, 9-15, 25-29, 33-18. Considering both sending end and receiving end ranking.

From the Table 1, it is concluded that after sorting the difference of ranking between the receiving end and sending end tie-lines in descending order, we get the order 23-15-5-3-1. And hence, corresponding switching sequence of tie-lines will be 21-8, 22-12, 9-15, 25-29, 33-18.

Table 1. Difference of ranking among buses

Sending end of tie-line with ranking in brackets	Receiving end of tie-line with ranking in brackets	Difference of ranking
22(28)	12(13)	(28-13)=15
21(29)	8(6)	(29-6)=23
9(22)	15(27)	(27-22)=5
25(8)	29(5)	(8-5)=3
33(10)	18(11)	(10-11)=1

Figure 4 shows the voltage profile of different buses in basic configuration. In this figure there is no tie- line connected between the buses of the system. Figure 5 shows the voltage profile of different buses when the system is fully meshed. Table 2 shows the total power loss when SVC is placed at different buses. Total power loss is calculated at each bus. Table 3 shows the total reactive power loss in ascending order and at corresponding ranking of the buses. Figure 6 and Figure 7 indicate thattotal real and reactive power loss respectively are least when SVC is placed at 29th bus.

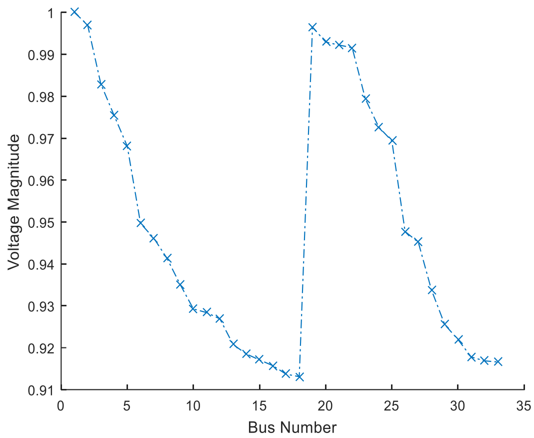

Figure 4. A plot between number of buses and voltage magnitude without tie-line

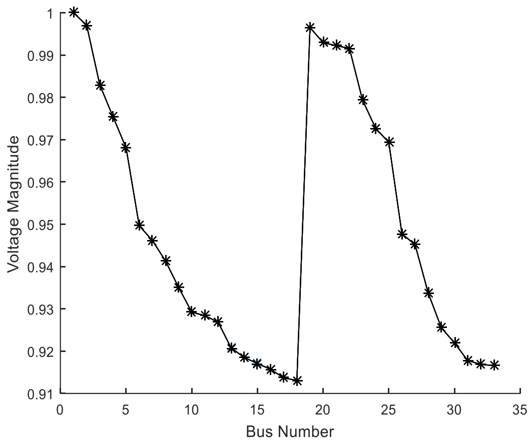

Figure 5. A plot between number of buses and voltage magnitude in fully meshed condition

Table 2. Total power loss when SVC placed at different buses

SVC Placed at Buses	Total Power Loss
1.	-
2.	2.8282 - 1.8880i
3.	2.8176 - 1.8824i
4.	2.7822 - 1.8640i
5.	2.8123 - 1.8797i
6.	2.8151 - 1.8792i
7.	2.6886 - 1.7911i
8.	2.6781 - 1.7870i
9.	2.8093 - 1.8746i
10.	2.8069 - 1.8729i
11.	2.7860 - 1.8589i
12.	2.7745 - 1.8514i
13.	2.7694 - 1.8477i
14.	2.6707 - 1.7803i
15.	2.8254 - 1.8854i
16.	2.8007 - 1.8683i
17.	2.7996 - 1.8673i
18.	2.7508 - 1.8339i
19.	2.8296 - 1.8886i
20.	2.8281 - 1.8873i
21.	2.8279 - 1.8870i
22.	2.8278 - 1.8869i
23.	2.8098 - 1.8779i
24.	2.7203 - 1.8266i
25.	2.7178 - 1.8250i
26.	2.8060 - 1.8736i
27.	2.8041 - 1.8726i
28.	2.8073 - 1.8734i
29.	2.6800 - 1.7853i
30.	1.9022 - 1.2761i
31.	2.6626 - 1.7739i
32.	2.5841 - 1.7204i
33.	2.7415 - 1.8276i

Table 3. Total reactive power loss in ascending order and corresponding ranking of the buses

Total Reactive Power Loss	Corresponding Buses	Ranking of buses
1.2761	30	1
1.7204	32	2
1.7739	31	3
1.7803	14	4
1.7853	29	5
1.7870	8	6
1.7911	7	7
1.8250	25	8
1.8266	24	9
1.8276	33	10
1.8339	18	11
1.8477	13	12
1.8514	12	13
1.8589	11	14
1.8640	4	15
1.8673	17	16
1.8683	16	17
1.8726	27	18
1.8729	10	19
1.8734	28	20
1.8736	26	21
1.8746	9	22
1.8779	23	23
1.8792	6	24
1.8797	5	25
1.8824	3	26
1.8854	15	27
1.8869	22	28
1.8870	21	29
1.8873	20	30
1.8880	2	31
1.8886	19	32

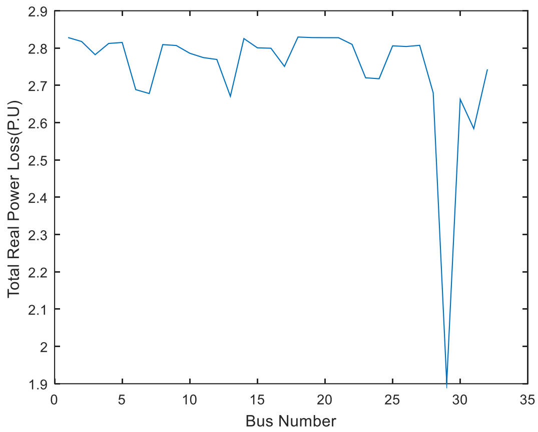

Figure 6. Total real power loss when SVC is placed at different buses

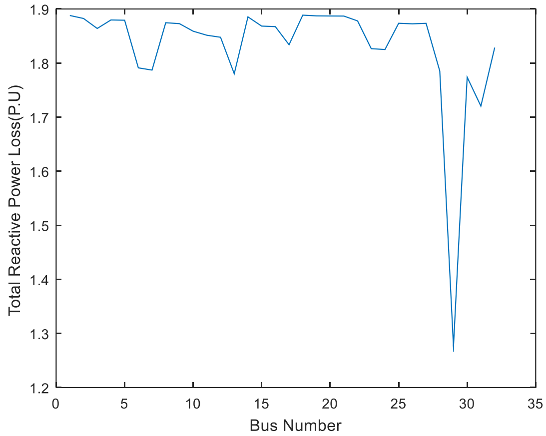

Figure 7. Total reactive power loss when SVC is placed at different buses

4. CONCLUSION

In this paper, a comprehensive analysis of different locations for SVC placement is analyzed to rank the buses which in turn suggested the switching sequence for any restoration problem. Test results show excellent performance with regard to the voltage stability issue. The proposed solution can be developed for offline or online applications. Finally, we consider this work to be an initial proposal that can lead to further research in related objectives such as switching sequence based on: i) transient stability and ii) economic aspects.

The classical thirty-three bus system has been enhanced by several extensions such as distribution of generators, FACTS devices, branches with switches and systems with energy storage capacities. It provides a resolution for online testing and analysis of voltage profile. Numerous data for reconfiguration have been tabulated for this work which helps in compensation of reactive power and switching of branch provides many opportunities a modern power distribution system. Appropriate simulations tried their best to generate a good database for further studies.

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