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3線-單接地配電線路의 信賴度改善을 위한 BEF 檢出 알고리즘

BEF Detection Algorithm to Improve Reliability of Three-Wire-Unigrounded Distribution Line

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ABSTRACT

The BEF on the radial distribution line refers to a class of ground faults in which the load-side power line only is grounded, with the distribution line broken into two parts, the source-side and the load-side. Because its mechanism is remarkably different from that of other earth faults, the fault current is very low, and then difficult to detect the BEF. Thus, it is necessary to analyze its properties and to find an appropriate method that can economically protect the BEF of nonautomation area in the substation.

As a result of analyzing the BEF data obtained by the RTDS, EMTP simulation, and the field test data of ETSA, we believe that it is the dominant factor in distinguishing the BEF from normal conditions by a criterion value that is appropriately handled from the zero-sequence current. Thus, with this criterion value, a BEF detecting algorithm is constructed which measures the variations of the zero-sequence current and processes then properly so as to make the fault decision. To prove the accuracy of this algorithm, it is compared with the field test data of ETSA under various conditions. The results show that the proposed algorithm is accurate.

국문요약

배전선로에서 지락사고가 발생할 경우 신속한 검출은 감전사고 예방, 전기화재 방지 및 전력설비의 최

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적 운용에 있어서 중요하다. BEF(Back-fed Earth Fault)는 일종의 배전선로 지락사고로 부하측이 지락되는 경우이며 지락전류가 매우 작기 때문에 전류 검출에 의하여 배전 계통을 보호하기는 어려우나 배전 자동화 지역에서는 UVR(Under Voltage Relay)을 이용하여 보호한다. 그러나 배전 자동화가 되지 않은 지역에서는 UVR에 의해 보호가 불가능하므로 BEF의 특성을 해석하여 경제적으로 BEF를 방지하여야 한다.

본 논문에서는 RTDS, EMTP 시뮬레이션, ETSA의 실증 시험 데이터를 비교, 검토하여 기준 영상전류치를 설정하고, 이를 적용하여 측정된 영상 전류와 설정된 기준치를 비교하여 3상-단일 접지 배전 시스템의 정상 상태와 BEF의 구분이 가능한 BEF 검출 알고리즘을 제안하였다. 다양한 조건에서 ETSA의 현장 시험에 적용하여 검토한 결과 3상-단일 접지 배전 시스템에서 제안된 BEF 검출 알고리즘의 타당성이 입증되었다. 따라서 본 알고리즘을 적용하여 배전선로를 운용하면 BEF에 의한 재해의 예방이 가능하리라 사료된다.

1. Introduction

In electric power systems, fault detection is one of the important factors for the prevention of electric shocks, the electric fires, and the damage of power system. Power systems have varieties, for example, the electric equipment applied, power suppling methods, electric loads, and other factors associated with them. Because of these facts and the randomness of fault occurrence, there are specific types of faults unsolved yet. Among them the BEF problem of the three wire unigrounded distribution system, which is found in Australia, and South Asia, is being studied in this paper. The backfed earth fault of this type distribution line is shown in Fig. 1.

This system is very advantageous for detecting the ground fault, because unbalanced current is not created. Even though the load is not balanced, unbalanced current is eliminated through the primary winding of pole transformers. But, when the BEF occurs, the fault currents to the earth pass through the primary winding of the load-side transformer. Thus, earth current becomes very small and depends on the contact condition of fault point, and the load of DTR2. It is, therefore, difficult to distinguish the fault current from normal current. These features of the BEF are different from other ground faults. In consequence, the existing protective relay systems hardly detect the BEF.

Detection schemes of zero sequence admittance were proposed two years ago[1]. However, this method has some problems of nonoperation and maloperation in some cases, due to slack contact point of ground fault, and noise components of normal voltage and current.

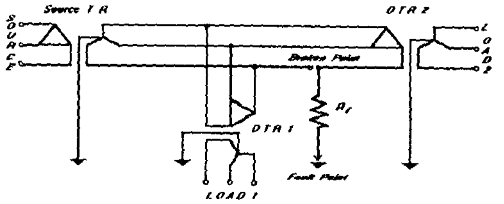


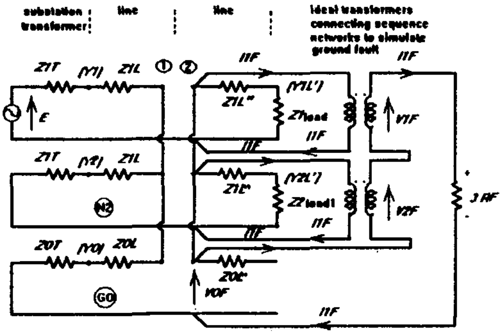
Fig. 1 BEF of uniground distribution system

In this paper, the advanced BEF detection algorithm using the expert system is presented. The fault condition of the system is compared with the nomal state value.

2. Theoretical Analysis of the BEF

In three wire uniground distribution systems (Fig. 1), the conventional protective relaying systems easily can detect the ground fault if the source-side line is grounded, with the distribution line broken. But, when the BEF occurs, the protective systems may no longer detect the fault because of small fault current; consequently, the reliability of the power systems goes down. To make clear the cause of such a phenomenon, the characteristics of the distribution systems when the BEF appears should be analyzed.

When the BEF arises, the downed line voltage is applied to the fault point via the primary windings of load-side transformer, and the circuits are reconstructed with the ungrounded systems due to the delta connection of the primary windings. In these cases, the fault current to the earth flows mostly less than pick up values (5Apeak) of the sensitive ground relay, and then the grounding arc occurs depending on the ground conditions. Therefore, the existing sensitive ground relay may not detect the BEF. Fig. 2 shows equivalent circuits using symmetrical components when the BEF occurs.



* NOTES :

$$Y1=\frac{1}{Z1T+Z1L}\quad Y1L'=\frac{1}{Z1L''+Z1_{load}}$$

$$Y0=\frac{1}{Z0T+Z0L}\quad Y2L'=\frac{1}{Z1L''+Z2_{load}}$$

Fig. 2 Symmetrical component networks, when the BEF occurs

At the fault point, the relation between voltage and current may be obtained by the symmetrical component method in Fig. 2, given as follows.

$V_{1F}+V_{2F}+V_{0F}-3R_FI_F=0$ ······················ (1)

$V_2+(V_2-V_{N2})+(V_2-V_{G0})-3R_FI_F=0$ ······· (2)

therefore,

$3V_2-V_{N2}-V_{G0}-3R_FI_F=0$ ······················ (3)

$(Y_1+Y_1+Y_0)V_1-Y_1V_{N2}-Y_0Y_{G0}=Y_1E_1$ ····· (4)

$(Y'_{1L}+Y'_{2L})V_2-Y'_{2L}V_{N2}+3I_F=0$ ··············· (5)

$-Y_1V_1-Y'_{2L}V_2+(Y_1+Y'_{2L})V_{N2}-I_{1F}=0$ ····· (6)

$-Y_0V_1-Y_0V_{G0}-I_{1F}=0$ ·························· (7)

where, V_1, V_2, V_{n2} and V_{G0} are the node voltages at ①, ②, N2 and G0 to the reference node, respectively. And replacing line constants and other data into the equations (3) to (7), fault current(I_F) is calculated less than 5A in most cases.

3. BEF Detection Algorithm

In three wire-uniground distribution systems under normal conditions, zero-sequence voltage is zero, and zero-sequence current also is zero, because each unbalanced phase current is compensated with other phase current due to the delta connection of primary windings of the load-side transformers.

When the BEF occurs, zero-sequence current appears, due to the feedback circuit to source through the earth as well as the increasing effect of load-side line voltage according to the downed conductor. This zero-sequence current can become a signal source to detect the BEF, but it may not be reliable because it is too small and cannot distinguish from the noise signal. Thus, we propose the advanced algorithm to detect the BEF by zero-sequence current and to decide the trip by which it is appropriately handled.

Flow chart of the BEF detection algorithm is shown in Fig. 3. The criterion function I_{0i} is com-

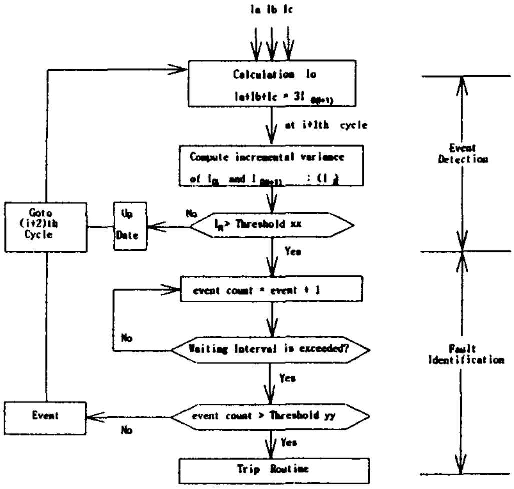


Fig. 3 Flow chart of the detection algorithm of BEF

puted in average values at each half cycle, and then the algorithm checks whether the event occurs. The event signal is generated if I_{0i} exceeds a threshold value, and the event number increase with the event occurrence for waiting interval. If the event number is counted for the waiting interval, and is larger than the threshold value, then the system recognizes when the BEF occurs. Otherwise, a simple event is confirmed, and the procedure is repeated.

4. RTDS and EMTP Simulation

〈Modelling〉

The model for the EMTP(Electro Magnetic Transient Program) simulation is shown in Fig. 4. This model has some merit because fault place is able to move easily on the distribution line, in proportion to the increase of DTR1 and DTR2 load.

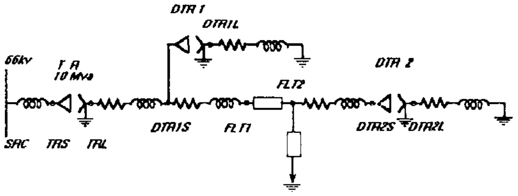


Fig. 4 Model for EMTP of BEF

▷Frequency : 50Hz

▷Source Impedance $Z_1=7.6448+j\ 19.63$

▷MTr(Main Transformer)

MVA : 10MVA %Z : 10.97

Voltage ratio : 66KV/6.35KV

▷Line Impedance(3Km) :

$Z_0=2.4282+j\ 4.5321$

$Z_1=1.1300+j\ 1.3020$

▷DTR(Pole Transformer)

KVA : 500KVA %Z : 8.2

voltage rating : 11KV/245V

$\cos\theta$: 0.9

This data is the real case value finding in the KEPCO power system.

〈Simulation scheme〉

EMTP simulations are performed on the conditions of balanced loads and unbalanced loads, as shown in Table 1. And the BEF type of fault modelled are one phase ground fault (one phase line opens at 0.2 sec and then load-side line only is grounded at o.3 sec, fault is eliminated at 0.31 s, again earthen at 0.32 s, not grounded at 0.34 s, and grounded at 0.36 sec continually as bouncing effects).

Table 1 Conditions of load modelling

Model No.	Type	DTR1	DTR2	Remarks
1	balance	full	full	A_Φ fault
2		full	50%	
3		50%	full	
4	unbalanc	no(C_Φ)	full	A_Φ fault
5		full	no(C_Φ)	
6		no(B_Φ)	no(C_Φ)	

〈Simulation Results〉

The simulation results with the models of Table 1 are as shown in Table 2. In this section, voltage, current waveform, and zero-sequence current of model No. 6 only are shown in Fig. 5, 6, 7 and 8, respectively because these models have the most severe conditions.

These are the EMTP simulation results. However, RTDS(Real Time Digital Simulator)'s is abbreviated, because it is very similar to EMTP's.

As shown in Table 2, variations of I_0 from model 1 to 6 (of the BEF) become significant. Therefore, it seems that the algorithm can be trusted to detect the BEF.

On the one hand, the variations of zero-sequence current according to that of the loads (of the DTR1 and DTR2 in Fig. 1), and the fault impedance(of the fault point) are examined. The results are as follows. The variations of zero-sequence current are insignificantly affected by the variations of DTR1 load and the fault impedance. On the other hand, the zero-sequence current varies with the load of the DTR2, as shown in Fig. 9. But the variations of the load will not damage the performance of the proposed algorithm, since the variations of zero-sequence current is sufficiently large to detect the BEF, even under the small load.

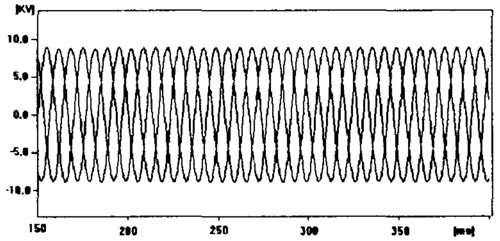


Fig. 5 Voltage waveforms of model 6

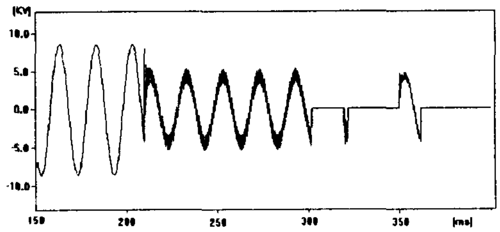


Fig. 6 Fault point voltage waveform of model 6 (FLT2A)

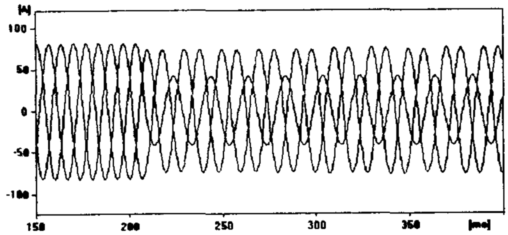


Fig. 7 Current waveforms of model 1

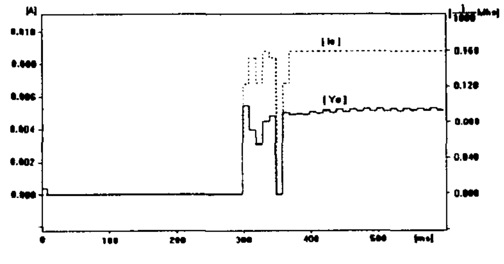


Fig. 8 Zero sequence current, and zero-sequence admittance of each half cycle of Model 1

Table 2 Analyzing results of EMTP simulations

Model No.	Fault Type	Amplitude on BEF		
		V_0[kV]	I_0[A]	Y_0[mho]
1	balance A_Φ Fault	0.009	0.0085	0.09E-3
2		0.10	0.0048	0.05E-3
3		0.11	0.0087	0.08E-3
4	unbalance A_Φ Fault	0.12	0.0087	0.08E-3
5		0.07	0.0082	0.12E-3
6		0.065	0.0084	0.13E-3

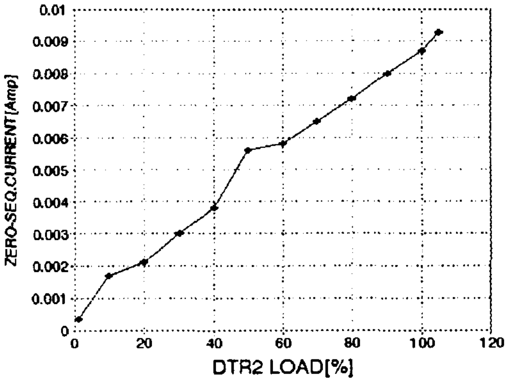


Fig. 9 Variations of zero-sequence current according to DTR2 load

5. Field Data Analysis

The power system to be field-tested is organized as shown in Fig. 10, where the ratings are as follows;

MTr : 3φ 66kV/11kV 10MVA, DTr2 : 3Φ 11kV/245kV 500kVA

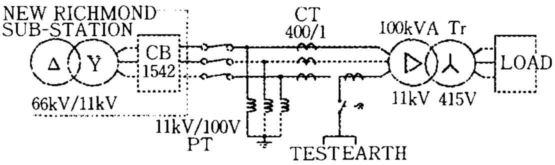


Fig. 10 Field test system of BEF

The field tests are performed under various conditions, as in Table 3, at the ETSA(Electricity Trust of South Australia) test center.

The field-test data are processed by the BEF detection algorithm proposed here, and the results are summarized in Table 3. In the typical case the variation of I_0 and Y_0 of the test No. 2 are shown in Fig. 11. The results are very similar to those of the EMTP simulations. But there are slight differences in that the variations of zero-sequence current are insignificant in tests 3, 4, and 5 in Table 3. These results are due to the measured phase currents having noise components, and thus it is difficult to distinguish the BEF from normal state, under the high impedance ground fault, more and more. But the proposed algorithm will, fortunately, never be applied in these cases, since the BEF rarely occurs under such special conditions.

Table 3 Analysis results of field test data(ETSA) of DTR2(3Φ)

Test No.	Model Type	Fault Case	Amplitude on BEF		
			V_0[kV]	I_0[A]	Y_0[mho]
1	106% load	balance A$_\Phi$ BEF (solid Earth)	0. 35	1. 70	5. 0E-3
2			0. 10	1. 70	16E-3
3	no load		noise signal		
4	106% load	balance A$_\Phi$ BEF (dry Bitumen)	noise signal		
5		balance A$_\Phi$ BEF (solid Earth)	niose signal		

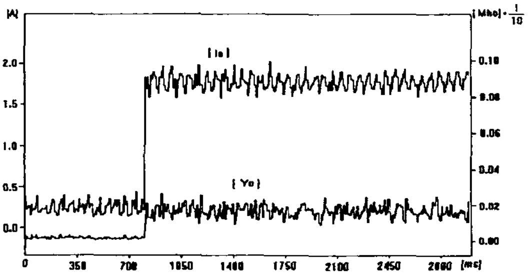


Fig. 11 Variation of zero-sequence admittance, zero-sequence current of test 2

6. Conclusions

This paper presents the advanced algorithm using an expert system for detecting the BEF in the three-wire unigrounded distribution systems. The BEF data obtained by the EMTP simulation and the field tests of ETSA are analyzed under various conditions. The results are as follows;

1) Variation of zero-sequence current is the most sensitive factor in detecting the BEF.
2) Variation of zero-sequence current depends on the change in loads of the load-side line transformer (DTR2 in Fig. 1). But this factor does not cause problems in detecting the BEF.
3) Variation of zero-sequence current is insignificantly influenced by the change in loads of the source-side line transformer (DTR1 in Fig. 1), and also by the change in fault impedance(of the fault point).

To prove the performance of the proposed algorithm, simulations are carried out with the RTDS output and the field-test data under various conditions.

4) The simulation results show robust performance, even in most cases. But we have to accept that the BEF has a lot of hard conditions, for example, high impedance faults or no loads of DTR
5) This BEF detection algorithm can be applied to prevent disaster, for example, electric shock, electric fires, damage of electric power system etc..

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