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Coordination of protective relays in the substation

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ABSTRACT

To make an electrical system reliable and cost-effective, its protection coordination is crucial. Protection coordination is a study to determine the trip settings of protective devices. This research proposes protection coordination for Mehran University of Engineering and Technology, Jamshoro, Sindh. This study includes the coordination of relays connected at each department to the main relay connected with the main vacuum circuit breakers (VCB) by using the time characteristic curves (TCC) and time delay setting of relays using ETAP software. This method is used for the trip of a particular circuit breaker at a proper time. Hence, if a fault occurs in any department only that department will be disconnected, and the rest of the departments will remain in a working condition. This study helps to maintain the system's high reliability.

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1. INTRODUCTION

Numerous faults and transients occur in the power system. As a result, there will be over currents and over voltages that may damage the conductors as well as insulation [1]. In addition, equipment may be damaged, and system may fail. Objective of protection coordination is to minimize the duration interval of disconnection in case of failure of an equipment and fault occurrence [2]. Coordination of over-current relays during faults will lessen the effect of permanent tripping. hence, it will continue to supply [3]. The electrical layout has two main vacuum circuit breakers (VCB) for protection purposes. there is a chance of disconnection of the whole network when any department is subjected to a severe fault. therefore, there is a requirement to revise the existing protection system of the Mehran University of Engineering and Technology.

For the proposed network there are twenty-four departments including hostels, and an admin block. The 11 kV feeder supplies 5.9 MW power to the university. There are two main vacuum circuit breakers and twenty-four substations at Mehran University of Engineering and Technology [4]. Each substation has one transformer, which is further connected to each department. In this research, three departments out of twenty-four are taken under analysis for a better understanding of relay settings and coordination of protective devices [5]. This research describes a comprehensive review of protection coordination schemes in power systems, including overcurrent protection, distance protection, differential protection, and busbar protection. Zeineldi *et al.* [6] analyze the advantages and disadvantages of each scheme and their suitability for different types of power system components. The study explains a comprehensive overview of the fundamental principles of protection coordination in power systems. The author discusses the various protection schemes and technologies used for different power system components, including generators, transformers, transmission lines, and distribution systems. The paper also explores the challenges and opportunities for future developments in protection coordination [7]. This paper focuses on protection coordination for microgrids, which are small-scale power systems that can operate independently or in connection with the main grid. The authors review the various protection schemes and technologies used in microgrids. The paper also discusses the challenges and opportunities for future developments in protection coordination for microgrids [8].

Highlights a review of recent developments in protection coordination in power systems, including the use of advanced protection schemes and technologies, such as digital protection, adaptive protection, and differential protection. The authors also discuss the challenges and opportunities for future developments in protection coordination, including the integration of renewable energy sources and the integration of information and communication technologies [9]. This study presents research on finding the optimal settings for overcurrent relays in power systems. Overcurrent relays provide protection against faults and ensure the stability of the system. The authors propose a method for determining the optimal settings for these relays based on mathematical optimization techniques. The method takes into account various factors such as relay sensitivity, fault clearing time, and system stability to determine the optimal settings. The results of the proposed method are compared with traditional methods and it is shown that the proposed method provides better protection and improved system stability [10]. This research focuses on the coordination of overcurrent relays in power systems. Overcurrent relays are a protective device used in electrical power systems to trip a circuit breaker in the event of an overcurrent condition, such as an excessive current flow caused by a short circuit or a fault [11]. This article discusses the optimization of overcurrent relay coordination in power systems. Overcurrent relays are protective devices that are used in electrical power systems to trip a circuit breaker in the event of an overcurrent, such as a short circuit or fault [12]. This paper presents a new approach for determining the optimal setting of overcurrent relays in power systems using the ABC algorithm, which is a nature-inspired optimization algorithm. The algorithm considers various factors, such as system configuration, fault conditions, and relay settings, to determine the optimal setting for each relay [13], [14] focuses on the study of overcurrent relay settings in power systems. Overcurrent relays trip a circuit breaker in the event of a fault [15]. The authors evaluate the performance of the improved bat algorithm through simulation studies and compare it with other commonly used methods for overcurrent relay coordination.

The results show that the improved bat algorithm provides improved performance over traditional methods, leading to a more effective and reliable protection system [16]. propose a new approach for determining the optimal setting of overcurrent relays in power systems using the firefly algorithm. The algorithm takes into account various factors, such as system configuration, fault conditions, and relay settings, to determine the optimal setting for each relay [17]. Author focuses on the protection coordination in substations using distance and impedance relays [18]. Researchers analyze various protection coordination methods and techniques used in electrical power systems and provide an overview of their advantages and disadvantages. The study in [19] provides a comprehensive review of the state-of-the-art techniques for protection coordination in substations. author discusses various protection coordination methods, including time-current characteristics and impedance relay coordination, and provides a detailed analysis of their advantages and disadvantages [20]. Discusses various protection coordination methods, including traditional time-current characteristics and modern techniques based on optimization algorithms [21].

The paper discusses various protection coordination methods, including traditional time-current characteristics, modern techniques based on optimization algorithms, and techniques based on artificial intelligence. provides a comprehensive review of the various techniques used for protection coordination in substations [22]. Authors conducted a review of protection coordination in substations and discuss the different types of protection schemes and the role of relays in protection coordination [23]. The research conducted a review of protection coordination in substations, focusing on the recent advancements in the field. They discuss the different types of protection schemes and the challenges of protection coordination. However, during converter pulse operation, high derivatives of either voltages dv/dt and currents di/dt cause electromagnetic interference (EMI) [24]–[26]. Protection coordination is a critical aspect of power system operation and control that plays a key role in ensuring the safe and reliable distribution of electrical energy. The use of various protection schemes and technologies, as well as the challenges and opportunities for future developments, have been thoroughly reviewed in the above literature.

2. MATHEMATICAL MODELLING FOR PROPOSED SCHEME

The over-current relay senses the over-current (3 to 4 times greater than normal current) and sends the signal to the circuit breaker to trip [4]. It includes a time delay element and an instant element. It includes instantaneous settings and time dial settings along with Time characteristic curves [5]. For larger amount of current, the relay must take very short period of time to operate [6]. Equation of relay setting are covered in the following section. Whereas, the ratings of equipment, used in the system model is enlisted in Table 1. Equations for relay settings

- Full load current:

$$I_{FL} = \frac{\text{MVA}}{\text{V}*\sqrt{3}} \quad (1)$$

- Fault current:

$$I_F = \frac{\text{MVA}}{\text{V}*\sqrt{3}*\%\text{Z}} \quad (2)$$

- Pick up current = 120% *full load current [7]:

$$Pickup\ setting\ of\ relay = \frac{\text{Pickup current}}{\text{Current transformer ratio}} \quad (3)$$

- Plug setting multiplier [6]:

$$PSM = \frac{\text{Fault current}}{\text{Pickup current}} \quad (4)$$

- Time setting multiplier/time dial:

$$TSM = \frac{\text{t}(\text{PSM}^{0.02}-1)}{0.14} \quad (5)$$

T = operating time, where t = 0. The Pick-up current is the one at which the relay starts to operate. Fault current is the current which occurs during fault [8].

Table 1. Ratings of equipment

Equipment	MVA ratings	Voltage (kV)	Equipment	MVA ratings	Voltage (kV)
Grid	6.5	11	Electrical lumped load	0.1	0.433
Electrical mechanical substation	0.2	11/0.433	Mechanical lumped load	0.1	0.433
Architecture substation	0.5	11/0.433	Architecture lumped load	0.4	0.433
BSRS substation	0.25	11/0.433	BSRS lumped load	0.2	0.433

3. METHODOLOGY

In order to model the system, ETAP software has been used, which is regarded as being the most comprehensive software for designing, planning, and simulating. This software has been extensively used in many powers flow calculation. One of the major advantages lie in simplifying the complex problems in the field of electrical engineering. This software is now an essential play an essential part in the design of power system. In the proposed study, the system is simulated by considering the fault analysis on various substations of a smaller section of a power system.

3.1. Modelling of electrical and mechanical substation

The system consists of protective devices like main vacuum circuit breaker (VCB), relay, current transformer. It is also comprised of distribution transformer, departmental circuit breaker, relay, current transformer and electrical, mechanical lumped load (ELME). ETAP Model of the system is depicted in Figure 1(a). The model comprises of all elements from grid to load.

3.2. Modelling of architecture substation

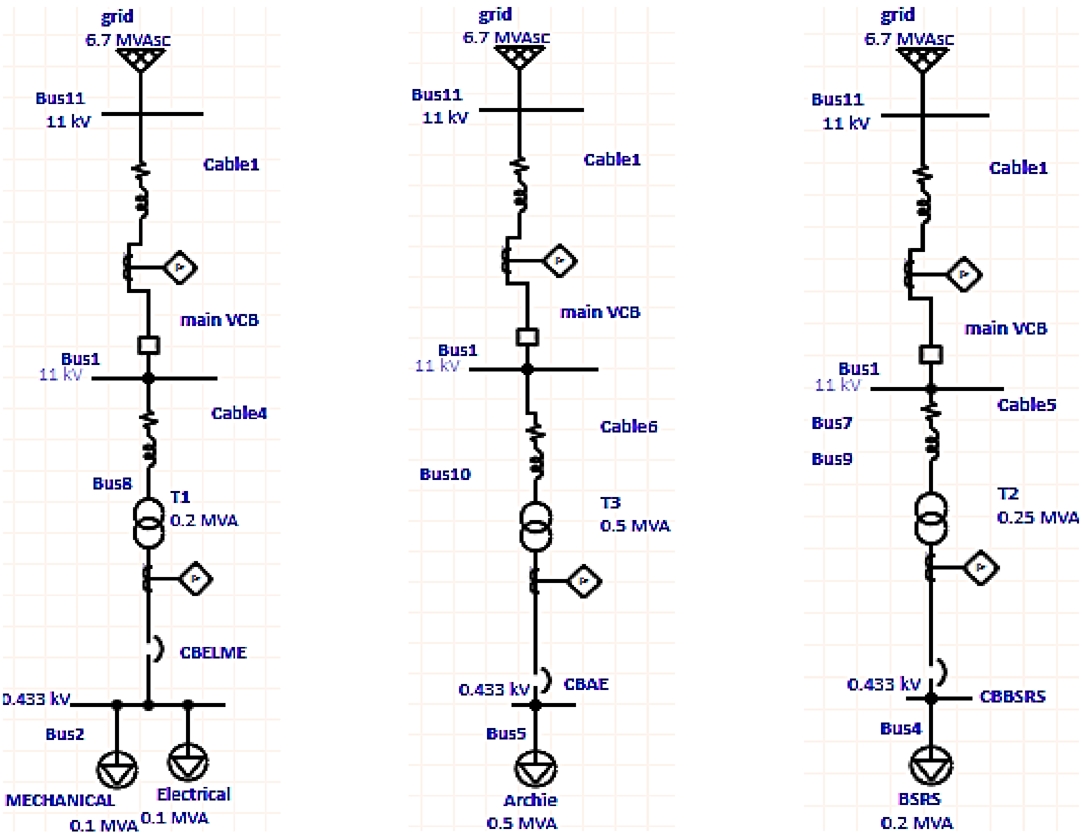
The system consists of protective devices like main vacuum circuit breaker (VCB), relay, current transformer. It also comprises of distribution transformer, departmental circuit breaker, relay, current transformer and architecture lumped load (AE). ETAP Model of the system is depicted in Figure 1(b). The model comprises of all elements from grid to load.

3.3. Modelling of BSRS substation

The system consists of protective devices like main vacuum circuit breaker (VCB), relay, current transformer, distribution transformer, departmental circuit breaker, relay, current transformer and BSRS lumped load (BSRS). ETAP model of the system is depicted in Figure 1(c). The model comprises of all elements from grid to load.

3.4. Mathematical calculations of overcurrent relays

In this section, calculations are performed on the basis of fault analysis. Over current relays majorly work on inverse time characteristics. A general concept of plug setting multiplier (PSM) and time setting multiplier (TSM) is employed to obtain their numeric values. Mathematical calculations are carried out by using the ratings mentioned in the Table 1.



(a) (b) (c)

Figure 1. Model of (a) electrical, mechanical substation, (b) architecture substation, and (c) basic sciences and related studies substation

3.4.1. Mathematical calculation of the main relay

The mathematical calculation of the main relay is as follows:

- From (1): $Full\ load\ current = 341.1$ Amps, hence, current transformer ratio = 400/5
- From (2): $Fault\ current = 34117.11$
- From (3): $pick\ up\ setting\ of\ relay = 5.1\ or\ 1xCT\ (SEC)$
- From (4): $PSM = 83.3$
- From (5): $TSM = 0.33$, where = 0.5

3.4.2. Mathematical calculation of electrical mechanical relay

The mathematical calculation of electrical mechanical relay is as follows:

- From (1): $Full\ load\ current = 266.6$ Amps. Hence, current transformer ratio = 300/5
- From (2): $Fault\ current = 26660$
- From (3): $Pickup\ setting\ of\ relay = 5.3\ OR\ 1XCT\ (SEC)$
- From (4): $PSM = 83.3$
- From (5): $TSM = 0.33$, where t=0.5

3.4.3. Mathematical calculation of architecture relay

The mathematical calculation of architecture relay is as follows:

- From (1): $Full\ load\ current = 666.7$ Amps. Hence, current transformer ratio = 700/5
- From (2): $Fault\ current = 66670.5$
- From (3): $Pickup\ setting\ of\ relay = 5\ OR\ 1XCT\ (sec)$

- From (4): $PSM = 83.3$
- From (5): $TSM = 0.33,$ where t=0.5

3.4.4. Mathematical calculation of basic science and related studies (BSRS) relay

The mathematical calculation of basic science and related studies (BSRS) relay is as follows:

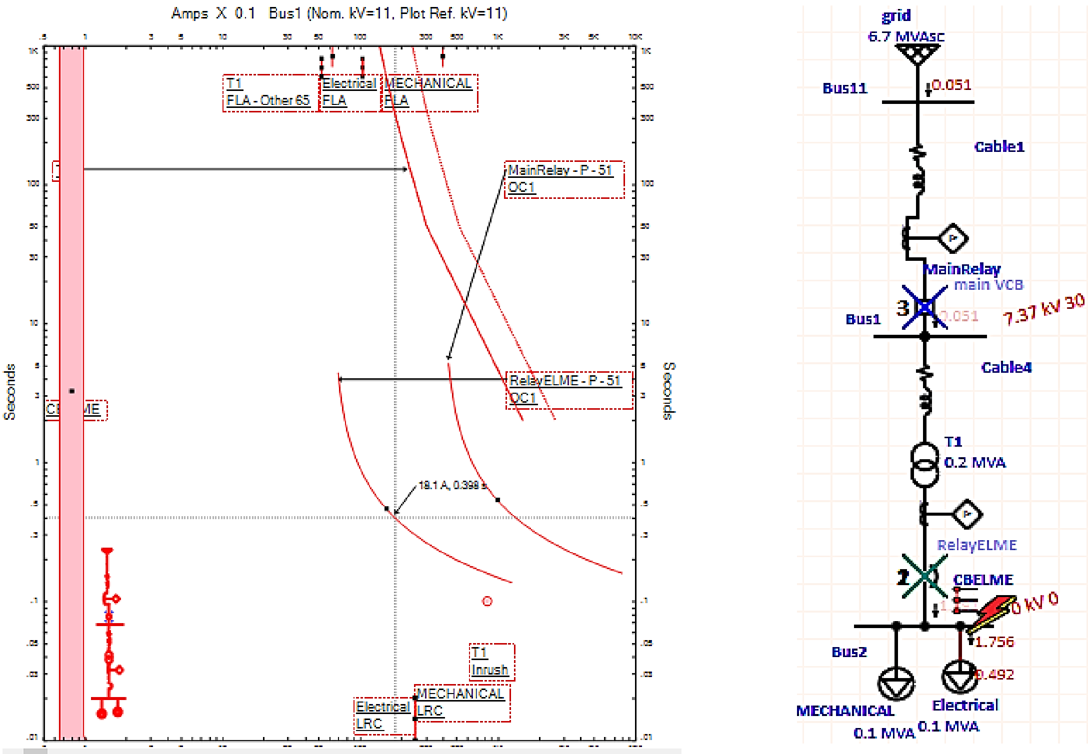
- From (1): $Full\ load\ current = 333.3$ Amps. Hence, current transformer ratio = 400/5
- From (2): $Fault\ current = 33336.2$
- From (3): $Pickup\ setting\ of\ relay = 5.7\ OR\ 1\ XCT\ (sec)$
- From (4): $PSM = 83.3$
- From (5): $TSM = 0.33,$ where t=0.5

4. RESULTS AND DISCUSSION

Results describe the over current characteristics of the fault current. Time characteristics curve shows the relation between the current and time. According to Inverse Time characteristics, the protection system activity is inversely proportion with time. In simple words, it describes how fast the breaker trips at any magnitude of current.

4.1. Time current characteristics curve of electrical/mechanical substation

Two curves show the relay operation, when a fault occurs. Figure 2(a) shows time characteristics curve of the substation. Figure 2(b) shows ETAP model of the substation. The relay (connected at electrical mechanical substation) will trip first and then the main relay will operate as shown in Figure 2(a). Figure 2(b) describes the protection coordination.



(a) (b)

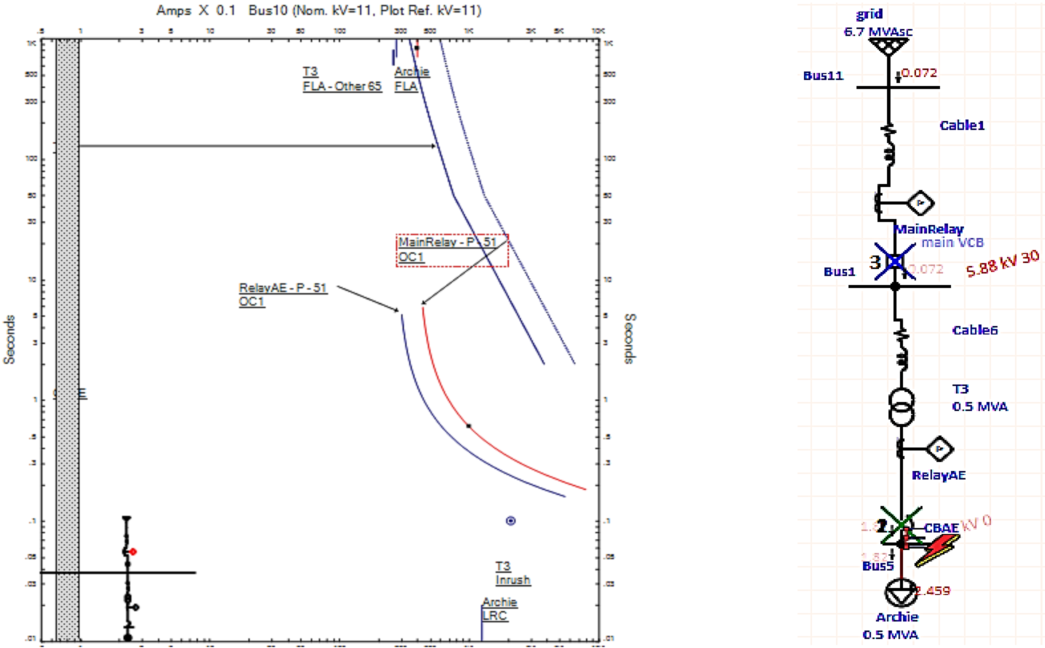
Figure 2. Protection coordination of electrical, mechanical substation based on (a) TCC curve and (b) ETAP model of substation

4.2. Time current characteristics curve of architecture substation

Two curves show the relay operation, when a fault occurs, the relay (connected at Architecture substation) will trip first. The main relay will only operate once the fault is occurred at that substation, thereby isolating the faulty area. Time characteristics curve is depicted in Figure 3(a). Figure 3(b) describes the protection coordination.

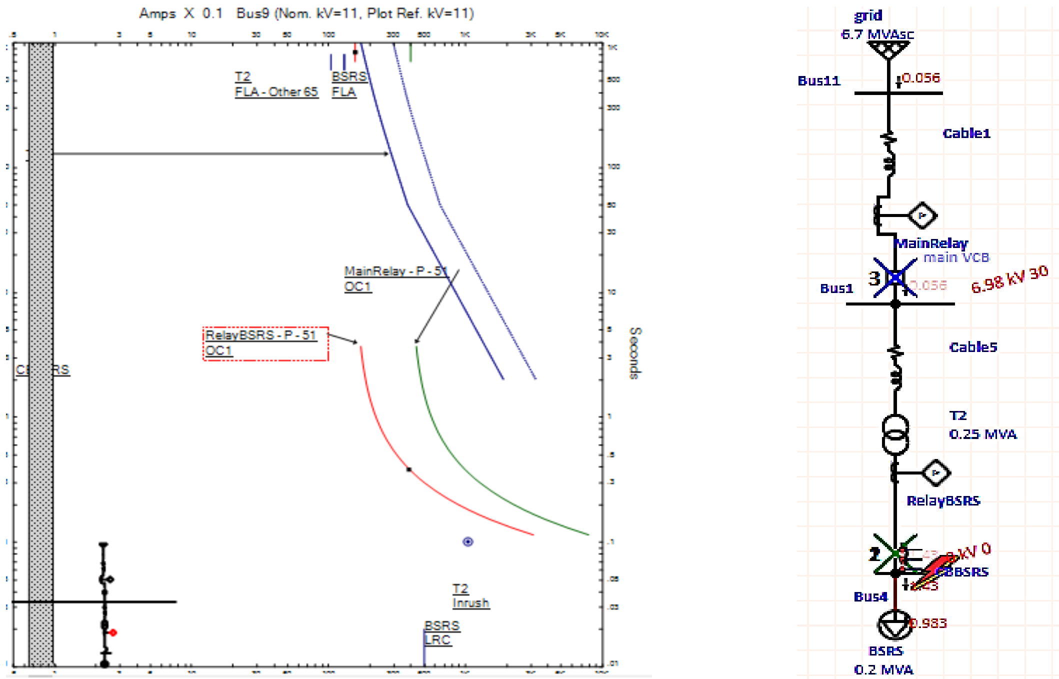
4.3. Time current characteristics curve of basic science and related studies substation

Two curves show the relay operation, when a fault occurs, the relay (connected at basic science and related studies substation) will trip first. Once that relay is tripped then the main relay will operate, thereby isolating the faulty portion. Time characteristics curve is depicted in Figure 4(a). Figure 4(b) describes the protection coordination.



(a) (b)

Figure 3. Protection coordination of architecture substation based on (a) TCC curve and (b) ETAP model of substation



(a) (b)

Figure 4. Protection coordination of BSRS substation based on (a) TCC curve and (b) protection coordination of substation

The results describe the effectiveness of protection coordination in substation. The ETAP results show that if a fault occurs at any department, the relay connected at the substation sends the signal to nearer circuit breaker and it will trip. After 2 ms, if that circuit breaker fails to operate then the main vacuum circuit breaker will trip (at 3rd msec). The results highlight the contribution of relays and circuit breaker in preventing an all-out breakdown of the substation.

5. CONCLUSION

In summary, protection coordination can be properly accomplished when primary relays operate first. During a fault condition, if the primary relay does not work, then the second relay will operate to isolate the faulty part from the rest of the system, enabling us to supply power to the healthy part of the system without delay and reducing the severity of the fault. We can use delayed operation by increasing the time for relay operation. To achieve this, circuit breakers associated with that relay are operated at longer intervals.

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