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Optimal Coordination of Overcurrent Relay Protection Case Study Sawakin Substation

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Abstract— **Continuous and reliable power supply is the main goal and target for power system networks. Coordination is necessary to achieve proper fault identification and fault clearance sequence, without good protection coordination, the protection system will lose its features i.e. selectivity, dependability, and sensitivity. In this paper, the protection coordination is designed for Sawakin substation system using the conventional technique and simulating the system in ETAP software for validation. this paper presents two scenarios of different fault type and locations had been separately formulated and optimized. The time dial setting and plug setting of the selected overcurrent relays are designed according to the coordination procedures and constraints, to speed up the tripping times and to isolate the faulty section as soon as possible. The coordination starts first by coordinating the phase over-current elements, for different paths from furthest downstream (load side) up to the upstream (source side). Next, the earth fault relays are coordinated for the same paths and finally the instantaneous element as a backup protection was applied successfully.**

Keywords*— *Relay Coordination, Overcurrent Relay, short circuit analysis, tripping sequence, optimal coordination of relay.

I. Introduction

In any power system network, protection should be designed such that protective relays isolate the faulted portion of the network at the earliest [9]. Overcurrent Relays are the simplest type of protective devices available. Setting up the pick-up values for individual relays is easy but the problem arises when each relay has to be coordinated with the other relays in the system. This problem is further aggravated when there are large interconnected systems. The unique feature of ETAP software i.e. the star view is very useful in case of large interconnected power systems. Thus, this project shows the overcurrent relay coordination of a given system using ETAP's star view. The important characteristics of an overcurrent relay are selectivity, reliability, and discrimination. For any type of fault be it symmetrical or unsymmetrical, the overcurrent relay should operate efficiently and provide correct discrimination [1]. The overcurrent relay settings must be set such it operates for faults in its zone or the main faults. Also, these relays should operate after a particular delay and act as back up protection for other relays.

II. System Description

Sawakin substation is installed with a capacity of 120MVA to supply power to Sawakin, Toker and AL-Mahgar. And this substation is fed from the national grid of electricity via transmission line from Port Sudan, Sinkat and GNPOC (Bashayir) with a voltage of 110kv which is converted to 33/11 using two main transforms, and additional equipment such as CT, VT, Busbar, Relay and other equipment's, Each equipment has its main protection and backup protection (i.e. overcurrent relay which that the coordination between them will be discussed in this paper). The single line diagram is shown in Fig.1

III. Load Flow And Fault Analysis

Before system protection design is carried out, it must be ensured that the system is running under normal condition. This can be checked through load flow where low bus voltages, overload cables and equipment are checked [4]. Moreover, short circuit study where device duty check is performed.

A. Load flow analysis

Load flow study is performed in ETAP using all the data for the single line diagram of Sawakin Substation system. Load flow analysis is done for determining the operation of existing system and in planning the future expansion of the power system. It is analyzed in normal steady state condition. From load flow study we are able the get the voltage's magnitude and phase and active and reactive power flow in the line [3].

B. Fault analysis

To be able to determine device coordination, a short-circuit fault analysis must first be performed. The goal of the short circuit studies is to find the maximum fault current, which appears only whenever there is a fault in the circuit [5,7].

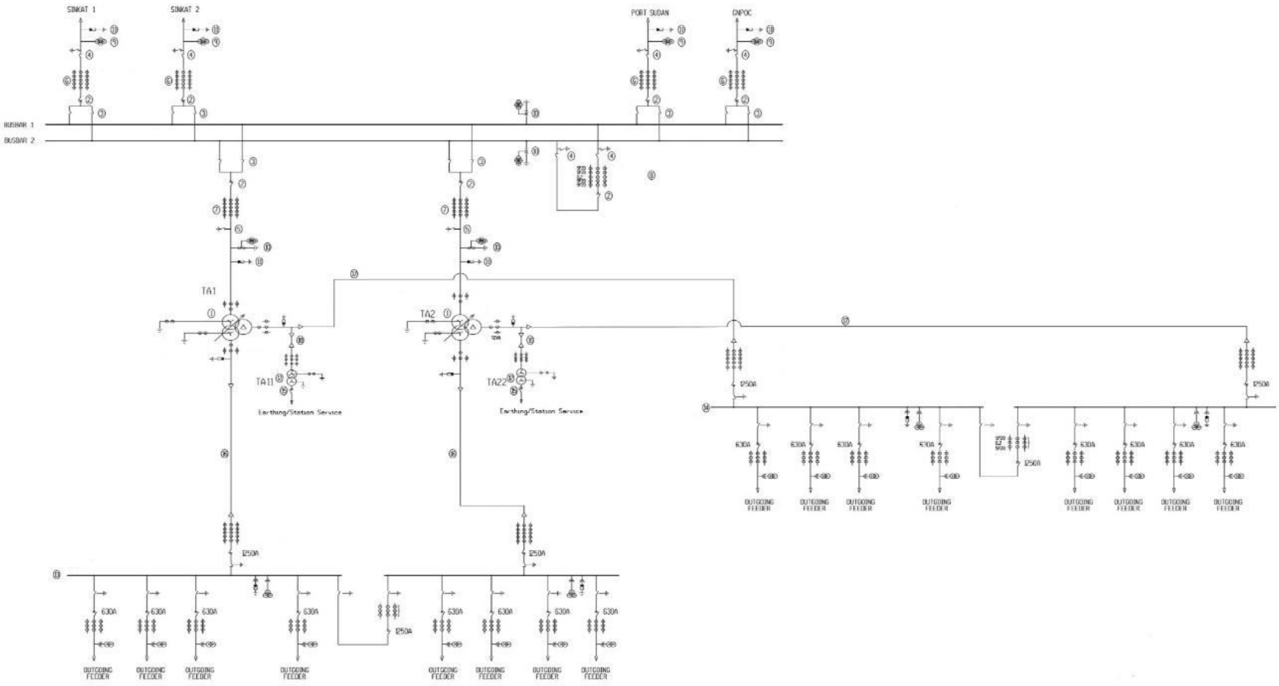


Fig.1 Single Line Diagram for Sawakin Substation

IV. RELAY SETTING

Relay coordination means that the backup relay must operate after a sufficient time for the main relay operation [4]. It plays an important role in the protective system and considered a serious job for protection engineers [2]. This paper shows overcurrent relays coordination of 110/33/11kV substation using ETAP's star view. A star view is a feature in ETAP which presents relays, their associated characteristic curves, and CBs with their actions and opening times [6].

A. *Overcurrent Relay setting*

Plug Setting Multiplier (PSM) gives the relay current setting and the time settings are given by the Time Multiplier Settings (TMS).

The formula for finding the PSM is given by:

$$PSM = \frac{I_f}{CTR * I_{pickup}} \qquad (1)$$

Where I_p is relay pickup current value, I_f is full load current, and CTR is current transformer ratio.

The relay could be set on 110% of the full load current or more (up to 200%), Pickup current setting determined from the following equation:

$$I_{pickup} = \frac{K_r * f_l}{K_d * CTR} \qquad (2)$$

Where f_l is full load current, K_r is the reliability coefficient, and it is taken as 1.3, and K_d is the drop-off coefficient, and it is taken as 0.95.

Operating time of normal inverse time type overcurrent relay obtained from the equation [5]:

$$T_{op} = TMS * \frac{0.14}{PSM^{0.02} - 1} \qquad (3)$$

Where T_{op} is relay operation time, and TMS is Time Multiplier Settings.

B. *Coordination time interval*

The coordination time between the primary and backup protective devices is called coordination time interval (CTI). The CTI should lie between 0.2 to 0.4sec [8]. CTI can be expressed as follows:

$$T_{buckup} - T_{main} \geq CTI$$

Where T_{buckup} is backup relay's operating time and T_{main} is main relay's operating time [8].

C. *Setting Instantaneous units*

Instantaneous units are more effective when the impedance of the power system elements being protected are large in comparison to the source impedance. They offer two fundamental advantages:

- They reduce the operation time of the relay for severe system faults
- They avoid the loss of selectivity in a protection system consisting of relays with different characteristics [9].

The criteria of setting instantaneous units vary depending on the location, and the type of system element being protected, three groups of elements can be defined [9]:

1) *Lines between substations*: The setting of instantaneous units is carried out by taking at least 125 per cent of the maximum fault level at the next substation.

2) *Distribution lines:* The setting of the instantaneous element of the outgoing feeders can be set at value between six and ten times the rating current [5].

3) *Transformer units*: The instantaneous element of the overcurrent relays installed on the primary side of the transformers should be set at a value between 125 and 150 per cent of the short-circuit current existing on the low voltage side.

D. Earth fault relay setting

Earth fault relay is responded just for residual current of the system for that it is not affected by load current. The standard settings for earth-fault relays are 20 per cent of the full-load current or minimum earth-fault current on the part of the system being protected [5]. The pickup and time settings for earth fault, can be calculated in a similar way as we calculated for over current relay.

V. RESULTS AND DISCUSSION

To obtain proper relay coordination between relays using ETAP, the following two cases can explain this:

A. Case1:

When A three-phase fault was simulated on 33kV feeder with bus section circuit breaker OFF as shown in fig.2.

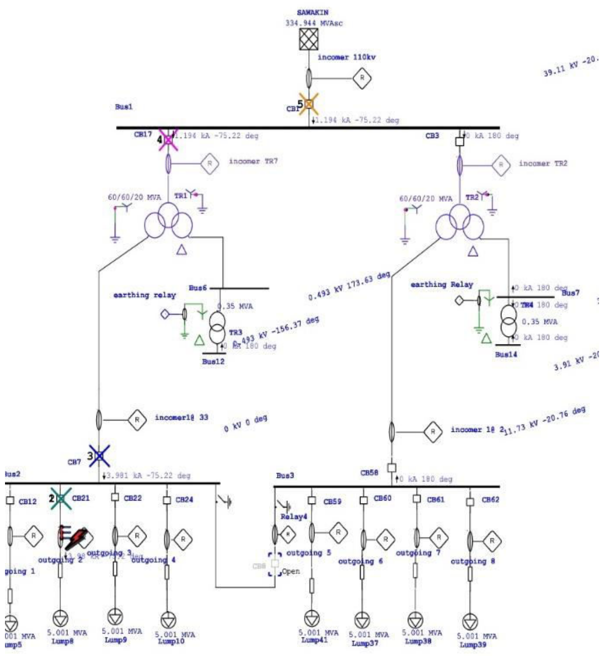


Fig.2 Three-phase fault on outgoing feeder with bus section CB OFF

The sequence of operation for three-phase fault on 33kVoutgoing feeder with bus section OFF is shown in fig.3.

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between CT50 & OHL12. Adjacent bus: Bus2

Data Rev.: Base   Config: Normal   Date: 10-16-2020

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	outgoing 2	3.981	10.0		Phase - OC1 - 50
20.0	CB21		10.0		Tripped by outgoing 2 Phase - OC1 - 50
99.4	outgoing 2	3.981	99.4		Phase - OC1 - 51
109	CB21		10.0		Tripped by outgoing 2 Phase - OC1 - 51
419	incomer1@ ...	3.981	419		Phase - OC1 - 51
429	CB7		10.0		Tripped by incomer1@ 33 Phase - OC1 - 51
696	incomer TR7	1.194	696		Phase - OC1 - 51
706	CB17		10.0		Tripped by incomer TR7 Phase - OC1 - 51
1359	incomer 110...	1.194	1359		Phase - OC1 - 51
1369	CB1		10.0		Tripped by incomer 110kv Phase - OC1 - 51

Fig.3 sequence of operation for case 1

From fig.3, it is clearly that the feeder relay was tripped first at 10 milliseconds by instantaneous function (OC-50) followed by the outgoing feeder relay (OC-51) by 99.4 millisecond then incomer of busbar 33KV relay (OC-51) after 419 milliseconds, After that the incomer of transformer relay (OC-51) by 696 milliseconds. Finely110KV incomer were tripped.

B. Case2:

When A three-phase fault was simulated on 33kV feeder with bus section circuit breaker ON as shown in fig.4.

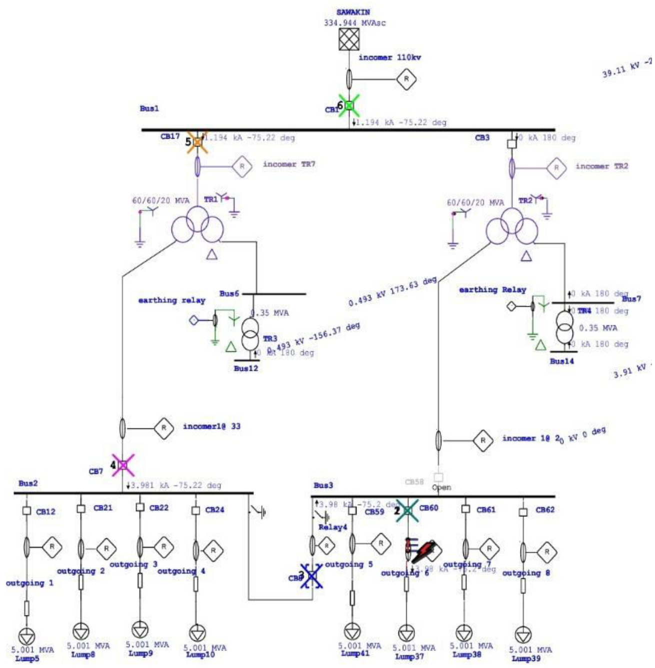
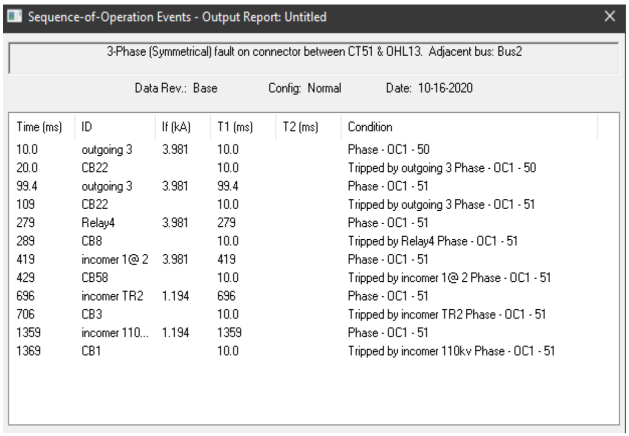


Fig.4 Three-phase fault on outgoing feeder with bus section CB ON

The sequence of operation for three-phase fault on 33kVoutgoing feeder with bus section ON is shown in fig.5.



Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between CT51 & OHL13. Adjacent bus: Bus2

Data Rev.: Base Config: Normal Date: 10-16-2020

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	outgoing 3	3.981	10.0		Phase - OC1 - 50
20.0	CB22		10.0		Tripped by outgoing 3 Phase - OC1 - 50
99.4	outgoing 3	3.981	99.4		Phase - OC1 - 51
109	CB22		10.0		Tripped by outgoing 3 Phase - OC1 - 51
279	Relay4	3.981	279		Phase - OC1 - 51
289	CB8		10.0		Tripped by Relay4 Phase - OC1 - 51
419	incomer 1@ 2	3.981	419		Phase - OC1 - 51
429	CB58		10.0		Tripped by incomer 1@ 2 Phase - OC1 - 51
696	incomer TR2	1.194	696		Phase - OC1 - 51
706	CB3		10.0		Tripped by incomer TR2 Phase - OC1 - 51
1359	incomer 110...	1.194	1359		Phase - OC1 - 51
1369	CB1		10.0		Tripped by incomer 110kv Phase - OC1 - 51

Fig.5 sequence of operation for case 2

Bus section Overcurrent Protection Curve at the system's maximum fault current should be laid above the 33KV outgoing feeders Overcurrent protection curves. From fig. 5, it is obviously that the feeder relay was tripped first at 10 milliseconds by instantaneous function (OC-50) followed by the outgoing feeder relay (OC-51) by 99.4 millisecond then by the bus section relay (OC-51) by 279 milliseconds after that the incomer of busbar 33KV relay (OC-51) after 419 millisecond and so on as shown in fig.5.

C. Relay Coordination Curves

The relay coordination curves for phase and earth faults in the system are shown in fig. 6 respectively.

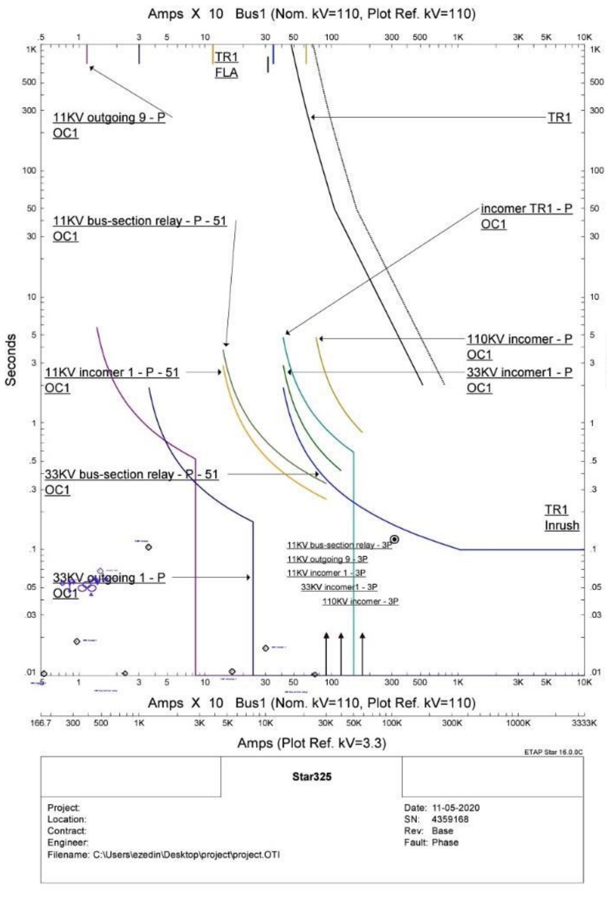


Fig. 6 (a): over current relay coordination carves for phase faults

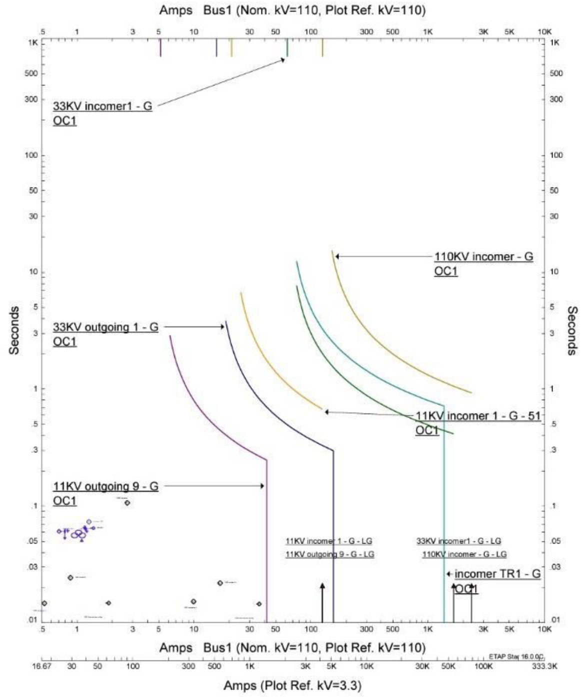


Fig. 6 (b): over current relay coordination carves for earth faults

VI. CONCLUSION

The goal of this project was to obtain a more efficient and accurate coordination for overcurrent and earth fault relays in Sawakin substation systems. According to this study, it was observed that protection coordination between the main and backup relays at Sawakin substation in connection to the power grid will not deal with a critical problem and overcurrent relay settings can be able to carry out their duties. From the implemented fault scenarios, it was noticed that relays must be IDMT type. The relay settings have been selected based on the load flow and short circuit analysis, to obtain a proper relay setting and coordination between relays using ETAP.

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