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Prevention of Cascading Failure in Electrical Protection Power System of Nuclear Power Plants.

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1. 1. Introduction

Major blackouts in nuclear power generation stations are rare events, but their impact can be catastrophic. Cascading failure is the main cause of large blackouts for all kinds of generating stations, cascading failure always occurs with initiating events. [1] One of the important devices of the electrical protection and control system is input device such as current transformers and voltage transformers. [2] Current transformer plays a vital role to guarantee the reliability and security of the protection system, as a critical component in a protection system, it must ensure correct relay operation (dependability) and prevent errors in operation (security). It should also ensure that the monitoring and measurement of current quantities are as expected. [3]

In this regard, this paper proposed the system configuration of the ECT and IEC 61850 based electrical protection and control system for nuclear power plants to resolve the challenges of how to prevent the cascading failure from propagating in the nuclear power generating stations by preventing the initiating event of the failure of the electrical protection system and to improve the performance of nuclear power plant electrical protection and control systems.

1.1 Cascading failure in nuclear power plants

Cascading failure is “a defect that will cause a relay or a relay system to incorrectly and inappropriately remove a circuit element(s) as a direct consequence of another commencing event. The most distinctive and fatal characteristic of cascading failures is the evidence that their consequences appear when the power system is under emergent conditions, such as during or instantly after faults occur, under-voltages, overloads, or as a consequence of another switching actions. [2]

2. Investigation of Loss of Offsite Power(LOOP) at a Nuclear Power Plant

In 6th of March, 2018 during normal operation of the Hanbit Unit (2) the emergency diesel generator (EDG) automatically start up by the low voltage signal generated by the 4.16 kV safety bus. The non-safety bus (NB-S02) is supplied with power from the on-site auxiliary transformer (UAT#1) and from the start-up transformer (SUT#2) when the normal power is lost. In the process of replacing the central chiller, which is the load of the non-safety bus, the stop light signal of the on-site control panel was turned on so that the operator judged that the central chiller was stopped. In reality, however, the central chiller circuit breaker was not opened and the central chiller compressor continued to supply power, only the central chiller compressor lubrication pump was stopped. As the compressor continues to operate with the lubrication function stopped, the bearing temperature rises, resulting in motor winding disconnection (phase B) and ground fault (A, C phase) (see fig.1).

2.1 Sequential incident propagation process

In the process of stopping the central chiller (GB-Z050), one breaker (NB-S02 -18) has been expanded to the Loss of Offsite Power (LOOP).① the breaker did not open due to short-term malfunction. At this time, the central chiller was still running. ② the lubrication pump stopped and caused the motor to overheat. In this state, the power supply breaker (NB-S02-01) was operated and the circuit breaker tripped. ③ the operator mistakenly identified the cause of the failure and he tried to restore the loss of voltage by switching to the alternate power source. ④ the ground fault relay of the (NB-S02-03) breaker also operated and the breaker was tripped. ⑤ the operator attempted twice manually switching to the alternate power source to recover the low voltage of the 4.16 kV non-safety bus without the cause of the fault being resolved on the non-safety bus (NB-S02).

Due to the propagation of fault a ground fault has occurred in a non-safety busload, the startup transformer main relay (86-Lockout Relay) was activated and an attempt is made to recover the loss of power as mentioned above. At this time, the ground fault relay (51N) of the startup transformer (SUT 2) was operated and the switchyard breakers (PCB-7F00) and (7F71) were opened, and the safety bus (PB-S02) also lost power. Subsequently, the (PB-S02) low-voltage relay checked the voltage loss and the emergency diesel generator 'B' was automatically started to supply power to the safety bus (see fig 1). So, the breakdown of the high-voltage circuit breaker was extended in a chain leading to loss of offsite power (LOOP) event.

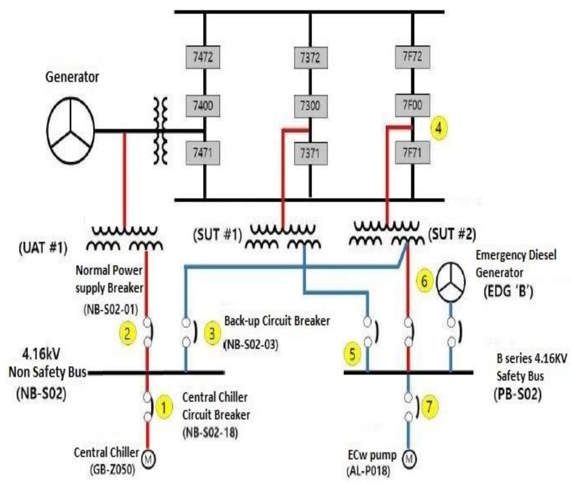
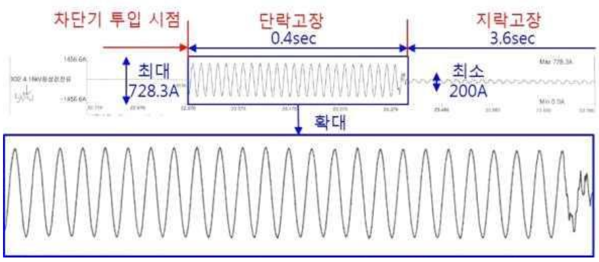


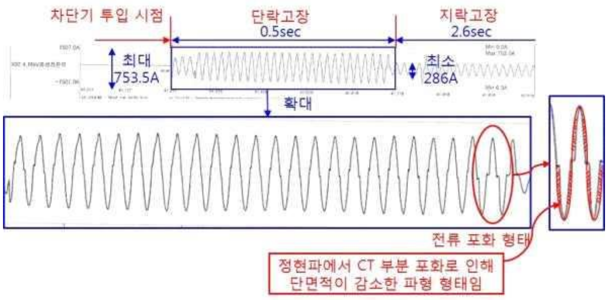
Fig.1. Schematic diagram of the accident propagation

2.2 *Incident main causes*

According to the results of the KINS investigation report, the (NB-S02-01) circuit breaker open Because the (NB-S02-18) circuit breaker was not operated, the opening coil of the (NB-S02-18) breaker failed to rotate the opening latch due to poor lubrication condition, the lubricant recommended by the manufacturer was used and the maintenance method was improved. After the stop of the lubrication pump which caused the failure of the motor, the motor start / stop logic circuit was improved to prevent the central chiller to operate individually. As the ground fault relay (51N) of the circuit breaker (NB-S02-03) was found to be caused by the CT saturation due to the failure to operate the breaker secondarily, the waveform of the ground current generated at the time of manual closing of the breaker, the waveform did not show saturation during the first manual reclosing, but the secondary current waveform was partially crushed and decreased during the second reclosing see fig. 2 (a,b).



a. Fault current waveform at first closing



b. fault current wave form at the secondary reclosing

Fig 2. Fault current waveform at first and second closing

3. Prevention of Recurrence of Incident

3.1 *Improvement measures using IEC61850 standard*

Hanbit unit (2) has been operating safely for more than 30 years since June 1987, but some of the improvements reflected in the power facilities of the power plant after that have not been used yet. In particular, nuclear reactors built prior to Shin Kori 3 & 4 adopt the analog relays, which do not meet the functions and performance of digital relays. However, in the case of old power plants, digital relays are increasingly used to replace electric power facilities. In this paper, IEC 61850 standard, digital relays (Intelligent Electronic Device (IED)) and electronic current transformer (ECT) are adopted to prevent accidents such as those described above. (See Fig. 3).

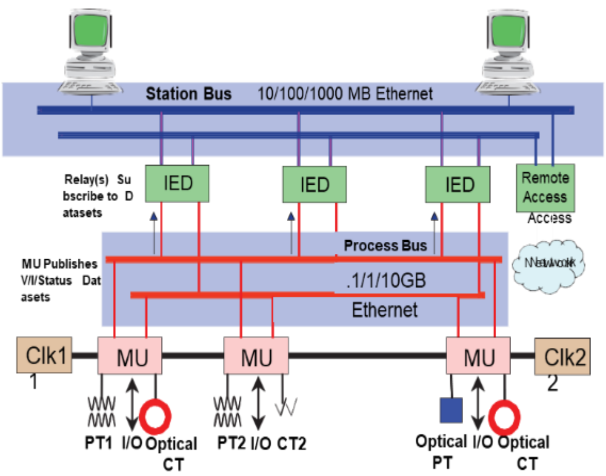


Fig 3. IEC61850-based power monitoring and control system configuration

3.2 *Items to be improved for accident preventions*

In order to prevent or solve accidents and failures in the above cases, the following five measures are needed.

- Interlocking the central chiller motor and chiller lubrication pump to prevent stopping the lubrication pump when the chiller is operating.

- The operation of the motor is made by using the breaker auxiliary contact and the motor circuit current value at the same time.
- In order to stop the motor before a short circuit or ground fault occurs due to overheating of the motor (the protective relay, the motor overcurrent relay and the thermal overload relay (49)) need to cooperate in protection by online communication between each other.
- The closed relay can be reset only after the cause has been removed. If both the closed circuit of the branch circuit and the closed relay are installed in the incoming circuit, the incident can be easily identified.
- An electronic current transformer (ECT) is applied to areas where CT saturation is a concern or expected to happen.

3.3 Effect of applying IEC61850 based digital relay

If the central chiller and lubrication pump are operated in conjunction with each other as in the above example, the logic circuit is configured so that the lubrication pump is not stopped during the operation of the central chiller by recognizing the breaker state using the I / O input device of the Merging Unit (See Figure 4). In addition to the overcurrent relay (50/51), the digital relay provides a function of thermal overload relay (49), so that it can detect more accurately than the overcurrent relay (51) when the motor is overheated. However, in order to utilize the performance of (49), it is necessary to input the thermal model of the motor to the relay, which is out of scope of the paper.

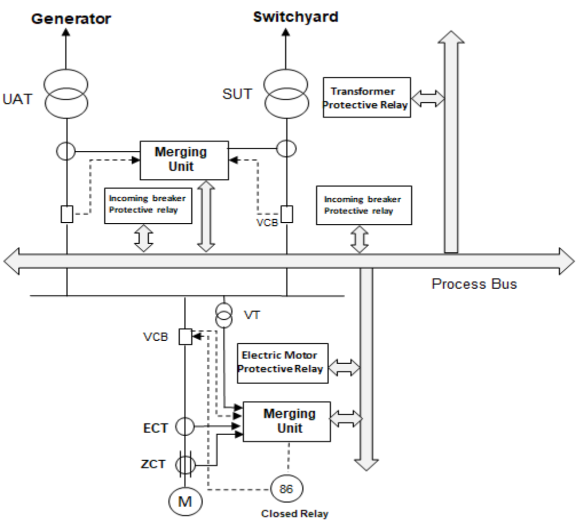


Fig. 4. IEC61850 based digital relay protection

Digital relays incorporate a closed relay function using an internal logic circuit, but in many cases, a mechanical closed relay is installed separately from a digital relay for reliable and safe accident handling and circuit operation. At this time, it is very cumbersome and complicated to construct the interlock circuit using the control cable and the contact point between the branch circuit and the closed relay of the bus lead-in circuit breaker. However, if IEC 61850 and MU are applied, the interlock circuit between closed relays can be constructed easily and logically [5]. When the closed relay of the branch circuit for the motor is operated, the breaker is not opened, so that it is found that the branch circuit is abnormal when the closed relay of the bus enters again. If the closed relay of the branch circuit operates, the interlock circuit can be logically configured so that the input circuit breaker is not re-inputted.

3.4 Effect of applying electronic current transformer (ECT)

3.4.1 Mitigation of Current transformer saturation problem.

Saturation is one of the major challenges faced by any CT installed in power systems where faults with high short circuit are thought to be frequent, MV of NPP is not an exception in this case. When a CT is saturated and therefore, the relay response might fail to meet its operating characteristic and causing miss-coordination between protection devices. [3-5]. this paper will focus on how to prevent cascading failure by mitigation of CT saturation as describing below.

3.4.2 Simulation results of existing CTs

CT performance was simulated by electromagnetic transient program revised version (EMTP-RV) for the branch circuits of Fig.1. The ratings of CT and technical data of the circuit used in the simulation are as follows;
CT Rating: 3000/5A, Accuracy Class: C600, Standard Burden: 1.0 **Ω**, short circuit current (Symmetrical RMS): 50kA, short circuit current (Asymmetrical RMS): 75kA. Fig 5 shows the secondary currents of ideal CT, when the magnetic core of the CT is saturated. Saturation by the proposed Conventional CTs which are currently used on Hanbit (2) NPP MV switchgears have a major saturation problem at high fault currents.
As shown in Fig 5. The secondary current distortion reduces the effective value (RMS) of the secondary current of the conventional current transformer and consequently it causes the time delay of a relay operation and incoordination among protective devices this problem can lead to mal-operation of the protective relays and finally lead to cascading failures. Therefore,

it is necessary to present a methodology for detection and compensation of the CT saturation.

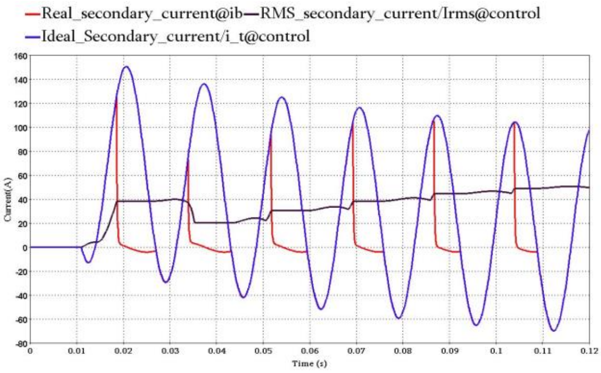
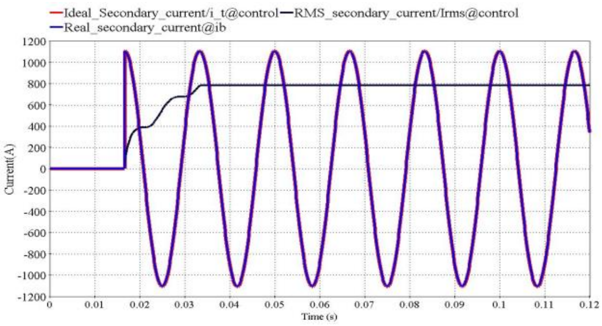


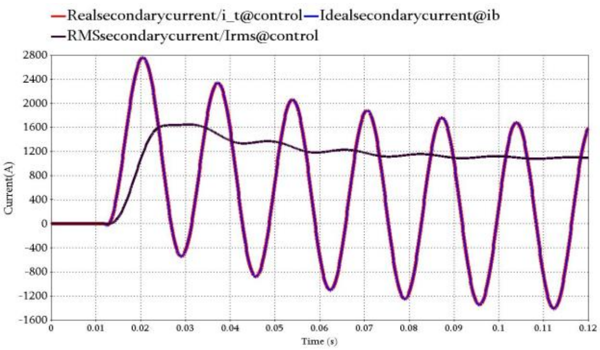
Fig. 5. Short circuit fault current on CT secondary circuit.

3.4.3 Simulation results of Proposed ECTs

It was assumed that ECT replace the conventional CTs in Fig. 5 and with the same operation conditions. According to the simulation result, ECT produce clean sine wave secondary current without distortion at short circuit fault condition. Fig 5(a,b) shows the simulated secondary output currents, under (symmetrical and asymmetrical) short circuit currents. As can be seen, in all instances, the plotted real secondary output currents were not distorted nor displaced from the ideal sinusoidal waves. This is an indication that ECT does not saturate at high symmetrical and asymmetrical fault currents.



a. Symmetrical SC current on ECT secondary circuit



b. Asymmetrical SC current on ECT secondary circuit

Fig. 5. Short circuit fault current on ECT secondary circuit.

3.5 Improvement's after applying (ECT)

Since ECT does not cause saturation even at very high fault currents, it can eliminate the possibility of relay operation or malfunction due to residual flux. Also, when applied together with the IEC61850 standard, the current value measured in ECT can be used together in many relays [4]. When a short-circuit accident occurs in the bus, the relays are set to operate the relay 51 for the interrupter after a predetermined time delay, in order to cooperate with the lower branch circuit relay 50. Therefore, the short-circuit of the bus during the relay trip delay time (200 ~ 300ms) is forced to be continued and often arcing. However, when the IEC61850-based digital relay is applied, the relays can communicate with each other, thereby preventing a bus short-circuit accident without time delay. If both the upper relay and the lower relay detect a short-circuit current, it indicates that a short circuit has occurred in the branch circuit. If a short-circuit current is detected only in the upper relay, it means that a short-circuit occurred in the bus. This makes it possible to quickly detect a bus accident without installing a bus differential relay on the switchgear bus.

4. Conclusions

The use of power equipment for a long time may degrade performance and cause unexpected malfunctions or misfire. Unexpected means that there are no measures to anticipate such an accident or breakdown. The above-mentioned operation of the high-voltage power distribution system breaker section is a representative example. In spite of the motor stop signal, the circuit breaker was not opened and a ground fault occurred in the motor. One branch circuit accident occurred in a chain, leading to an accidental loss of power. After a detailed review of the accident analysis report, short-term measures were taken along with the cause pitfall, but additional measures were required to operate the facility in the long term and stable. In this paper, we proposed the ultimate solution to prevent cascading failure in nuclear power generating stations by using an electronic current transformer (ECT) and the digital relays (intelligent electronic Device (IED) as a key solution. With communication via the internet and dedicated intranets in nuclear power generating stations. Combination of IEC 61850 standard and the ECT can enhance interoperability and reliability of the protection, monitoring and preventing cascading failure in the medium voltage networks in nuclear power plants .

Acknowledgement

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