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USING NETWORK RECONFIGURATION AS A TOOL FOR MITIGATING VOLTAGE SAGS IN PRACTICAL DISTRIBUTION SYSTEMS

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ABSTRACT:- Voltage magnitude is one of the major factors that influence the quality of power supply. In this paper a practical method is presented for mitigating voltage sag in power distribution systems by means of network reconfiguration. The method initially identifies the weak areas in the system when it is subjected to faults in the system. Then it tries to reconfigure the network by locating the weak areas as far away as possible from the main source. Network reconfiguration is implemented by changing the opening and closing switching status of the switches in a network. A practical test distribution system is analyzed and reconfigured to illustrate the applicability of the proposed method. The results proved that the proposed voltage sag mitigation method can improve the system voltage profile during faults and hence decrease the use of voltage sag mitigation devices. Such a technique can be used to improve power quality and reliability of power distribution networks.

***Keywords*:-** power, distribution network, reconfiguration, voltage sag.

1- INTRODUCTION

Electric power distribution system delivers power to customers from a set of distribution substations. Although distribution systems are designed in mesh configuration, they are generally operated in radial configuration to simplify the method for over current protection of feeders.

To help restore power to customers following a fault, most distribution feeders are provided with tie circuits connecting neighbouring feeders from either the same or different substations Broadwater(1).

In power distribution systems, voltage sags are said to often occur and therefore is regarded as a main power quality problem Nita(2). It is defined as a decrease in root mean square voltage between 0.1 and 0.9 p.u. for duration of 0.5 cycle to1 minute IEEE Std(3). Voltage sags has attracted the attention of utilities and sensitive customers, and therefore many studies have been carried out to mitigate voltage sag problems. One method used for mitigating voltage sag is by means of network reconfiguration. Sang(4) proposed network reconfiguration as a voltage sag mitigation method by using feeder transfer in power distribution systems. Switches at sectionalizing points of a distribution network are used to find the weak points during voltage sags and to transfer the customers at the weak points to other sources. Chen(5) presented a voltage sag mitigation method by means of a series of utility strategies implemented for a period 10 years and upgraded on the basis of actual data during the period.

The motivation of this work to apply network reconfiguration for mitigating voltage sags in power distribution networks by determining an optimal network design which takes into account uncertain factors such as load growth. In this study the problem of voltage sag is performed and analyzed in distribution networks by using the ETAP (Electrical Transient Analyzer Program) software simulation tool.

2-VOLTAGE SAG MITIGATION USING NETWORK RECONFIGURATION

Network reconfiguration is an important function employed in automated distribution systems basically to reduce distribution feeder losses and improve system security. In network reconfiguration, loads can be transferred from feeder to feeder by changing the open/close status of the feeder switches. The number of closed and normally opened switches in a distribution system, and the number of possible switching operations is tremendous.

Voltage sag mitigation by means of network reconfiguration can be achieved by changing the network branch switches. To provide the least changes in network configuration with respect to voltage sag experienced by customers and to obtain the best system voltage profile, optimal switching actions within the existing predefined network switches need to be performed. The proposed network reconfiguration method is developed according to the principle of the Kirchhoff's laws. To illustrate the proposed network reconfiguration method, consider a typical radial distribution system shown in Figure 1. The system consists of a substation supplied by a main source feeder and four other feeders, namely, feeders A, B, C and D. Switches, SW1, SW2 are normally closed and SW3 is normally open as shown in Figure 1a. During the event of a fault at Bus-A1, voltage sag is said to occur at the substation bus. The voltage magnitude during voltage sag can be determined by,

$$V\% = (1 - \Delta V) \times 100 \quad (1)$$

in which the voltage drop, ΔV, before reconfiguration is given by:

$$\Delta V\,(before\,) = \frac{Zs}{Zs + Za1} \text{ in p.u} \qquad (2)$$

The derivation of (2) is shown as follow:

Since the fault occurred at bus (A1) and Switches, SW1, SW2 are normally closed and SW3 is normally open, so approximately all fault current pass through impedances Zs and Za1, as shown in figure 1a then

$$I_{fault} = \frac{v}{z_{a1} + z_s} \qquad (3)$$

$$\Delta V = E - V = I_{fault} \times z_s \quad in\ volt \qquad (4)$$

$$\Delta V = \frac{V}{z_{a1} + z_s} \times z_s \quad in\ volt \qquad (5)$$

$$\Delta V = \frac{\Delta V\ (involt)}{V_{base}} \quad in\ \ p.u \qquad (6)$$

$$\Delta V = \frac{z_s}{z_{a1} + z_s} \quad in\ \ p.u \qquad (7)$$

Since voltage sag occurs at the substation bus, feeders B, C and D are also affected by the voltage sag. In order to mitigate this voltage sag and improve the voltage profile of the substation bus, ΔV needs to be decreased by increasing the impedance towards the fault current. This can be achieved by changing the status of the switches in which SW1 is opened and SW3 is closed as shown in Figure 1b, The voltage drop (ΔV) after reconfiguration can be determined by,

$$\Delta V_{(after)} = \frac{Zs}{Zs + (Za1 + Za2 + Za3 + Zb3 + Zb2 + Zb1)} \qquad (8)$$

It is clear from the above equation that the voltage drop (ΔV) after reconfiguration becomes less than the voltage drop before reconfiguration. From equation (1) and considering the voltage drop before and after reconfiguration, the following condition for voltage magnitude can be obtained.

$$V_{(after)}\% > V_{(before)}\% \qquad (9)$$

From equation (9), it is clear that the substation bus voltage magnitude is raised and voltage sags at the feeders B,C and D are mitigated.

3-TEST SYSTEM AND METHODOLOGY

A practical test distribution system is selected to validate the proposed network reconfiguration method. The system consists of three voltage levels, namely, 132kV, 33kV and 11 kV. The 132 kV from the transmission grid is first stepped down to 33 kV and 11 kV at the main substation as shown in Figure 2. Feeders 1 to 8 are connected to the 11kV side of the main substation through bus INTAKE-1 and INTAKE-2 respectively. While on the 33 kV side, two incoming feeders supply additional outgoing feeders through bus INTAKE F1 and INTAKE F2. A mini hydro plant is also connected to the bus B23. Furthermore, nine network switches SW1 to SW9 are scattered in such a way to make sure that the system is operating in radial mode at all times.

Before the application of the network reconfiguration to mitigate voltage sag, it is assumed that all bus voltages are maintained within the limits of ±6% of their respective voltage levels for proper operation. However, for faults occurring at buses B1 and B12 as shown in Figure 2, these buses are said to be main sources of voltage sags and are considered as weak areas in the system.

In the simulation, initially, a base case load flow is solved to evaluate the pre-fault voltage magnitude at each node as the pre-sag values before reconfiguration. Then, three phase to ground faults and single phase to ground faults are simulated at bus B1 and B12, respectively and all the node voltages during and after faults are recorded for identifying the weak areas in the network. The final step of the simulation involves network reconfiguration where the network switches are manually changed to mitigate the effect of voltage sags in the weak areas. For mitigating voltage sag in the first weak area, network reconfiguration is implemented by changing the status of switches SW1 from close to open mode and SW2 from open to close mode. Once it is done, all buses which were supplied through bus B3 are now supplied via bus B7, which makes the faulted bus B1 far way from the main source.

Similarly, for mitigating voltage sag in the second weak area, where fault is assumed at bus B12, network reconfiguration is applied by changing the status of the switches SW3 to open mode and SW4 to close mode. Figures 3 and 4 show the new reconfiguration of the system to mitigate the voltage sags appearing in the first and second weak areas, respectively.

4- SIMULATION RESULTS AND DISCUSSION

To illustrate the effectiveness of network reconfiguration (Rec) in mitigating voltage sags, the magnitudes of the bus voltages before and after reconfiguration are tabulated as shown in Tables 1 and 2. It is important to take note of the difference in voltage magnitudes at each bus, before and after network reconfiguration.

By comparing the results of the voltage magnitudes before and after network reconfiguration as in Table 1 and Table 2, it is noted that all the voltages at the buses which are affected by the faults show an increase in voltage magnitudes after reconfiguration. For example, voltage sags that appear in 17 out of the total buses in the system are completely mitigated after reconfiguration. As for the other remaining buses, the voltage magnitudes are slightly increased. However, the results of the voltage magnitudes in the second weak area are slightly different in which sag magnitudes are further degraded at the 7 buses, namely, bus number 15, 21, 22, 23, 24, 25 and 26 as depicted in Tables 1 and 2.

In terms of system losses, the total power losses at base case are 1900.6 kW and 187.2 kVar, while the losses after network reconfiguration in the first and the second weak areas are 1927.5 kW and 308.2 kVar and 1972.5 kW and 429.7 KVar, respectively. The increased in losses from the base case values are due to the faulted conditions in the system.

Figures 5a) and 5b) show the voltage sags before and after network reconfiguration at buses Intake-1 and Intake-2 during faults occurring at buses B1 and B12, respectively. From the plots, it can be seen that voltage sags are mitigated at Intake-1 and Intake-2 from about 63% to 98 % and 77 % to 90 %, respectively.

Figures 6 and 7 shows the voltage magnitudes of all system buses during faults at buses 3 and 14 respectively. The improvement of voltage magnitude for the most number of system buses is clear by the effect of applying network reconfiguration for two case studies.

5- CONCLUSION

This paper has presented a method to mitigate voltage sags in distribution systems by means of configuring the network. Simulation results proved that by changing the switching status of the network switches, the fault locations can be placed farther away from the main intake source so that voltage sag affected areas can be minimized. The appropriate switching actions can be made on the basis of basic electrical laws. For further research work, the optimization technique will be used to determine the optimal network reconfiguration in voltage sag mitigation.

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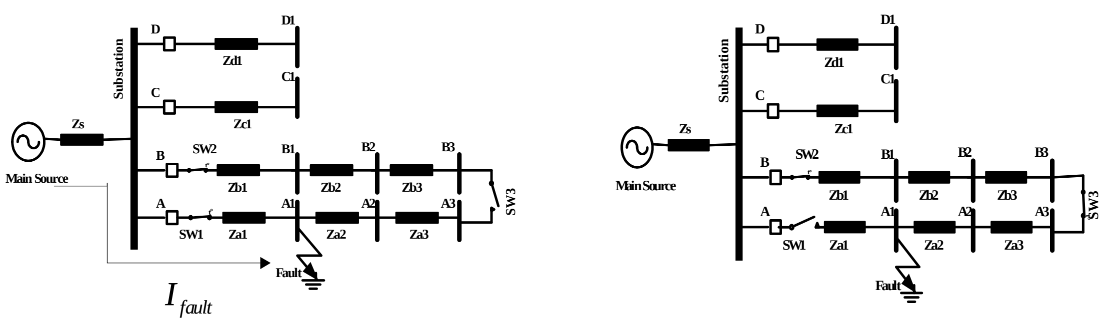
Table (1): Bus voltages in the system before and after reconfiguration.

Bus and Voltage information			Voltage Magnitude %			
			1st Area (B1)		2nd Area (B12)	
No.	Bus name	Nominal KV	Before Rec	After Rec	Before Rec	After Rec
1	A	33	94.24	97.28	95.41	96.61
2	B	33	92.63	95.62	93.78	94.63
3	B1	11	Fault	Fault	75.83	91.02
4	B2	11	13.27	17.22	73.07	91.69
5	B3	11	38.88	50.45	67.69	93.26
6	B4	11	51.92	75.61	54.21	92.44
7	B5	11	58.39	64.93	78.32	96.97
8	B6	11	80.54	82.62	91.03	101.54
9	B7	11	61.01	93.01	45.71	89.87
10	B8	11	60.23	91.57	46.23	89.66
11	B9	11	58.97	89.21	47.19	89.40
12	B10	11	58.2	87.75	47.83	89.82
13	B11	11	56.64	85.41	46.56	89
14	B12	11	60.55	92.31	Fault	Fault
15	B13	11	60.70	92.54	17.14	8.72
16	B14	11	63.80	98.16	76.81	90.21
17	B15	11	63.74	98.06	76.73	90.13
18	B16	11	64.51	98.53	77.35	90.56
18	B17	11	64.92	98.30	77.48	90.34
20	B18	11	65.96	98.08	77.95	90.14

Table (2): Bus voltages in the system before and after reconfiguration.

System information			Voltage Magnitude %			
			1st Area (B1)		2nd Area (B12)	
No.	Bus name	Nominal KV	Before Rec	After Rec	Before Rec	After Rec
21	B19	11	64.91	96.78	77.09	52.13
22	B20	11	66.40	97.04	78.19	28.10
23	B21	11	66.27	96.84	78.03	28.04
24	B22	11	72.31	98.24	82.29	38.24
25	B23	11	77.78	99.53	86.15	48.24
26	B24	11	91.07	102.2	95.46	73.33
27	BG1	3.3	104.97	103.3	104.60	103.11
28	BG2	3.3	103.55	103.2	103.69	100.01
29	C	33	92.31	95.29	93.46	94.63
30	D	33	90.62	93.54	91.74	92.89
31	E	33	91.44	94.39	92.58	93.74
32	N	33	90.36	93.27	91.48	92.63
33	INTAKE-1	11	64.21	98.79	77.30	90.79
34	INTAKE-2	11	64.21	98.79	77.30	90.79
35	INTAKE-F1	33	95.57	98.65	96.76	97.97
36	INTAKE-F2	33	95.57	98.65	96.76	97.97
37	MAIN-S	132	99.57	102.7	100.80	102.07
38	GRID SWNG	132	103.00	103.0	103.00	103.00
39	G1	3.3	107.84	105.2	106.31	105.25
40	G2	3.3	104.97	103.3	104.60	103.11



(a) (b)

Fig.(1): Typical power distribution system a) Before reconfiguration b) After reconfiguration.

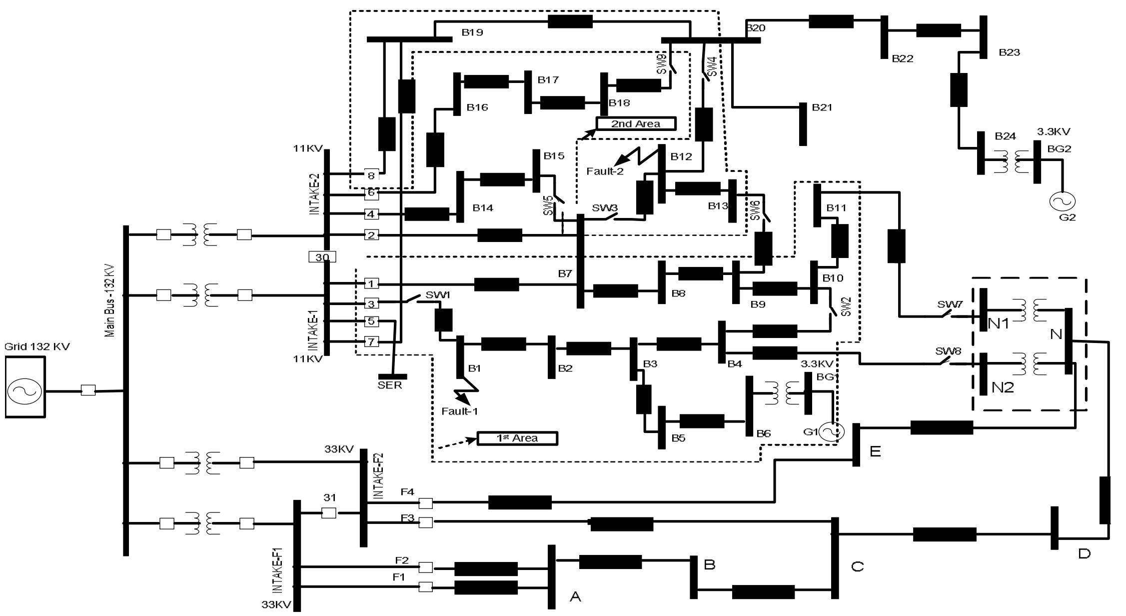


Fig. (2):practical test distribution system.

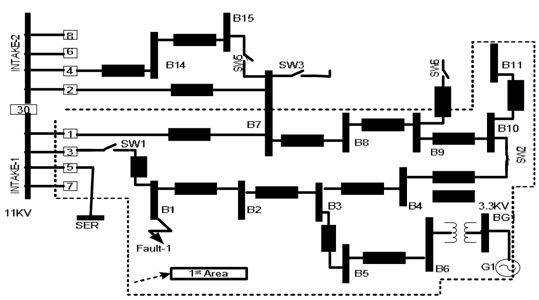


Fig.(3): Reconfigured section of the first weak area.

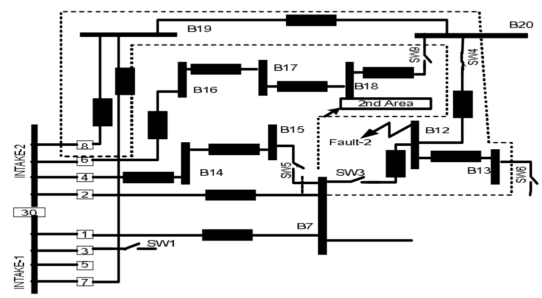
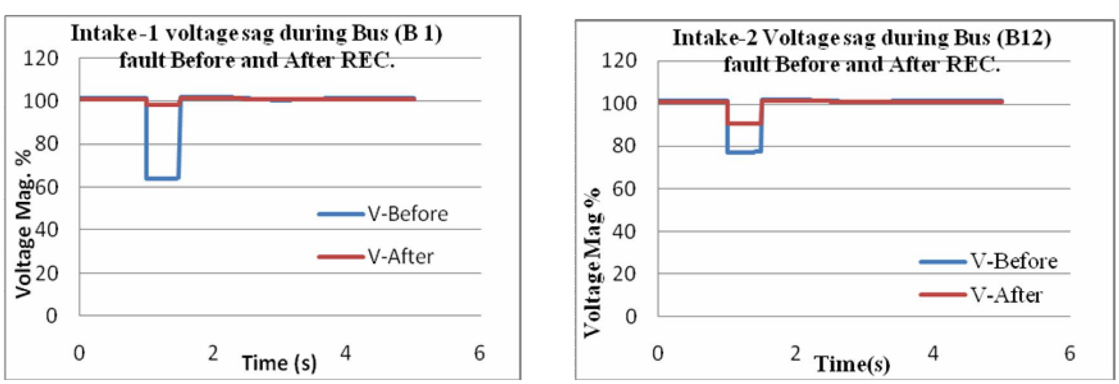


Fig.(4): Reconfigured section of the second weak area.



(a) (b)

Fig.(5): Voltage sag mitigation at the a) Intake-1 substation b) Intake-2 substation.

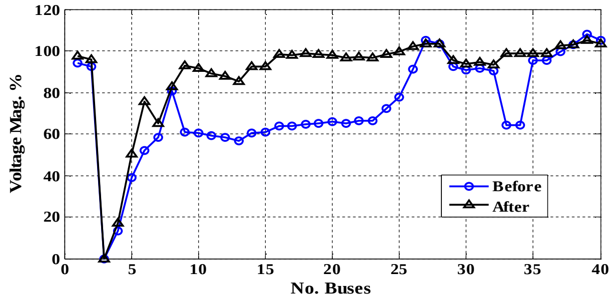


Fig. (6): Voltage Magnitude for all system during the fault at bus number 3 before and after network reconfiguration**.**

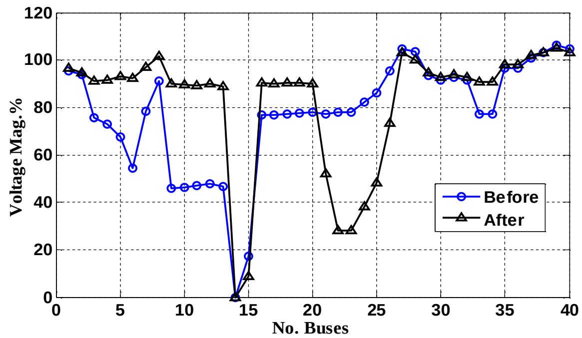


Fig.(7): Voltage Magnitude for all system buses during a fault at bus number 14 before and after network reconfiguration.

استخدام إعادة ترتيب الشبكة كطريقة للتخفيف من ضعف الفولتية في أنظمة التوزيع العملية

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الخلاصة

مقدار الفولتية هو واحد من العوامل الرئيسية التي تؤثر على نوعية القدرة المجهزة.في هذا البحث تم إيجاد طريقة عملية للتخفيف من ضعف الفولتية في نظم توزيع القدرة بواسطة إعادة ترتيب الشبكة.الطريقة في بدايتها تحدد مناطق ألضعف في النظام عندما يتعرض النظام إلى خطأ. بعدها تقوم بإعادة ترتيب الشبكة لجعل مناطق الضعف ابعد ما يمكن عن المصدر الرئيسي. حيث عن طريق تغير حالات الفتح والإغلاق للمفاتيح الموجودة في الشبكة يتم إعادة ترتيب الشبكة.وتم تحليل وإعادة ترتيب نظام اختبار عملي لتوضيح تطبيق الطريقة المقترحة. أثبتت النتائج ان الطريقة المقترحة للتخفيف من ضعف الفولتية تستطيع تحسين فولتية النظام أثناء حدوث الأخطاء وبالتالي التقليل من استخدام أجهزة تخفيف ضعف الفولتية. حيث يمكن استخدام هذه التقنية لتحسين نوعية القدرة وموثوقية شبكات توزيع القدرة.