논 문
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태양광발전이 연계된 배전계통의 보호기기 오동작에 대한 최적 운용방안에 관한 연구

A Study on the Optimal Method for Mal-function of Re-closer at the Distribution Feeders Interconnected with PV Systems

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Abstract – Recently, new dispersed power sources such as photovoltaics, wind power, fuel cell etc. are energetically interconnected and operated in the distribution systems, as one of the national projects for alternative energy. This paper deals with the optimal countermeasures for the mal-function of protective devices at primary feeder in distribution systems when new power sources like photovoltaic (PV) systems are interconnected, based on the symmetrical components of short circuit studies. When new power sources are considered to be interconnected to distribution systems, bi-directional power flow and interconnection transformer connection of new power sources may cause the operation problems of protective devices (mainly re-closer), since new power sources can change typical characteristics of distribution systems. Therefore, this paper shows an analysis skill of the mal-functional mechanism of protective relay and proposes the optimal solution for the mal-function problem using the symmetrical components of fault analysis. And, this paper also shows the effectiveness of proposed method by the simulation at the field distribution systems.

Key Words : Protective devices, New energy sources, Protective coordination, Symmetrical components, Re-closer, MATLAB / SIMULINK

1. Introduction

As power systems have been deregulated and decentralized thanks to the technology development making small-sized generators more competitive and reliable, new power sources (NPS) such as photovoltaic cell, solar energy, fuel cell, wind power, energy storage, and etc. have been actively interconnected and operated in distribution systems. Moreover, since unstable oil price and environmental consciousness are strongly promoting higher penetration level of such renewable energy in these days, much more NPS are expected to be interconnected into distribution systems. In several countries, the protective coordination guidelines on the interconnection of NPS have been established and even special laws also have been enacted to promote the interconnection of NPS. However, the bi- directional power flow and interconnection transformer connection of NPS may cause the various operation problems of protective devices which are mainly re-closer, because NPS can change typical operation characteristics of protective coordination in distribution systems. The reverse power flow and connection type of NPS have severe impacts on typical distribution systems, for example power quality problems, protection coordination problems, and so on. Specially, it is frequently reported in the field systems that the protective devices (Re-closer) located at the un-faulted primary feeder are malfunctioned when a single line ground fault (SLG) is occurred at a primary feeder of same bank (Main Trans-former: M.Tr). The malfunction of protective device could result the severe damage of many customers like a several interruptions. Therefore, this paper proposes an analysis skill for the mal-functional mechanism of protective relay considering the abnormal operation characteristic of NPS and presents the countermeasure for the mal-function problem through the modeling and numeric calculation by using symmetrical components of fault analysis theoretically.

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2. Mal-functional Cases of Protection Device in Distribution Systems

Fig. 1 shows the configuration of "BUK-PYEONG" substation (154/22.9KV) of "DONG-HAE" branch,"KANG-REUNG" office, in Korea Electric Power Corporation (KEPCO). As shown in Fig. 1, 1MW Photovoltaic (PV) system is located at the "BUK-PYEONG" primary feeder, and the connection type of inter-connection transformer is Yground-Delta connection. Many cases of malfunction of Re-closer located at the un-faulted primary feeder are reported in the time when a single line grounded fault is occurred at the other primary feeders at the same bank. In other words, when a single line grounded fault by external contact, lighting arrestor (LA) damage and burn-out of transformer at "SAM-WHA", "DONG-SAM" and "EO-DAL" primary feeder is happened, Re-closer located at the "BUK-PYEONG "primary feeder, un-faulted primary feeder, is operated, so called, malfunctioned. So, many customers of the primary feeder suffer severe interruption problems.

Actually, it is reported that the OCGR (Over Current Ground Relay) of Re-closer at "BUK-PYEONG" is operated and the neutral current (N phase) was metered as 130 ~ 400A.

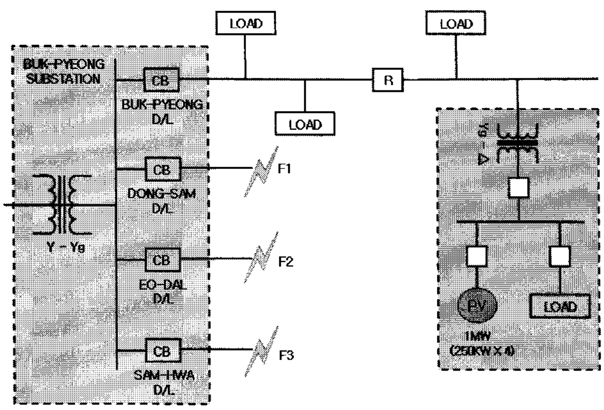


Fig. 1 Distribution system in "BUK-PYEONG" substation

3. Analysis for Mal-function of Protective Devices

3.1 Analysis based on the Symmetrical component method

3.1.1 Modeling for PV system and distribution systems

To make modeling for PV systems and distribution systems, the impedance configuration of field system shown as Fig. 1 and specification of main transformer in Table 1 are collected and arranged from the field sites. By using symmetrical components, the equivalent circuits of zero phase sequence impedance and positive /negative phase sequence impedance are presented in Fig. 2 and Fig. 3

Table 1 % Impedance Data of "BUKP-YEONG" Substation

Bank	% Impedance of Transformer				NGR (2nd)
	Z12 (45MVA)	Z23 (15MVA)	Z31 (15MVA)	Base	
#3	15.970	2.230	8.460	Self-capacitance	0.6Ω
	35.499	14.867	56.400	100MVA	11.14
	15.970	6.690	25.380	45MVA	
Line Connection	Y - Y - Delta				

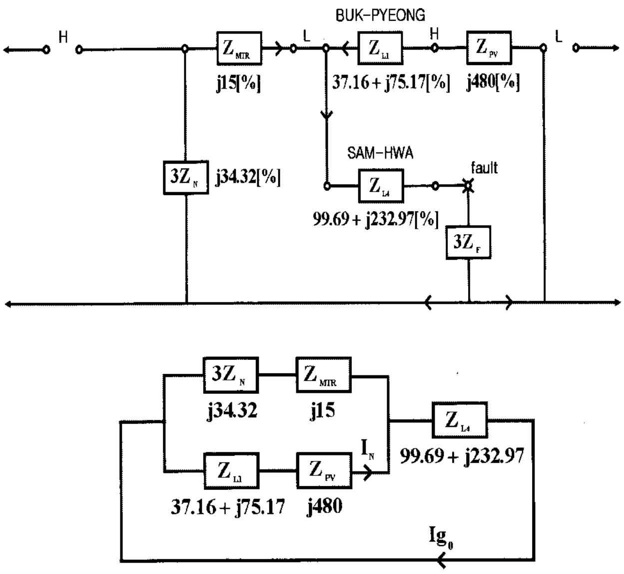


Fig. 2 Zero phase sequence component of equivalent circuit fdfd

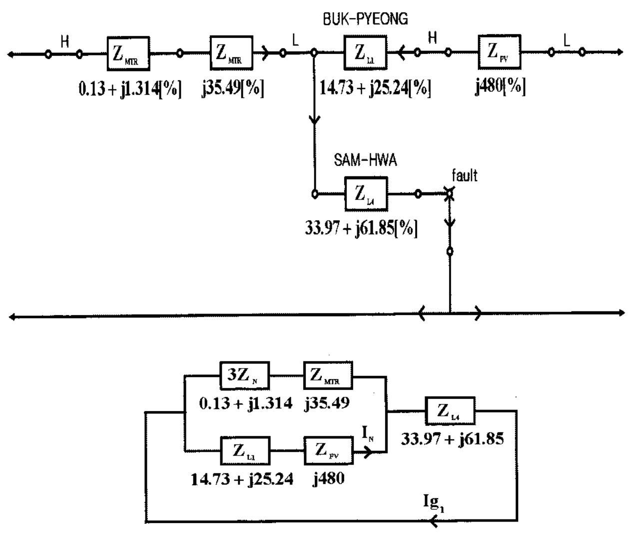


Fig. 3 Positive / negative phase sequence component of equivalent circuit

3.1.2 Analysis for mal-function of re-closer

Based on the above equivalent sequence circuit by using symmetrical methods, the single line fault (SLG) currents of each primary feeder at the same bank are acquired as following steps. Firstly, the zero phase sequence impedance at the faulted point of "SAM-HWA" primary feeder is obtained as :

$$Z_0 = j49.32 + (37.16 + j555.17) + (99.69 + j232.97)$$

$$= 296.68\angle 1.23\Omega$$

and the positive and negative phase sequence impedances are calculated as follows.

$$Z_1 = Z_2 = (0.13 + j36.804)//(14.73 + 505.24)$$

$$+ (33.97 + j61.85)$$

$$= 102.04\angle 1.23\Omega$$

Thus, SLG current at the faulted point is

$$I_g = \frac{3\times 100}{Z_1 + Z_2 + Z_0 + Z_{3F}} \times \frac{100{,}000}{\sqrt{3}\times 22.9}$$

$$= \frac{3\times 100}{2(102.04\angle 1.23) + 295.98\angle 1.23} \times \frac{100{,}000}{\sqrt{3}\times 22.9}$$

$$= 1{,}513.43\angle -1.23A$$

and also the SLG current (neutral line current) at the unfaulted primary feeder of "BUK-PYEONG" which is interconnected 1MW PV systems, can be obtained by using current divider theory as follows.

Namely, the SLG current on neutral line of "BUK-PYEONG" primary feeder can be calculated as about 123A to 493A depending on the position of grounding fault at the faulted feeder of "SAM-HWA". Thus, the possibility of malfunction of re-closer located at "BUK-PYEONG" primary feeder can be checked, because N phase OCGR of re-closer is normally set to 70A less than the SLG current on neutral line. It was confirmed that this was not due to the influence of fault current supplied by photovoltaic systems, which is about 30A which is about 1.5 times of maximum rated current, but due to connection type of interconnection transformer of NPS. This paper shows that protective device (OCGR) is malfunctioned by grounding current on N phase flowing through the zero phase sequence path supplied by Yground-Delta connection of the transformer of NPS.

3.2 Analysis based on the MATLAB / SIMULINK

Main Transformer (154/22.9KV) of "BUK-PYEONG" substation and the modeling based on the MATLAB / SIMULINK is represented in Fig. 4. Fig. 5 shows the % impedance data of several primary feeders and the modeling is represented in Fig. 5. And also, Fig. 6 describes the modeling of PV system through inverter using the MATLAB / SIMULINK

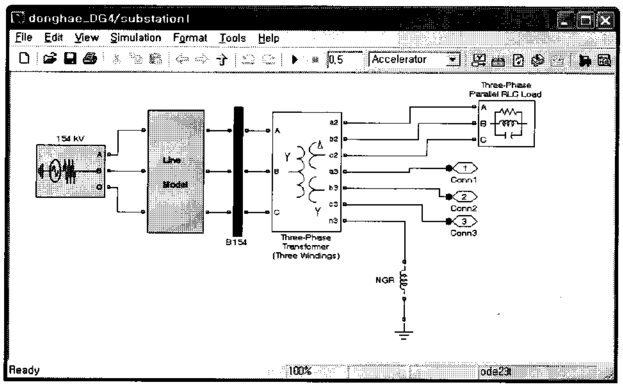


Fig. 4 Modeling for Main Tr. in "BUK-PYEONG" substation using MATLAB / SIMULINK

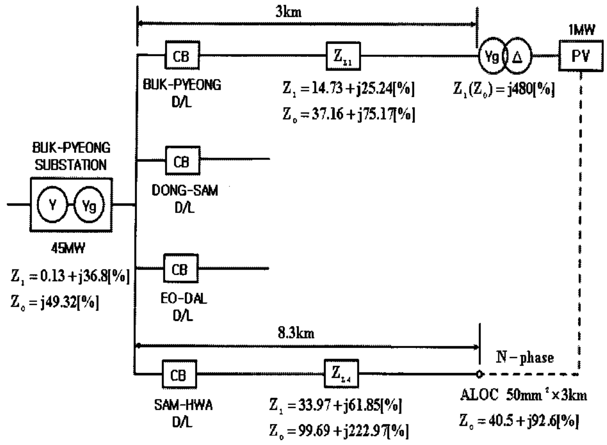


Fig. 5 % Impedance data of distribution systems

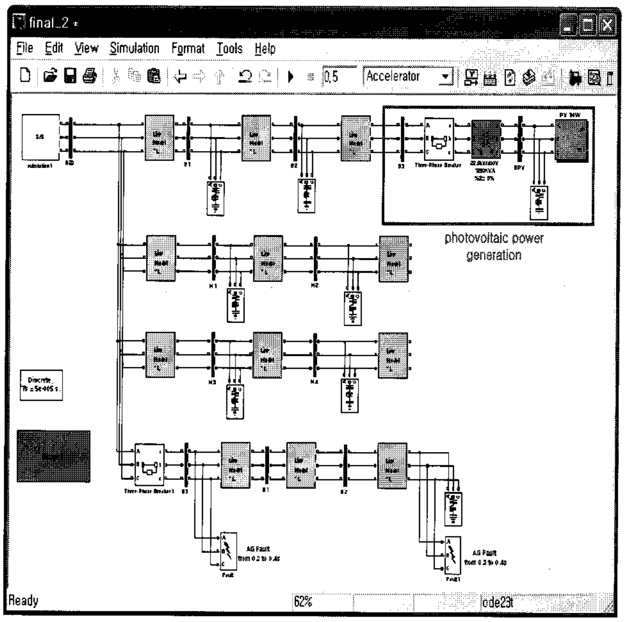


Fig. 6 Modeling for distribution system using MATLAB / SIMULINK

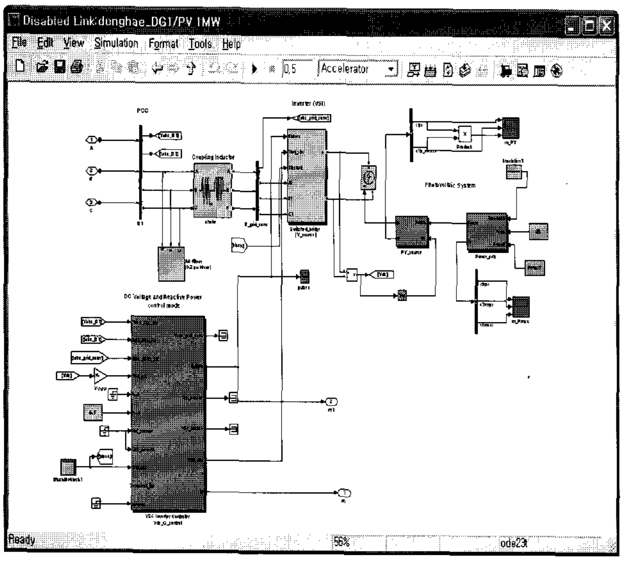


Fig. 7 Modeling for PV systems MATLAB / SIMULINK

4. Countermeasure to improve the malfunction of Protection Devices

4.1 Countermeasure by the symmetrical

As eliminating the zero phase sequence current path of interconnection transformer is the best method for malfunction of protective device, this paper presents the method to reduce fault current of neutral line at the unfaulted primary feeder under 70A by inserting proper neutral grounding resistance (NGR) to connection line of the transformer. Namely, it is supposed that NGR of 100 Ω(300×19.1%) is inserted to neutral line by changing connection type of the transformer from Y-ground-delta to Y-high resistance ground-Delta connection. By considering this concept, the equivalent circuit of zero phase sequence impedance and positive/negative sequence impedance are described as Fig. 8 and Fig. 9.

Thus, the SLG current (neutral line current) at the unfaulted primary feeder of "BUK-PYEONG" can be obtained by the equivalent circuit.

$$I_N = \frac{j49.32}{(5767.16 + j555.17) + j49.32} \times 1{,}502.04\angle -1.23$$

$$= 12.68\angle 0.25A$$

Namely, it is found that if Y-high resistance grounding - delta connection type is applied, the malfunction of protective device (re-closer) can be prevented by remarkably reducing the ground fault current of neutral line as only 13A. This paper shows that the inserting NGR to interconnection transformer is one of the effective counter -measures.

4.2 Countermeasure by the MATLAB/SIMULINK

4.2.1 Simulation analysis without PV system

Fig. 10 shows the simulation results for a single grounded fault, in the case where 1MW PV system is not interconnected with "BUK-PYEONG" primary feeder. This paper assumes that a single grounded fault occurs at 0.2s and the duration time is 0.2s, by the modeling based on the MATLAB / SIMULINK. The results show that the fault current (zero sequence current) at the "BUK-PYEONG" primary feeder is only around 12A, so the re-closer located at the feeder is not operated (malfunctioned) because the OCGR setting value of the re-closer is set as 70A

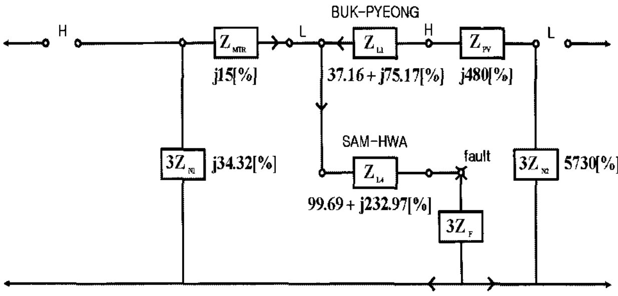


Fig. 8 Zero phase sequence component of equivalent circuit

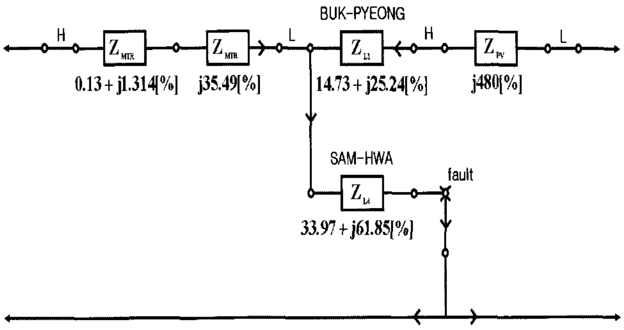


Fig. 9 Positive / negative phase sequence component of equivalent circuit

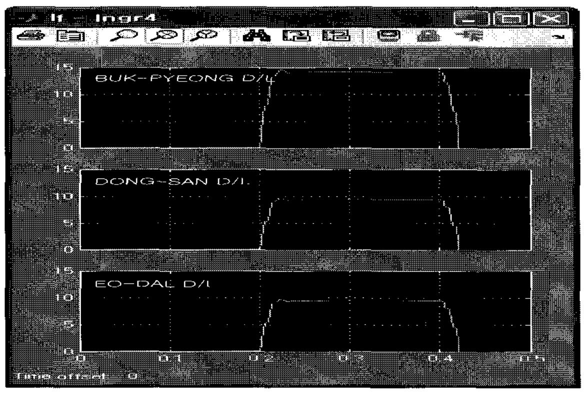
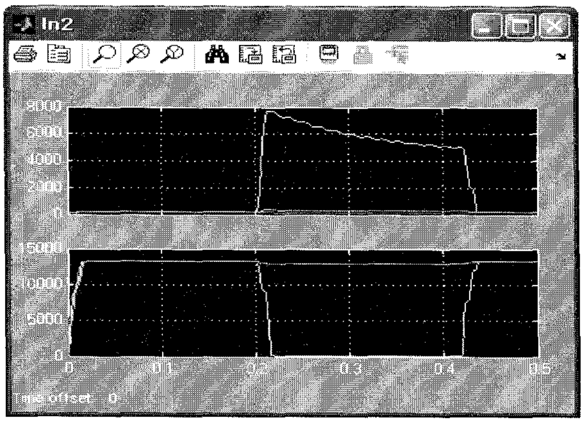


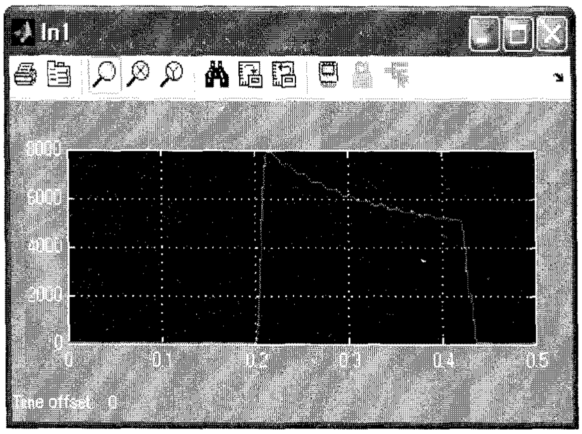
Fig. 10 Single grounded fault currents for primary feeders without PV system

4.2.2 Simulation analysis with PV system

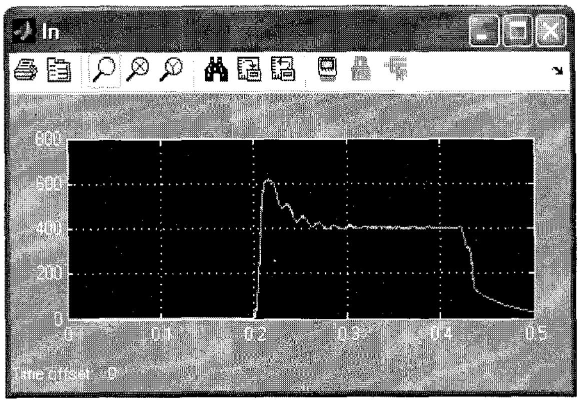
This paper considers two simulation cases for the fault locations. One is a sending point near the substation, the other is a ending point of last customer. In the Fig. 6, the sending point and ending point on "SAM-WHA" primary feeder is considered as the locations of single grounded fault. Fig. 11 shows the simulation results for a single grounded fault of "SAM-WHA" primary feeder, in the case where 1MW PV system is interconnected with "BUK-PYEONG" primary feeder at the same bank. This paper assumes that a single grounded fault occurs at 0.2s and the duration time is 0.2s by modeling based on the MATLAB / SIMULINK. The results show that the fault current(zero sequence current) at the "BUK-PYEONG" primary feeder is around 160A to 400A, depending on the fault location, sending point and ending point. The simulation shows that the re-closer located at "BUK-PYEONG" primary feeder can be operated (malfunctioned) because the fault current exceeds the OCGR setting value of the re-closer (70A). Therefore, we confirm that interconnection with PV system can cause the problems for the malfunction of re-closer.



(a) Bus Current and Voltage of "BUK-PYEONG" substation



(b) Single Grounded fault current of "SAM-WHA" feeder



(c) Single Grounded fault current of "BUK-PYEONG" feeder.

Fig. 11 Single grounded fault currents for primary feeders with PV system

4.3 Countermeasure for re-closer mal-function

The simulation results show that the fault current (zero sequence current) at the "BUK-PYEONG" primary feeder is around 160A to 400A, in the case where 1MW PV system is interconnected with "BUK-PYEONG" primary feeder. The fault current of PV system actually can be provided as small as 1.5 times of a rated current (about 32A). So, the simulation results present that the Y-grounded-delta connection type of interconnecting transformer offers a passage of zero sequence current.

To solve this problem, this paper assumes that the path of zero sequence current is removed by changing Y-grounded-delta connection of the transformer into Y-ungrounded-delta connection. The results for the countermeasure show that the fault current (zero sequence current) at the "BUK-PYEONG" primary feeder is only around 10 - 15A, so the re-closer located at the feeder is not operated (malfunctioned) because the fault current is not reached to OCGR setting value of the re-closer(70A).

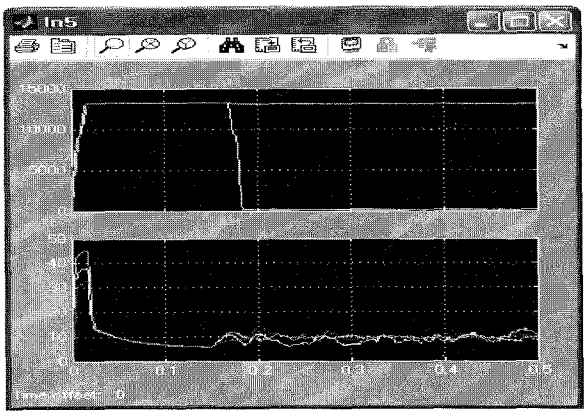


Fig. 12 Single grounded fault currents of "BUK-PYEONG" primary feeder for Y-ungrounded-delta connection of interconnection transformer

5. Conclusion

This paper proposes the mechanism of malfunctional problem of protective devices and the countermeasure for the problem by using the symmetrical component method and MATLAB/ SIMULINK. The results are summarized as follows.

(1) It is confirmed that if ground fault occurs in other primary feeder of same bank in the distribution substation, very high ground fault current flows in the neutral line(N phase) of unfaulted primary feeder which is interconnected with NPS, thereby causing OCGR of the feeder to result in malfunction.

(2) It is confirmed that the fault current flowing on the neutral line is not affected by fault current by NPS, but by zero phase sequence current path of interconnection transformer of NPS.

(3) This paper shows that protective device (OCGR) is malfunctioned by grounding current on N phase flowing through the zero phase sequence path supplied by Yground-Delta connection of the transformer of NPS.

(4) It is found that if Y-high resistance grounding-Delta connection type is applied, the malfunction of protective device (re-closer) can be prevented by remarkably reducing the ground fault current of neutral line. It was confirmed that the inserting NGR to interconnection transformer is one of the effective countermeasures.

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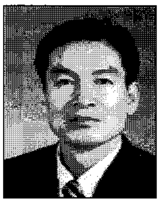

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