순간전압강하 저감을 위한 방사상 배전계통에서의 부하 절환 스위칭

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Load Transfer Switching for Reducing the Voltage Sag's Effect in Radial Power Distribution System

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Abstract - In this paper, we present a method for mitigating the effect of voltage sag in radial power distribution systems using load transfer switching (LTS). The term of LTS is defined that the weakness load points for voltage sag transfer to the alternative source during the fault clearing practices. The sequences of proposed LTS method is divided into the search of weakness points for voltage sag using the risk assessment model and transfer behavior of weakness points. Through the case studies, we verify the effectiveness of proposed LTS method and present the searching method of effective application points of LTS method using the risk assessment model.

1. Introduction

The several methods to reduce the number and severity of voltage sag and to dull the sensitivity of equipment for voltage sag have developed. The main subject can be divided into the utility and customer side countermeasures. Utilities concentrate their effort to prevent the faults and to modify the fault clearing practice in power system. These efforts may reduce the number and duration of voltage sags. However, the faults in power system can never be completely eliminated. To increase the bus voltage during voltage sags, G. T. Heydt proposes the series voltage booster. And Detroit Edison Power Co. utilize the static transfer switch (STS) to solve the power quality problems [1]. Customer side solutions usually involve the power-conditioning equipment for sensitive loads. They present the enhancement of ride-through capability for voltage sag using the power-conditioning devices. These methods have merit of showing direct and clear effect for the individual equipment. However, the customer side solutions cannot be applied to whole customers' loads because the power conditioning devices have restriction for capacity and price. Therefore, it is necessary to develop the mitigation method that considering the sufficient capacity and inexpensive price in utility side.

This paper presents a mitigation method of voltage sag using load transfer switching (LTS) method in radial power distribution system. The term of LTS is defined that the weakness load points for voltage sag transfer to the alternative source during the fault clearing practices. This method is basically utility side solution of voltage sag. The proposed LTS method is carried out using the switching behavior for the sectionalizing points of distribution networks. It consists of two main sequences. One is the search of weakness point for voltage sag. It is carried by the reliability evaluation using risk assessment model of voltage sag. The other is the transfer behavior of weakness points of voltage sag to the alternative source during the fault current exist.

2. Voltage Sag in Radial Power Distribution System

The duration of voltage sag is determined by the clearing time of the protective device. The duration of first voltage sag for the fault in model distribution system is calculated as (1). The t^1_{TD}, t^1_{Re} and t^1_{CB} in (1) represent the duration of first voltage sag, the operation time of relay and circuit breaker, respectively. The superscript 1 in (1) represents the status of no-reclosing.

$$t^1_{TD} = t^1_{Re} + t^1_{CB} \tag{1}$$

In overheads distribution system, automatic reclosing is commonly used. In this paper, we account the successive voltage sags due to the reclosing with circuit breaker or recloser as one if they occur within a certain fault [2]. And also, the duration of voltage sag is assumed the longest one as (2). The superscript n in (2) represents the order of voltage sags that occurred within a fault.

$$t_{TD} = \mathrm{Max}(t^n_{TD});\ n=1,2,3,\ \ldots\ldots,\ k \tag{2}$$

Where,

t_{TD} : total duration of sag within a fault

t^n_{TD} : n^{th} sag duration within a fault (n=1...k)

t^1_{TD} : sag duration due to the no-reclosing

t^k_{TD} : sag duration due to the $(k-1)^{th}$ reclosing

The magnitude of voltage sag is related with fault current. For the radial distribution system in Fig. 1(a), it assume that the magnitude of voltage in neighbor feeders is almost equal to the distribution bus voltage. The magnitude of voltage sag is defined by the M_{VS} in (3). The M_{VS} is the percentage of voltage sag magnitude in faulted phase. The V^{fp}_{Bus} in (3) is the magnitude of bus voltage in faulted phase. When a fault occurs, the lowest one among the three phase voltages for each event is selected as the magnitude of voltage sag (M_{VS}) [2].

$$M_{VS} = (1 - |V^{fp}_{Bus}|) \times 100[\%] \quad (3)$$

3. Mitigation Method of Voltage Sag in Radial Power Distribution System

The proposed mitigation method in this paper is named load transfer switching (LTS) method. The LTS method is that the sensitive customer for voltage sag transfers to the alternative distribution source during the fault current exists. The LTS method is entirely carried by utilities side.

The proposed LTS method is composed of two parts as follows.

1) Search of weakness load point for voltage sag
2) Transfer behavior of weakness load points

3.1 Search of Weakness Load Points

In this paper, we use the risk assessment model of voltage sag as mentioned in [3] for the weakness points search of voltage sag. The final result of the assessment method is defined as system average voltage sag risk index (SAVSRI) as (4).

$$SAVSRI = \frac{\sum R_{VS}}{\text{Total No. of Customer}} \quad (4)$$

3.2 Transfer Behavior Mechanism

To explain the transfer behavior mechanism of proposed LTS method, we illustrate the Fig. 4. It is assumed that the sensitive customer of voltage sag is the customer 4 in feeder 2. The LTS method consists of following steps.

1) A fault occurs in feeder 1 of Fig. 1. The relay of CB_1 measures the fault current. And the switch controller in feeder 2 simultaneously measures voltage sag.
2) The switch controller in feeder 2 transmits the switching operation signal to S/W_1 and S/W_2.
3) The normal open switch S/W_2 closes and the normal close switch S/W_1 simultaneously opens in Time T_1. At this time, the clean power is supplied to the customer 4 from the feeder 3 in neighbor bank. The circuit breaker CB_2 trips in Time T_2.

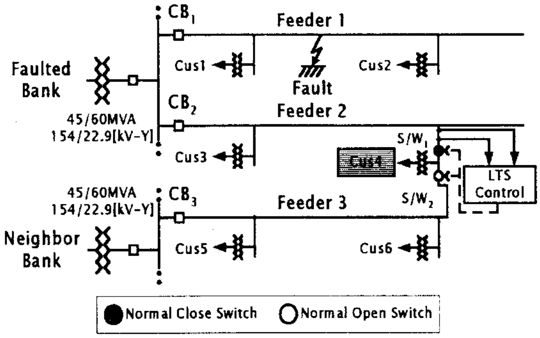

Fig. 1. Model radial distribution system applied the LTS

The high speed switching device is required for transfer behavior of LTS method as above mentioned. In these day, field application cases of high speed switching device is presented by several utilities. The static transfer switch (STS) and solid-state transfer switch (SSTS) [4] are most representative one. In this paper, the SSTS is selected as a switch device of proposed LTS method.

The principle configuration of SSTS is shown in Fig. 2.

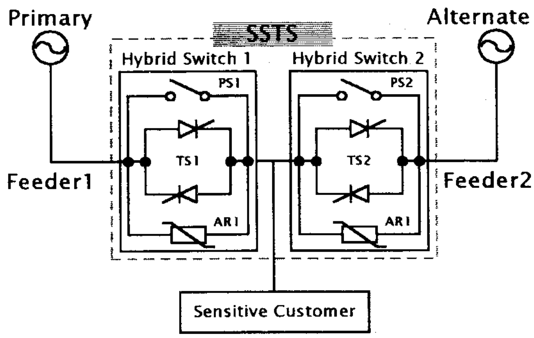

Fig. 2. Configuration of SSTS using the hybrid switch device

For the SSTS, a pair of hybrid switch devices are utilized for the LTS scheme. During normal operation, line current is by-passed by the parallel switch (PS1). When the transfer operation is required, PS1 is opened and TS1 is turned on, simultaneously. Upon sensing the voltage disturbances, the operation time of SSTS is made within 0.5[cycles].

4. Case Studies

4.1 Test System Model

The test system is the modified distribution bus 2 of RBTS (Roy Billinton Test System) [3].

4.2 Simulation Case

The case studies are composed of three parts as follows.

Case 1) Comparison of the SARFI with SAVSRI : The SARFI is proposed by R. C.

Dugan in 1998 and it is based on the frequency of voltage sag.

Table 1. Simulation results of case 1

Customer	SAVSRI	SARFI	Customer	SAVSRI	SARFI
Feeder1	0.0614	3.352	LP10	0.0359	2.715
Feeder2	0.1725	4.188	LP11	0.0359	2.715
Feeder3	0.0366	2.715	LP12	0.0359	2.715
Feeder4	0.0625	3.185	LP13	0.1509	2.715
LP1	0.0595	3.352	LP14	0.1509	2.715
LP2	0.0595	3.352	LP15	0.0554	2.715
LP3	0.0595	3.352	LP16	0.0933	3.185
LP4	0.3041	3.352	LP17	0.0606	3.185
LP5	0.3040	3.352	LP18	0.0606	3.185
LP6	0.0919	3.352	LP19	0.0606	3.185
LP7	0.0919	3.352	LP20	0.3067	3.185
LP8	0.1725	4.188	LP21	0.3068	3.185
LP9	0.1725	4.188	LP22	0.0933	3.185

Table 2. Simulation results of case 2

Customer	SAVSRI	SAVSRI Applied LTS	Customer	SAVSRI	SAVSRI Applied LTS
Feeder1	0.0614	0.0615	LP10	0.0359	0.0359
Feeder2	0.1725	0.0866	LP11	0.0359	0.0359
Feeder3	0.0366	0.0366	LP12	0.0359	0.0359
Feeder4	0.0625	0.0622	LP13	0.1509	0.1508
LP1	0.0595	0.0596	LP14	0.1509	0.1508
LP2	0.0595	0.0596	LP15	0.0554	0.0554
LP3	0.0595	0.0596	LP16	0.0933	0.0935
LP4	0.3041	0.3041	LP17	0.0606	0.0608
LP5	0.3040	0.3041	LP18	0.0606	0.0608
LP6	0.0919	0.0921	LP19	0.0606	0.0608
LP7	0.0919	0.0921	LP20	0.3067	0.3067
LP8	0.1725	0.1724	LP21	0.3068	0.0009
LP9	0.1725	0.0008	LP22	0.0933	0.0935

Table 3. Simulation results of case 3

Selected LTS Point	SAVSRI (for Whole System)	Percentage of Risk Reduction	Selected LTS Point	SAVSRI (for Whole System)	Percentage of Risk Reduction
LP1	0.0785	5.6529	LP12	0.0803	3.5051
LP2	0.0785	5.6811	LP13	0.0832	0.0651
LP3	0.0786	5.6311	LP14	0.0832	0.0601
LP4	0.0832	0.1070	LP15	0.0830	0.3325
LP5	0.0832	0.1070	LP16	0.0828	0.4849
LP6	0.0829	0.4777	LP17	0.0785	5.7066
LP7	0.0829	0.4195	LP18	0.0785	5.6965
LP8	0.0618	25.7775	LP19	0.0792	4.8305
LP9	0.0618	26.7402	LP20	0.0831	0.1351
LP10	0.0805	3.2605	LP21	0.0832	0.0768
LP11	0.0804	3.4234	LP22	0.0829	0.4770

Case 2) Comparison of the SAVSRI with SAVSRI applied the LTS method.
Case 3) Effectiveness comparison of the LTS method for each load points.

4.3 Simulation Results

The simulation results of Case 1 are shown in Table 1. From this result, we show that the SAVSRI is more adequate than SARFI for assessing the risk of voltage sag and the effect of mitigation method at load point.

The simulation results of Case 2 are shown in Table 2. Above of all, this result shows the dramatic risk reduction at the LP9 and LP21 which is applied the LTS method.

The simulation results of Case 3 are shown in Table 3. The SAVSRI of Table 6 represents the average value of entire system. The percentage of risk reduction shows the difference between the normal operation(not applied LTS) and the case that applied LTS for each load point. In Table 3, the dark areas show that the percentage of risk reduction is relatively large. The simulation results show that the LP8 and LP9 are most effective point of LTS for this system.

5. Conclusions

Through the case studies, we find the several results. First, the SAVSRI that is the index of proposed assessment model for voltage sag is more practically than SARFI that is the conventional index to assess the risk of voltage sag and mitigation method at load point, because the SAVSRI can reflect the difference risk of voltage sag due to the customer type. Second, the SAVSRI of load points are dramatically reduced in case of employing the proposed LTS method. And finally, the effective utilizing points of LTS method can be selected using the proposed assessment method. The proposed LTS method could be used to enhance the power quality of entire distribution system.

References

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