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Modeling of Inverse Time Overcurrent Relay Protection in Distribution Network

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***Abstract*—The reliable operation of the electric power system depends largely on the operation of relay protection and automation facilities. The primary equipment in electrical power systems, including generators, transformers, power transmission lines, and motors, relies on various types of protective relays, with overcurrent protection (OCP) being the most commonly used. Overcurrent protection can be divided into two main categories: definite time overcurrent protection and inverse time overcurrent protection. In our study, we focus on the relay protection systems used in the Baganuur branch of the Baganuur South-East Region Electricity Distribution Network (WESRDN), where most systems utilize definite time overcurrent protection. This type operates with a fixed time characteristic regardless of the magnitude of the fault current or the length of the line. However, it has the drawback that the protection time increases as it approaches the generator in series-connected lines and equipment. In contrast, inverse time overcurrent protection can adjust its timing characteristics based on the size of the fault current, which helps to overcome the earlier mentioned problem when applied to line equipment protection. Therefore, based on the example of the Baganuur branch's distribution network, we modeled the primary circuit and inverse time overcurrent protection using DigSILENT PowerFactory 15.1 software, and an analysis of the experiment results was conducted.**

Keywords— time characteristic, inverse time curve, dijital protection, electrical damage, inverse curve.

I. Introduction

Humanity of the twenty-first century cannot be imagined without technology, including electricity. Electric Power System (EPS) refers to the combination of power plants, substations, electrical grid networks, and electricity consumers [1]. The EPS is intended to operate in a stable and normal mode; however, it can experience faults and abnormal conditions. A fault is defined as a short circuit of any kind, which can lead to a sudden drop in voltage and frequency, posing a risk of complete system failure [15]. Therefore, it is essential to quickly detect the faulty element (equipment) and isolate it from the non-faulty parts of the system. To achieve this, a protective relay device is designed to monitor and measure specific parameters to identify the faulty component and to perform rapid switching and disconnection using circuit breakers [2], [12]. Relay protection comes in various types, depending on the nature of the fault and the equipment being protected. In our country, the distribution network typically uses overcurrent protection with definite time characteristics. This type of protection trips only after a fixed period, regardless of the fault current magnitude. Consequently, there is a risk that during a high fault current condition, the prolonged time delay could lead to equipment damage and a loss of system stability. By implementing inverse time characteristics in overcurrent protection, it is possible to achieve a faster trip time during high fault currents, thereby enhancing the protection's flexibility. Therefore, the objective of this research work will be to determine the performance of this protective mechanism using simulation.

II. Overcurrent Protection

Current protection is protection that works by sensing the value of the current passing through the protected object [3]. Overcurrent protection is classified based on its selectivity: relative selectivity for overcurrent protection (Definite time, Inverse time) and absolute selectivity for instantaneous overcurrent protection (Instantaneous time) [10]. Overcurrent protection with relative selectivity fulfills selectivity requirements through the use of time delay. Absolute selectivity for instantaneous overcurrent protection fulfills selectivity requirements through the method of adjusting the operating current. Overcurrent protection operates as primary protection in a network with a single-sided power source and as backup protection in a composite network. Overcurrent protection is used as primary and backup protection in generators, transformers, lines, and distribution networks [5].

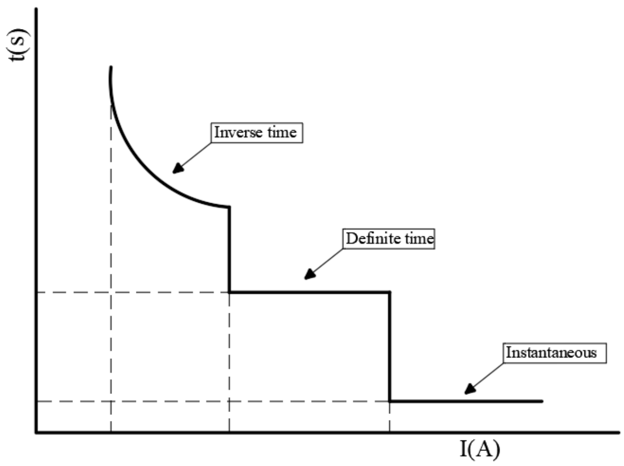

Fig. 1. Time characteristics of overcurrent protection

A. Instantaneous overcurrent protection

This type of protection is designed to operate with a time delay of $t_1 = 0$, which is slightly longer than the operating time of a discharger. The protective capability of this protection is evaluated based on the length of the protected zone [11].

$$I_{Op} = K_{Adj} \times I_{SC..max} \quad (1)$$

In this : I_{Op}-Protection operating current,

K_{Adj}- The adjustment coefficient calculated considering the calculation errors during short-circuit conditions, errors from current transformer (CT), and errors from measuring devices. It can be taken between $K_{Adj} = 1{,}2\ to\ 1{,}3$ according to the rules of usage of electrical equipment used internationally.

$I_{SC.max}$- Maximum Short-Circuit Current.

B. Definite time overcurrent protection

Overcurrent protection with definite time delay is widely used in networks with a single-sided power source. The operating current of the protection is adjusted to the maximum load current [13].

$$I_{Op} = \frac{K_{Rel} \times K_{Start} \times I_{Load.max}}{K_{Rec}} \quad (2)$$

In this: K_{Rel}-Reliability coefficient,

$K_{Rel} = (1{,}15 \div 1{,}3)$ - semiconductor relay;

$K_{Rel} = (1{,}2 \div 1{,}3)$ - electromagnet relay;

$K_{Rel} = (1.5)$ - induction relay;

K_{Start} - motor self-starting coefficient;

K_{Rec}- recovery coefficient. The reliability of this protection is checked by the sensitivity coefficient.

$$K_{sen} = \frac{I_{S.C.min}}{I_{Op}} \quad (3)$$

The sensitivity coefficient for primary protection is greater than 1.5, and the sensitivity coefficient for backup protection is greater than 1.2 .The operating time of the protection is calculated to be greater than the previous protection time by Δt .

$$t_{Op} = t_{pre} \times \Delta t \quad (4)$$

In this: t_{pre}- Previous protection time delay

$\Delta t = 0{,}5$

C. Inverse time overcurrent protection

The operating time of this type of relay has an inverse relation with the current. The higher the fault current, the shorter the operating time of the protection. Overcurrent protection with inverse time characteristics has types that comply with the Institute of Electrical and Electronics Engineers (IEEE) standard and the International Electrotechnical Commission (IEC) standard [14], [16].

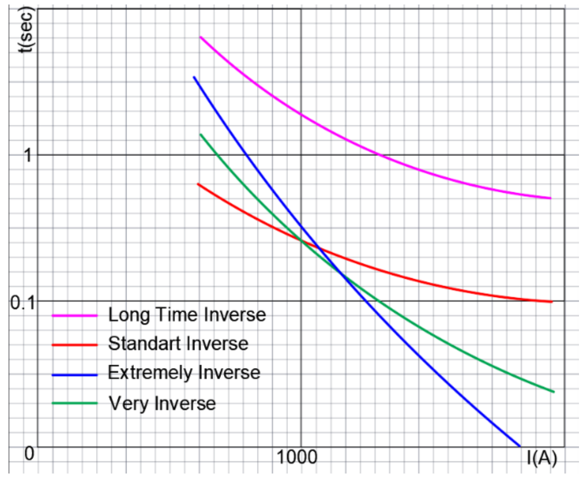

Fig. 2. Inverse time characteristic of overcurrent protection [7]

TABLE I. NOMENCLATURE OF INVERSE TIME CHARACTERISTICS [6]

№	Charactrestic curve	
	IEEE standart's	***IEC standart's***
1	Moderately Inverse	Standart Inverse
2	Inverse	Very Inverse
3	Very Inverse	Extremely Inverse
4	Extremely Inverse	Long-time inverse
5	Short-time inverse	Short-time inverse

The IEC standard is used in this study.

STANDART INVERSE TIME (S1)

The operating time decreases gradually as the current increases.

VERY INVERSE TIME (S2)

A steeper curve where the operating time decreases more sharply with increasing current.

EXTREMELY INVERSE TIME (S3)

An even sharper decrease in operating time with increasing current, suitable for highly sensitive applications.

LONG TIME INVERSE (S4)

It is designed for applications where the protection device is required to operate slowly under low-magnitude overcurrent conditions and faster for higher-magnitude currents. However, it operates with a longer time delay for moderate overcurrents compared to other inverse types like standard inverse or very inverse. IEC 60255 Equation for trip time:

$$t(I) = TMS\frac{k}{\left(\frac{I}{Is}\right)^{\propto} - 1} \quad (5)$$

In this : $t(I)$ - protection operating time,

TMS-Time Multiplier Setting ;

k - characteristic coefficient ;

I - the actual current;

Is - the current setting ;

TABLE II. INVERSE TIME CHARACTERISTIC COEFFICIENT [8]

Curve type	***k***	***a***
IEC standart inverse	0.140	0.020
IEC very inverse	13.5	1
IEC extremely inverse	80	2
IEC long time inverse	120	1

III. RESEARCH SECTION

In this research, we studied the relay protection used in the equipment and transmission lines of the BAGANUUR branch of the Baganuur South-East Region Electricity Distribution Network Network State-Owned Joint Stock Company. The Baganuur branch consists of 12 substations and approximately 95 pieces of equipment. The graph below shows the study of the relay protection currently in use at the Baganuur branch [4], [9].

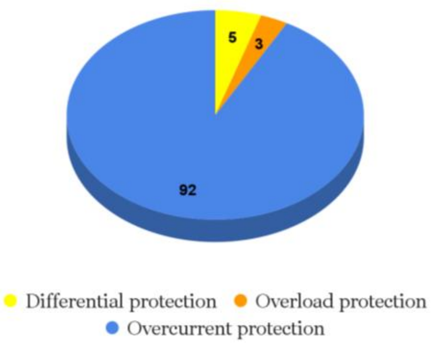

Fig. 3. Types of relay protection that is using in Baganuur branch

Of the relay protections used in the transmission lines and equipment of the Baganuur branch, 3% are overload protection, 5% are differential protection, and 92% are overcurrent protection.

The following graph categorizes the types of overcurrent protection characteristics.

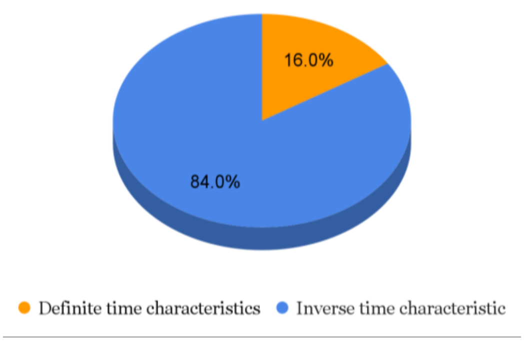

Fig. 4. Overcurrent protection with types of time characteristics

From the above graph, it can be seen that the majority of the relays used in overcurrent protection have a definite time characteristic. The operating times were set at 0.5 seconds and 1 second. This time delay is considered long for relay protection. When the short circuit current is high, a prolonged time delay becomes very dangerous, as it can lead to overheating and damage to the main equipment.

IV. EXPERIMENTAL SECTION

The primary scheme of the distribution network was modeled using DigSILENT PowerFactory 15.1 software. The data of the primary scheme is as follows:

- ✓ System
- ✓ line 1: 40km, Overhead line 2: 10km
- ✓ Power transformer (TR1): 10MVA, 50Hz, 6/35kV
- ✓ Power transformer(TR2): 3MVA, 50 Hz, 04/6kV
- ✓ Load 1: 1MVA, Load 2: 0,8MVA, Load 3: 0,2MVA, Load 4: 0,1MVA
- ✓ Current transformer (CT): 100/1 A
- ✓ Relay model: SEL 751-1A, ANSII SYMBOL: 51P1

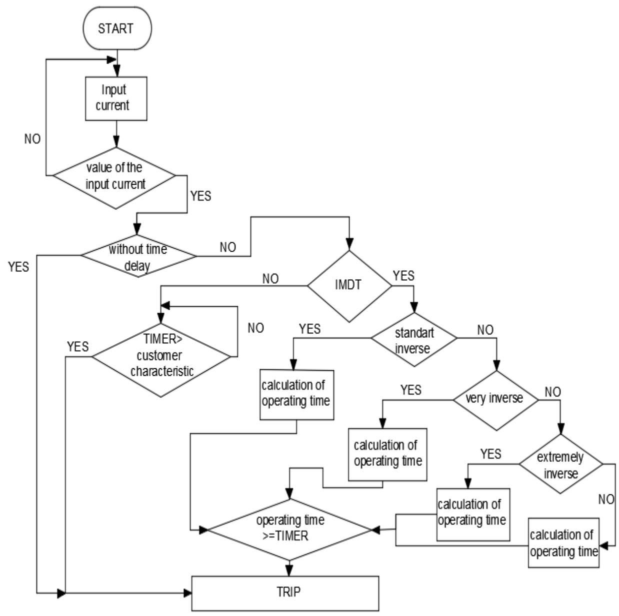

Fig. 5. Algorithm for the operation of the overcurrent protection

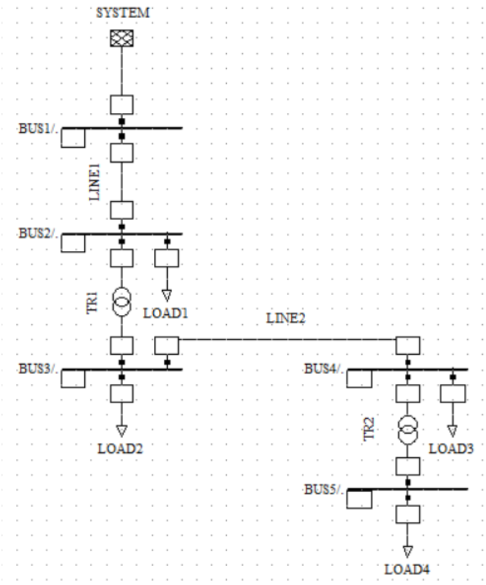

Fig. 6. Model of primary scheme that was used in experiment

The experiment will be performed on Line 2. It should be done with the minimum current which is 2-phase short circuit. First, the overcurrent protection with different types of inverse time characteristics will be tested at fault (is occurring at 50%) of the line to determine the operating time. Then , one of the time characteristics will be selected, and the faults will be generated at 25%, 50%, 75%, and at the end of the line (100%).

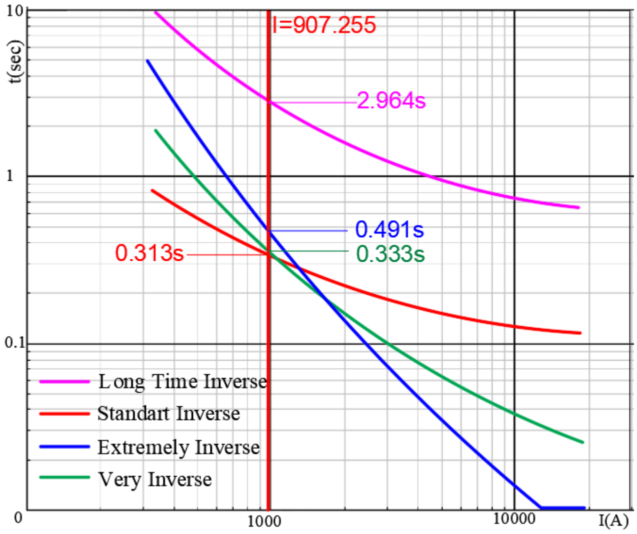

Fig. 7. At the end of the line (100%), Operating time of overcurrent protection with inverse time characteristic.

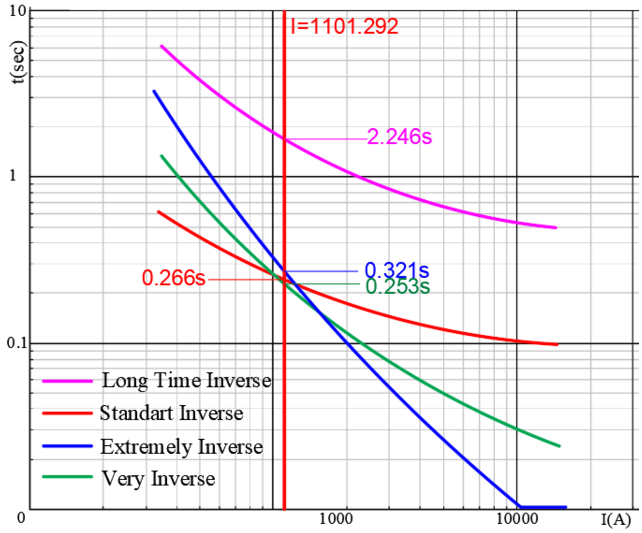

Fig. 8. Operating time of overcurrent protection with inverse time characteristics, when short circuit at 75%, or 7.5 km of the line.

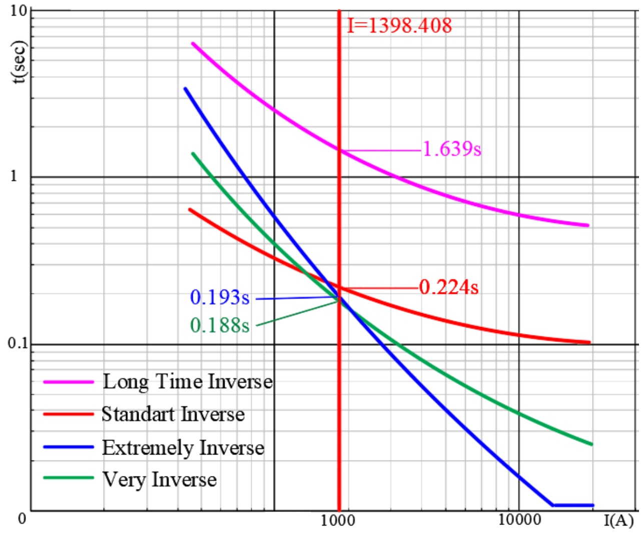

Fig. 9. Operating time of overcurrent protection with inverse time characteristics, when short circuit at 50%, or 5 km of the line.

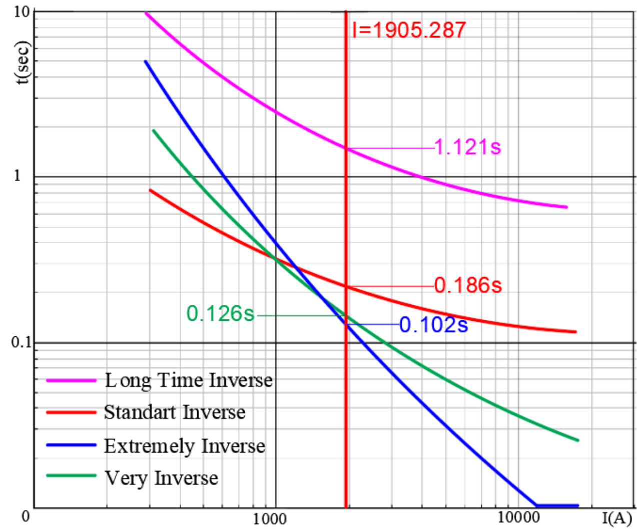

Fig. 10. Operating time of overcurrent protection with inverse time characteristics, when short circuit at 25%, or 2.5 km of the line.

TABLE III. THE OPERATING TIMES OF THE OVERCURRENT PROTECTION WITH INVERSE TIME CHARACTERISTICS DURING A TWO-PHASE SHORT CIRCUIT AT VARIOUS LINE LENGTHS

Overhead line length	***25%***	***50%***	***75%***	***100%***
IEC standart inverse	0.186s	0.224s	0.266s	0.313s
IEC very inverse	0.126s	0.188s	0.253s	0.333s
IEC extremely inverse	0.102s	0.193s	0.321s	0.491s
IEC long time inverse	1.121s	1.639s	2.246s	2.964s

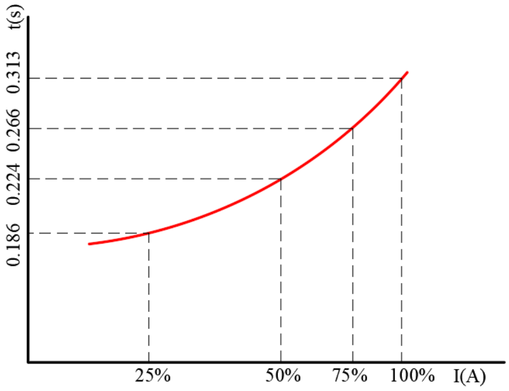

Fig. 11. The operating times of the overcurrent protection with Standard Inverse time characteristics, depending on various line lengths.

V. CONCLUSION

In the study, the time characteristics of overcurrent protection with inverse time characteristics—specifically Standard Inverse, Very Inverse, Extremely Inverse, and Long Time Inverse—were modeled and tested by creating short circuits at four points along the distribution line. Based on the results of these experiments, the suitability of different characteristics was determined depending on the properties of the line network.

When the line was close to the load, as shown in Figure 6, the Standard Inverse time characteristic of the overcurrent protection operated in the shortest time of 0.313 seconds. This indicates that using the Standard Inverse time characteristic of overcurrent protection is more suitable when the fault occurs near the consumer.

When the line was at 25% (Figure 9) or close to the generator, the Extremely Inverse time characteristic of the overcurrent protection operated in the shortest time of 0.102 seconds. This demonstrates that using the Extremely Inverse time characteristic of overcurrent protection is more suitable when the fault occurs near the generator.

At 50% (Figure 7) and 75% (Figure 8) of the line, the Very Inverse time characteristic of overcurrent protection operated in the shortest time. The Very Inverse time characteristic shows that it is more appropriate to know where the fault has occurred. Table 3 and Figure 10 illustrate that the operating time of the protection is inversely related to the short circuit current. Therefore, by using overcurrent protection with Standard Inverse inverse time characteristics in the distribution network, the operating time of the protection can be reduced, making it more flexible in terms of timing.

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