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전력용변압기 단선 보호용 NGR 성능 개선

The Improvement of NGR for Power Transformer Open Circuit Protection

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Abstract - As the electric system is getting larger to meet the increasing demand for electric power, the rating of power apparatus is becoming inevitably higher in its working voltage and larger in its capacity. According to KEPCO reports, power transformers in the KEPCO system have undergone troubles such as winding short insulation breakdowns every year since 1981. the cause of this troubles were high one line grounding fault currents in KEPCO systems that had direct grounding systems. KEPCO has installed the NGR(neutral grounding reactor) to lower this fault current and reduced winding short insulation breakdowns in power transformers. But when a circuit breaker opened a no load bus, some trips of circuit breakers for protecting transformer have occurred by mal-operation of 59GT(overvoltage ground relay) that detect disconnection of NGR. Therefore, in this paper, we analyzed the cause and examined the effect of time delay circuit to prevent wrong operation of 59GT.

Key Words : NGR(Neutral Grounding Reactor), 59GT(Overvoltage Ground Relay), Power Transformer

1. Introduction

High fault current flowed into 154/23 kV transformers when one line-to-ground fault occurred in KEPCO's power system because the system was the direct grounding system. In order to reduce transformer's faults such as winding short insulation, the NGR has been installed between transformer neutral point and ground.

If NGR is disconnected and one line-to-ground fault occurs, then there are line-to-line voltages on un-faulted lines to cause insulation problems on utilities and loads.

Therefore, 59GT has been used to watch disconnection of NGR in KEPCO but some trips of circuit breaker for protecting transformer have occured by wrong operations of 59GT, when circuit breaker opened only no load and line charged bus.

In this paper, we analyzed the cause by EMTP(Electro-magnetic transient program). And we also examined the effect of time delay circuit to prevent wrong operations of 59GT.

2. The ratings of NGR in KEPCO

Each phase of a distribution system has capacitance to ground. Although a system may be ungrounded in that none of its current-carrying conductors are intentionally connected to ground, an ungrounded system has its neutral point established by distributed system capacitance as shown in Fig. 1. If capacitive reactance is balanced, the voltages and currents are balanced as shown in Fig. 2 (a). If phase A is faulted to ground, voltage and current to ground in phases B and C increase in magnitude by 1.73 as shown in Fig. 2 (b). Fault current I_F is defined as the system charging current and its magnitude is three times the magnitude of the unfaulted phase-to-ground current.

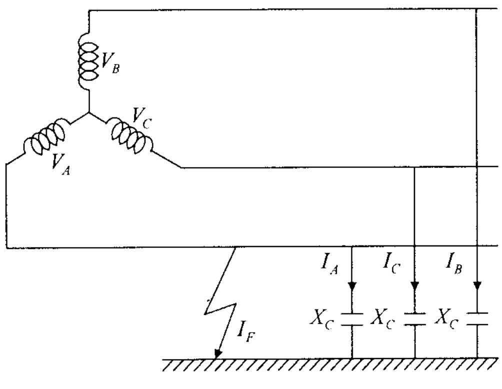
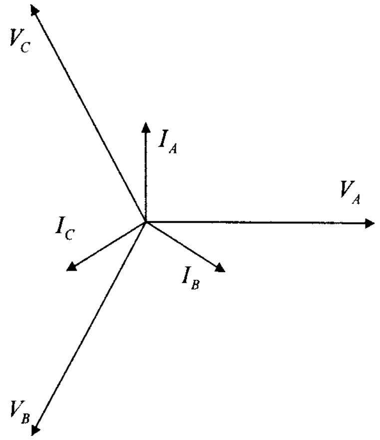
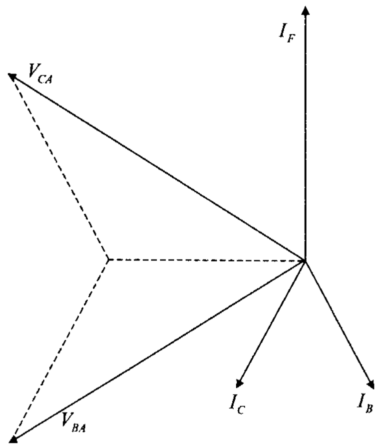


Fig. 1. Ungrounded system

When one phase-to-ground fault occur in ungrounded system, unfaulted phases must stand insulation of line-to-line voltage.



(a) Unfaulted



(b) Phase A faulted

Fig. 2. Phasor diagram in ungrounded system

Although one phase-to-ground fault occur in direct grounded system, unfaulted phases's voltages are equal to phase-to-ground voltage. Therefore, KEPCO adapted the direct grounded system for this advantage as shown in Fig. 3. But this system have disadvantage that transformer is shocked by high fault current I_N that flows through transformer's neutral point at one phase-to-ground fault as shown in Fig. 4. According to KEPCO reports it is shown that about 15 of 570 power transformers in the KEPCO system have undergone troubles such as winding shortss insulation breakdowns and ULTC faults every year since 1981.

To reduce this high failure rate(approx. 3%), KEPCO studied to insert the resistor or reactor between the MV neutral of the HV/MV transformer and the ground of the substation and determined to use reactor for limiting fault current into transformer.

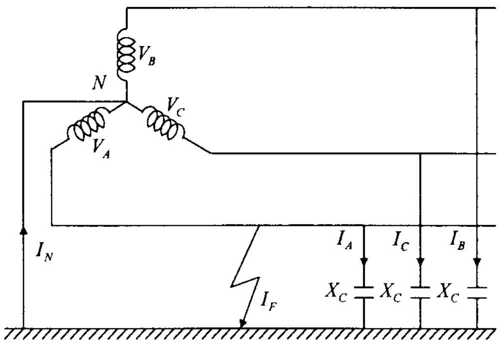
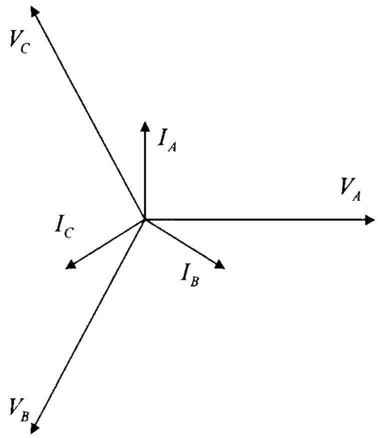
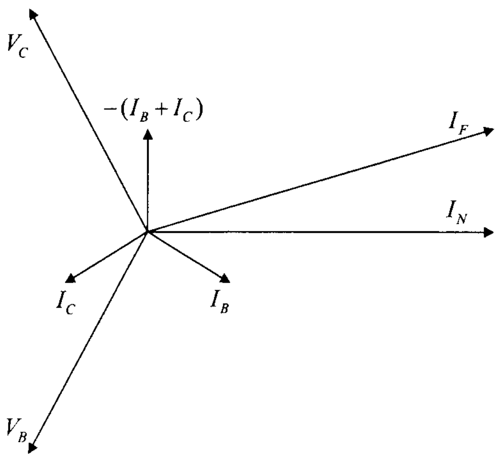


Fig. 3. Direct grounded system



(a) Unfaulted



(b) Phase A faulted

Fig. 4. Phasor diagram in direct grounded system

There are two kinds of neutral grounding by a resistor. The one is neutral grounding by a high resistor the other is neutral grounding by a low resistor. The neutral grounding by a high resistor lower the fault current in transformer but should maintain the insulation level of phase-to-phase voltage. The neutral grounding by a low resistor lower the insulation level less than phase-to-phase voltage but system has losses by the unbalanced current. And if one phase-to-ground fault occur in this system, one phase power consume too much to make transient stability unfavorable.

There are three kinds of neutral grounding by a reactor. Fig. 5 shows the neutral grounding by a reactor. The neutral grounding by a high reactor lower the fault current in transformer but should withstand the insulation level of phase-to-phase voltage as the neutral grounding by a high resistor. When this system is connected to long distribution line, the system have very high transient voltage at one phase-to-ground fault.

The neutral grounding by a petersen coil is very effective way in the neutral grounding by a petersen coil. If phase A is faulted to ground in this system, charging current I_g of fault point is

$$I_G = I_B + I_C = 3X_C V \qquad \text{---------------(1)}$$

And the current I_L of flowing peterson coil L is

$$I_L = \frac{V}{wL} \qquad \text{---------------(2)}$$

This system choose the value of L to become I_L equal to I_G. If I_L is equal to I_G, fault current I_F will be near zero. But the problems of this system are also to withstand the insulation level of phase-to-phase voltage and are difficult to adjust the value of L that make I_L equal to I_G as shown in Fig. 6.

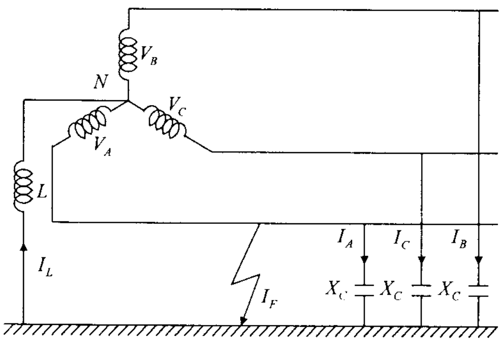
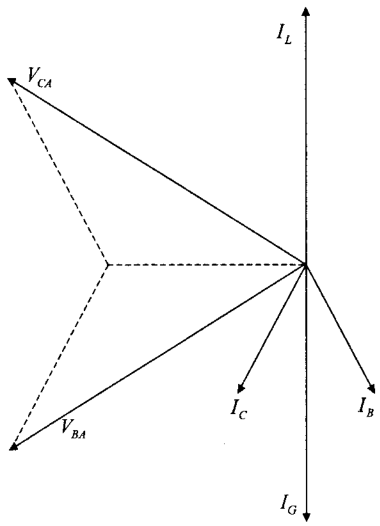
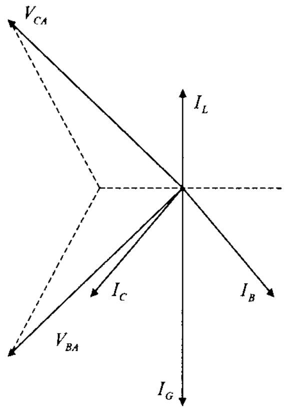


Fig. 5. Neutral grounded system by a reactor



(a) Neutral grounding by a petersen coil



(b) Neutral grounding by a low reactor

Fig. 6. Phasor diagram of phase A faulted

The neutral grounding by a low reactor can make the unfaulted phase voltage much lower than phase-to-phase voltage and it makes the current of transformer's neutral point lower than that in direct grounded system when one phase-to-ground fault occur as shown in Fig. 6.

Therefore KEPCO adapted this system to reduced the transformer trouble. The value of reactor L is determined to make one phase-to-ground fault current equal to 85% of three phase-to-ground fault current like equation (3). The value is about 6 ohms.

$$L = \frac{2X_1 - X_0 - X_2}{3} \qquad \text{---------------(3)}$$

where X_0 : Zero Sequence Impedance

X_1 : Positive Sequence Impedance

X_2 : Negative Sequence Impedance

3. Detection of NGR Disconnection

To reduce this high failure rate(approx. 3%), KEPCO have inserted low reactor between the MV neutral of the HV/MV transformer and the ground of the substation and faults of transformer have decreased since 1993.

Here, if NGR is open, the system becomes ungrounded system. At that time, If one phase is faulted to ground, voltages to ground in the other phases increase in magnitude by 1.73. Therefore KEPCO have used 59GT to detect disconnection of NGR as shown in Fig. 7.

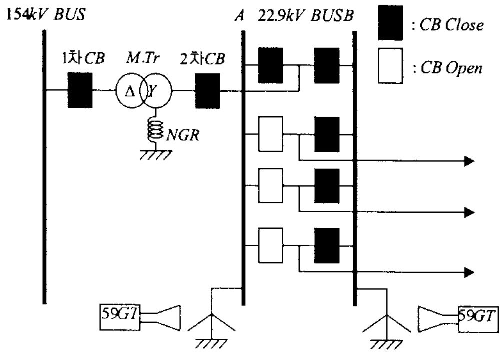


Fig. 7. Detection of disconnection of NGR by 59GT

59GT is connected the second side of 22.9kV PT(potential transformer, Y/open delta, 13.2kV/63.5V) that detect bus voltage. The input of 59GT is

$$E_{PT} = E_A + E_B + E_C \qquad \text{---------------(4)}$$

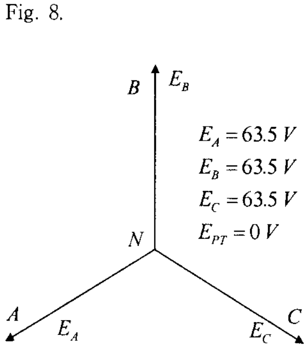
where E_{PT} : Input of 59GT

E_A : A phase voltage of 22.9kV bus $\times \frac{63.5\,V}{13.2k\,V}$

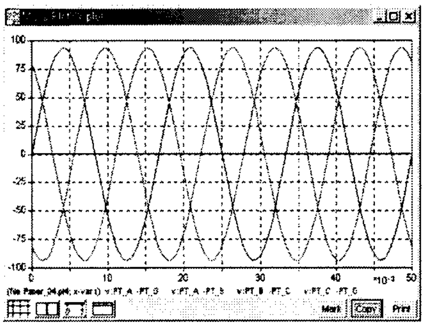
E_B : B phase voltage of 22.9kV bus $\times \frac{63.5\,V}{13.2k\,V}$

E_C : C phase voltage of 22.9kV bus $\times \frac{63.5\,V}{13.2k\,V}$

If system is balanced and unfaulted, E_{PT} becomes zero as shown in Fig. 8.



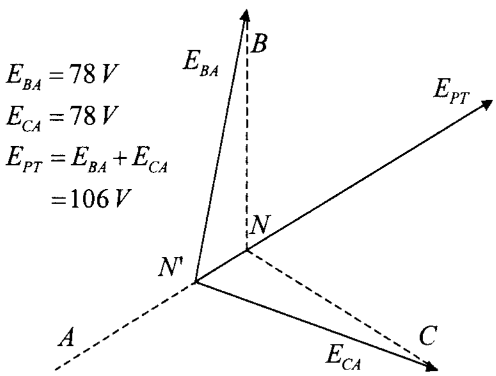
(a) Phasor diagram



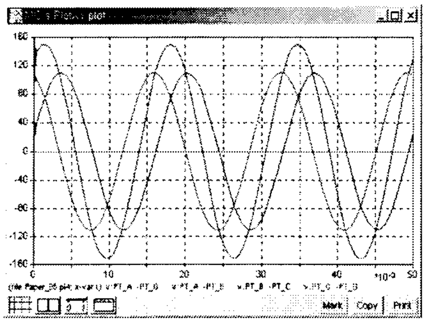
(b) Simulation result by EMTP

Fig. 8. E_{PT} voltage at unfaulted condition

If phase A is faulted to ground, voltage of ground point move to N′ from N and voltages to ground in phases B and C increase a little in magnitude comparing to 1.73 times in ungrounded system as shown in Fig. 9.



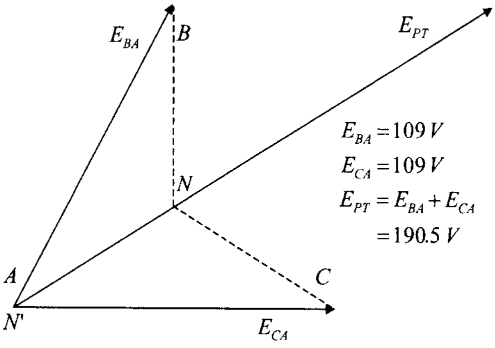
(a) Phasor diagram



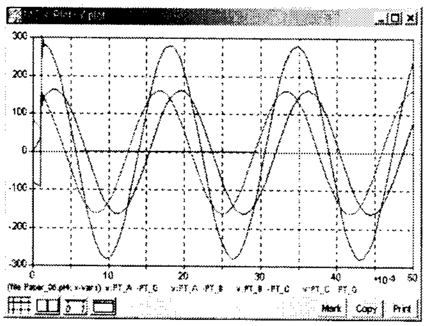
(b) Simulation result by EMTP

Fig. 9. E_{PT} voltage at one phase-to-ground fault

If phase A is faulted to ground in disconnection state of NGR, voltage of ground point move to N′ from N and voltages to ground in phases B and C increase in magnitude by 1.73 times like ungrounded system as shown in Fig. 10.



(a) Phasor diagram



(b) Simulation result by EMTP

Fig. 10. E_{PT} voltage at one phase-to-ground fault in disconnection state of NGR

In one phase-to-ground fault, we know that E_{PT}, the input voltage of 59GT is about 106 V at connected NGR and 190 V at disconnected NGR. The 190 V of E_{PT} is the value when ground fault resistance is zero in one phase-to-ground fault and NGR is open. If ground fault resistance is higher than zero, E_{PT} voltage is lower than 190 V.

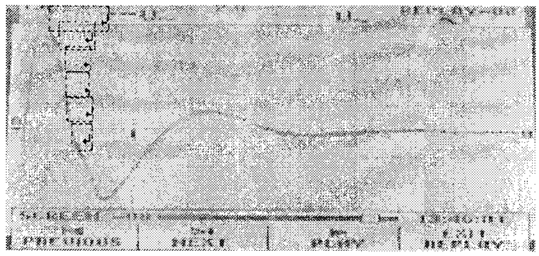
When ground fault resistance is assumed 50 ohm with that condition, E_{PT} voltage is above 120 V in KEPCO system as the result of EMTP simulation. Therefore transformer is tripped to prevent the overvoltage on system and load when 59GT detect above 120 V

4. Mal-operation of 59GT

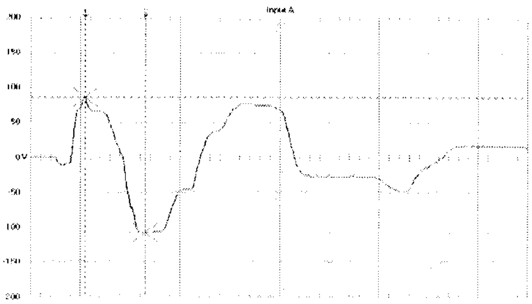
KEPCO has operated two buses of the second side of 154/23 kV transformer with section breakers for the purpose of parallel and load shedding. For regular examination of circuit breaker, one bus provide power to all load and the other bus is charged only without load as shown in Fig. 7.

At that condition, when a section breaker opened charged bus without load, 59GT made mal-operation to trip transformer.

In this chapter, we analyzed the cause of it with EMTP. After mal-operations, input voltages of 59GT were measured at the same conditions that a section breaker opened charged bus without load as shown in Fig. 11. But the voltages were below 120 V that couldn't operate 59GT.



(a) Input voltage of 59GT in M sbustation



(b) Input voltage of 59GT in Y sbustation

Fig. 11. Voltage at opening no load bus

When circuit breaker is opened and closed, it has discrepancy time among phases as shown in Table 1. The input voltage of 59GT appear different according to the discrepancy time and open angle of phase voltage of 22.9 kV bus. In the case of the first operation of section breaker open, discrepancy time maybe is longer than standard time because circuit breaker is closed for a long time in the state of current flowing that maybe make the contacts of circuit breaker strong by Joule's heat.

Table 1. Discrepancy time (Below 72.5 kV, KEPCO)

Classify	Time
3 phase open discrepancy time	Below 1/6 cycle
3 phase close discrepancy time	Below 1/4 cycle

In this paper, it is assumed that discrepancy times are 2.8, 10, 20msec and bus one phase-to-ground capacitance is 3.5μF for simulation of input voltage of 59GT by EMTP, when a section breaker opened charged bus without load. The result is shown in Fig. 12.

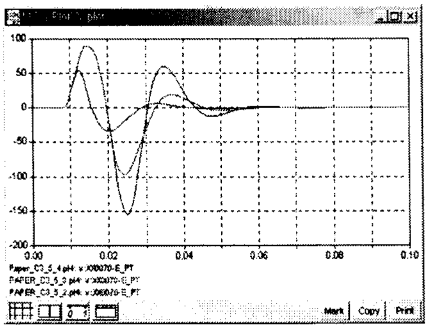


Fig. 12. Input voltages of 59GT by discrepancy times

When discrepancy time is 2.8msec, the input voltage of 59GT becomes about 50V. If discrepancy time become longer than 2.8msec, input voltage of 59GT is higher. As it is known in Fig. 12, when discrepancy time is 20msec, the voltage become above 150V that can operate 59GT sufficiently.

5. Improvement of 59GT

Transformer was tripped several times by mal-operation of 59GT, when a section breaker opened charged bus without load. Therefore 59GT was improved in order to delay operating time by adding R and C. The improved circuit of 59GT is shown in Fig. 13. In 59GT, the input voltage is rectified by diodes and then time for operating excitation coil is delayed by R-C time constant until the voltage of the coil becomes 24V.

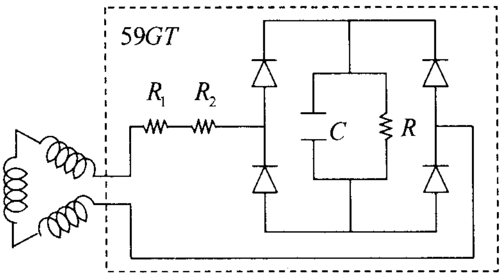


Fig. 13. Improved circuit of 59GT

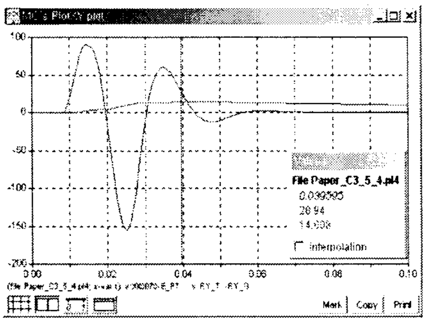


Fig. 14. Example waveform with time delay circuit

6. Conclusion

The mal-operation of NGR can be improved by adding R and C time delay circuit of NGR. The effect of time delay was proved by the EMTP simulation.

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