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Coordination of Overcurrent Relay for Radial and Parallel feeder Networks

Acharya Sandesh, Shrestha Ravi, Tamang Nishchal and Jha Shailendra Kumar
Department of Electrical and Electronics Engineering, Kathmandu University, Dhulikhel, Nepal
sandeshacharya11@gmail.com

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Abstract

Location of the fault is very important in power systems and its clearance should be carried out quickly to ensure continuous power supply to the load. Protection of the devices and their coordination is a crucial part for minimizing the fault. The research is focused on the simulations and analysis of over current relays' coordination for radial and parallel feeder networks. This research work provides coordination of overcurrent relays for the radial and parallel feeder networks analyzing the time current characteristics. Observations and setup for radial and parallel feeder network is experimented in the electrical lab. Hardware implementation and study of time of operation of overcurrent relays is compared with the simulation result and findings from the ETAP software. For effective coordination of the relays, coordination among the relays and the respective protective devices are focused. Backup protection for the primary relay is achieved through the effective coordination time interval between the relays. Proper relay coordination effectively clears out the fault thus making the protection more reliable. The minimization of fault durations and backup protection to the primary protection is major concern of this research.

Keywords: Overcurrentrelay, Coordination, Radial and parallel feeder, IDMT relay, Protective relaying

Introduction

The ability of the protective equipment is to minimize damage when failures occur. To have a minimum disturbance and clearance of fault in power system, it is important to determine the location of the fault and the distance where the fault has occurred. This enhances quick and reliable operation of power protection of the devices. The fault circumstances must be analyzed for the adequate and systematic protection. In case of any short circuit or any kind of electrical faults, it is required that any of the protective devices should not be damaged without taking down the whole system. It is therefore necessary to coordinate among different protective devices.

One of the critical and important elements in the family of power system is the overcurrent protection. This protection helps to protect in case of over current flowing through the branches or the feeders due to overload or short circuit.

Overcurrent protection is very important element in power systems. This protection is essential in order to minimize disturbances caused by any failure in the system and to ensure continuous power delivery. Overcurrent relays are one of the devices used to achieve these purposes. The overcurrent relays initiate the corrective mechanism to determine the operation time of the relay. Thus, the overcurrent relays must have high reliability and accuracy to detect any fault currents present and determine the operation time. The entire system will be tremendously affected if the relays fail to trip or cause mal-tripping[1].

Overcurrent and overload protection functions for both low-voltage and high-voltage of electric power (and also electric networks) are usually realized on current relays with dependent or independent time delay characteristics, or on high-speed differential relays or impedance (distance) relays (for power line protection). Electromechanical protection relays with instantaneous pick-up characteristics frequently provide even higher speeds[2].

For the effective operation in protective power system, protection of the device and equipment is crucial. Therefore, coordinating among different relays must be analyzed and enhanced with great importance. Active involvement of overcurrent relays helps to identify and protect from major kinds of faults in real power system scenario.

Protective relaying is necessary with almost every electrical plant and no part of the power system is left unprotected. The choice of protection depends upon several aspects such as type and rating of the protected equipment, its importance, location, probable abnormal conditions, cost, etc. The primary function of the relay is to operate only if a fault occurs and not under normal operation conditions. A protective relay senses the fault, identifies the location of the fault and sense a command signal to the appropriate device. After implication of proper relay coordination there will be efficient fault clearance. Thus, the protection scheme will be more reliable[3].

To carry out the real and proper settings of the protective relays, it is important to consider the adjustments in the relays. An active role of the overcurrent relay in the design procedure has great significance. To trip off the respective device, it is necessary to set correct values of TSM and TD appropriately. If in case the adjustment is not accurate, there can arise serious conditions in the faulty party and might damage the protective devices.

Proper settings of protective relays are essential for the reliable operation of electrical power systems, during both fault and normal system operating conditions. The ideal relay operating characteristics can also be influenced by parasitic phenomena, such as CT saturation[4].

For an overcurrent relay, time dial setting determines the actual operating time of the relay whereas plug setting determines the required amount of current values to be picked up. If the value of the PSM is less than one, it signifies that normal current is flowing in the circuit and there is no tripping of the devices. As the value of PSM is greater than one, it signifies now that larger value of current is flowing which is normally the fault current. The more value of PSM signifies that the multiples of larger current flowing. This can be much severe in the feeders or the branch. Hence the overcurrent relays should be operated as quickly as possible with a minimum interrupting time.

The protective relays are supposed to detect the fault with the help of current and voltage transformers, and selectively remove only the faulty part from the rest of the system by a tripping an appropriate device. The relay has to do with utmost sensitivity, selectivity and speed. In a power system, faults are not an everyday occurrence.

It is a normal practice to provide zone of protection which should operate and isolate the faulty element in case the primary protection fails. Further, the back-up protection must wait for the primary protection to operate, before issuing the trip command to its associated devices[5].

In other words, there should be delay in the back up protection over the primary protection by an appropriate amount so that back up protection holds some time to operate before tripping the primary protection. Thus, the coordinating time interval of the backup protection should be either greater than or equal to the operating time interval of the primary protection plus the operating time of the primary device. Whenever a fault occurs, it should be possible to interrupt the smallest section of the circuit to minimize the disruption of the supplies and coordination along with other protection device is exclusively important to achieve this.

Methodology

The methodologies adopted for the research work are enlisted below: i. Experimental setup for radial and parallel feeder protection coordination. ii. Simulation of radial and parallel feeder protection using ETAP

The experimental setup for the radial and parallel feeder protection consists of a CT, an overcurrent relay and contractors. The setup for this research activity is carried out in electrical lab of Kathmandu University. The setup is designed in a control box and the arrangement is made so as to experiment for both the radial and parallel feeder in a single control box. There are fault indicators in the control box whenever the overcurrent relay senses the fault and trips off the respective contractors. The change in load in the feeder side is provided through the variable resistors in the laboratory. The pickup values and the time dial setting of the relay have been adjusted according to the fault current. Different timing sequences of the relay have been observed at different pickup values of the current and the TDS.

The radial and parallel feeders have been simulated in the ETAP software. The overcurrent relays have been coordinated and the timing sequence of the relays is noted. The time of operation of the relays are observed for same values of pickup and TDS setting according to the experimental observations. The timing of operation is noted and the difference in time analysis is compared with the obtained results from the hardware and software simulations.

Results and Discussion

Experimental Study and analysis for Radial Feeder: In radial feeder, the flow of power or the current is in single direction which is from source to load under normal operating condition. The feeder is divided into different buses and each bus has been provided with relay and contractors. The experimental setup is adjusted in such a way that the relay nearest to the load has minimum time setting that operates instantly when higher current flows while time setting of other relays which acts as a backup to the primary has greater time delay setting. In the laboratory, he rated load is 3kVA is used which draws a load current of 4.33 full load ampere (FLA).

In the distribution feeder network shown in Figure-1, relay R4 has the responsibility of isolating the faulty section. Relays R1, R2, R3 and R4 are primary relays for faults for bus 1, bus 2, bus 3 and bus 4 respectively. Whenever fault is not cleared by R4 by the provided protective relay scheme, relays R3, R2, R1 works as back up protection. For fault in distributor side, ohmic value of load rheostats is increased while observing experimentally. In actual practice C.T. secondary rated current (1 Amp or 5 Amp) is used and relay rating should be same.

Figure-1 shows the radial feeder network where four contractors and relays are placed in series. Referring to the Figure-1, a lineis passed through the control circuit which contains the contactor and the current transformer which outputs to the over current relay. The faults in the laboratory are provided through the variable resistors. On occurrence of fault, the corresponding section relay will operate and the concerned auxiliary relay 3, 2 or 1 will energize giving signal to the concerned contactor and making it off. This will also activate the indicator which can be reset using reset button. Back up can be shown by using relays depending on their time of operation. Time of operation of relays can be measured by a time–interval counter connected or a stop watch.

When a fault occurs, both the primary relay OCR4 and the back-up relay OCR3, starts operating simultaneously. In case the primary protection (provided by OCR4 + Cont4) operates successfully, the bus 5 and the line gets de-energized but the loads on other buses remain unaffected. Therefore, the back-up protection provided by OCR3 + Cont3 resets without issuing a trip command. However, in case the primary protection fails to operate, the back-up which is already monitoring the fault, waits for the time in which the primary would have cleared the fault and then issues the trip command to its allied contractors. When the back-up operates, the time for which the fault persists is longer and disruption to the loads also lasts longer.

ETAP simulation and analysis for radial feeder: A fault is inserted in the load side (feeder side) which shows a fault current of 0.866kA at Bus 5 as shown in Figure-2. OCR4 senses the fault current and operates the Cont 4 to operate**.** The pickup value of the OCR4 is set at 8.34*CT sec and the TD at 0.2. From the ETAP simulations the operating time of the OCR 4 is observed 20.4ms. The Cont 4 is operated at a period of 10ms. The total time of operation for the primary protection of the load by OCR 4 and Cont 4 is 30.4ms. Similarly, OCR 3 has the pickup value of 9.92*CT sec and TD at 0.4. OCR 3 is operated at a period of 40.8ms and Cont3 at 10ms. This sequence of operation of the relays is depicted by the Table-1.

Figure-3 shows the coordination of the overcurrent relays simulated in ETAP for the radial feeders. In radial feeder, for a single load system, all the bus voltages are same which is 0.4kV and the fault current in the feeder side or the load side is 0.866kA. The coordination curve shows that with the increasing in fault current, lesser the time of operation of relay. With the further increase of the current, backup relays comes in pictures immediately thus tripping off the respective contractor sequentially. If the contractor nearest to the fault fails to trip off, the nearer contractor next to the faulty section comes to the action quickly.

Analyzing the backup protection, the coordination time interval between the OCR4 and OCR3 is (40.8-20.4) ms=20.4ms. This time indicates that after 20.4 ms difference OCR3 relay comes in action serving the backup protection to the OCR4 relay which is a primary protection to the fault current occurring in the load side and results in breakdown of the circuit. The CTI between the load side or the feeder side relay OCR1 and source side relay OCR4 is (91.7ms-20.4ms) =71.3ms. This interval of time is effective to prevent the fault current flowing to the healthy part of the loads. The timing sequence of the relays and the contractors is shown in Figure-4 for the radial feeder network.

Experimental observations for radial feeder: The Table-1 shows the time of operation for different relays for radial feeder where OCR4 is the primary protection for the load side (feeder side). Table-1 shows that for the OCR1, TD=0.2 the time of operation is 19.87ms. Similarly, for the OCR2, TD=0.4 the time of operation is 36ms, for OCR3 TD=0.6 the time of operation is 60ms and for OCR4 TD the time of operation is 89ms. The CTI between OCR1 and OCR2 is (36-19.87) ms=16.13ms. Typically, the process is repeated for different TD values of the overcurrent relays and different timing operations are noted.

For the fault current of 0.8666kA, the time of operation of the OCR1 from the ETAP simulation result is 20.4ms (Table-1) and the hardware output result is 19.87ms (Table-2). The difference in time analysis is (20.4-19.87) ms =0.53ms. Similarly, for the OCR4 the time of operation from the ETAP simulation is 91.7ms and from the hardware output result is 89ms. The difference in time analysis is 91.7ms-89ms=2.7ms.

Experimental Study and analysis for Parallel Feeder: In parallel feeder, the power flows indifferent paths from source to load. The network is divided into different branches and each branch is provided with relay and contractors.

To maintain the stability of the system, it is necessary to feed a load from the source by two or more than two feeders placed in parallel. If fault occurs in any part of the feeders or the section, then that particular section of the feeder is isolated from the system to maintain the continuity from the supply to the load side. This requirement of protection is fulfilled by the parallel network connection than a radial feeder network[6].

Figure-4 shows the parallel feeder network with two relays in one branch and the two relays in the next branch connected parallel for a single phase system. According to the Figure-4, for the fault at bus 3, either Cont4 or Cont2 should trip. Similarly, Cont3 or Cont1 should provide backup protection to the Cont4 or Cont2 respectively for the occurred fault at bus 3.When fault occurs at bus 3, if OCR4 operates then it should operate the Cont4 and OCR3 provides the back up to OCR4. This means that the time of operation of OCR3should be more than that of OCR4, current being the same.

ETAP simulation and analysis for parallel feeder: A fault is inserted at bus3 which a fault current of 1.45kA on the load side as shown in Figure-5. Since the network has two branches the fault current divided to 0.727 kA equally in each branches. Since the fault current is divided equally in each of the branches, OCR4 and OCR2 senses the fault current and trips off the respective contractors to operate sequentially. OCR4 sensed the fault current and operated Cont4 and OCR2 operated Cont2.

Figure-6 shows the coordination of the overcurrent relays simulated in ETAP for the parallel feeder networks. In parallel feeder network, for a single load system, all the bus voltages are same which is 0.4kV and the fault current in the feeder side or the load side is 1.45kA. The coordination curve shows that with the increasing in fault current, primary protection is achieved more quickly with lesser time of operation of relays. With the further increase of the current, backup relays comes in pictures immediately thus tripping off the respective contractor sequentially.

The pickup value of the OCR4 is set at 12*CT sec and the TD at 0.05. From the ETAP simulations the operating time of the OCR4 is observed 26.5ms. The Cont4 is operated at a period of 10ms. The total time of operation for the primary protection of the load by OCR4 and Cont4 is 36.5ms. Similarly, OCR2 has the pickup value of 12*CT sec and TD at 0.05. OCR2 is operated at a period of 85.6ms and Cont2 at 10ms. This sequence of operation of the relays is depicted by the Table-3. OCR3 and OCR1 provide the backup protection to the primary relays for the same fault current in each respective branches of the parallel feeder network.

The overcurrent relay 4 trips off at time 40.8ms disconnecting the fault current in lower branch of the feeder. Since same fault current is flowing in the upper branch of the feeder relay 3 senses the fault current and trips off the circuit at time period 20.4ms disconnecting the fault current. The backup protection for the OCR4 is provided by Cont. 3 tripping at a time of 227ms and for the OCR2 is provided by OCR1 tripping at a time period of 463ms. Analyzing the backup protection, the coordination time interval between the OCR4 and OCR3 is (227-26.5) ms=200.5ms. This interval of time is effective to prevent the fault current flowing to the healthy part of the loads. The timing sequence of the relays and the contractors is shown in Table-3 for the parallel feeder network.

Experimental observations for parallel feeder: The Table-2 shows the time of operation for different relays for parallel feeder observed in hardware. The arrangement setup for the parallel feeder is arranged according to the Figure-4 and a load of 3kVA is supplied which draws 4.33 FLA. Table-4 shows that for the OCR4, TD=0.05 the time of operation is 20.2ms. Similarly, for the OCR3, TD=0.05 the time of operation is 195ms. For OCR 2, TD=0.1 the time of operation is 80.3ms and for the OCR1, TD=0.1 the time of operation being 460.5ms. Typically, the process is repeated for different TD values of the overcurrent relays and different timing operations are noted.

For the fault current of 1.45kA, the time of operation of the OCR4 from the ETAP simulation result is 26.5ms (Table-3) and the hardware observation is 20.2ms (Table-2). The difference in time analysis is (26.5-20.2) ms=6.3ms. Similarly, for the OCR2, the time of operation from the ETAP simulation result is 85.6ms and the hardware observation is 80.3ms. The difference in time analysis is (85.6-80.3) ms=5.3ms.

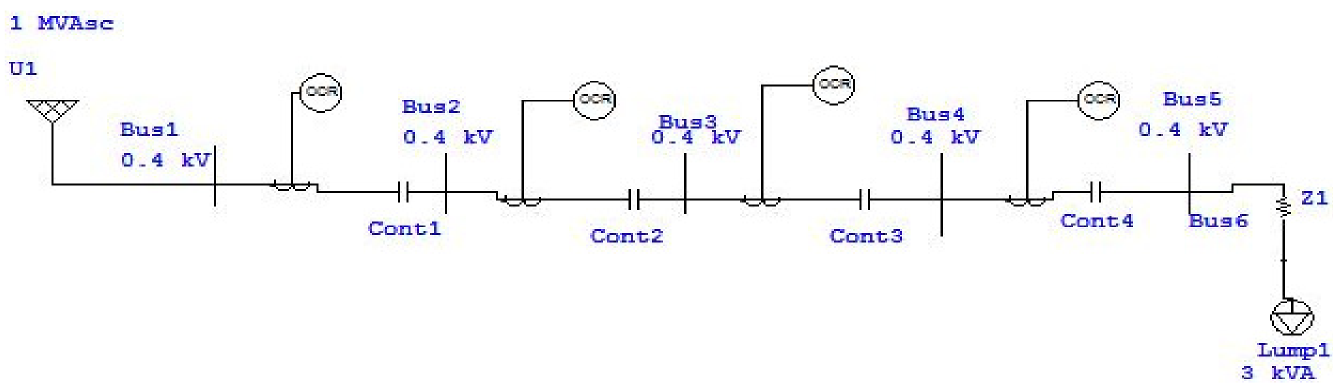

Figure-1
Radial feeder Network

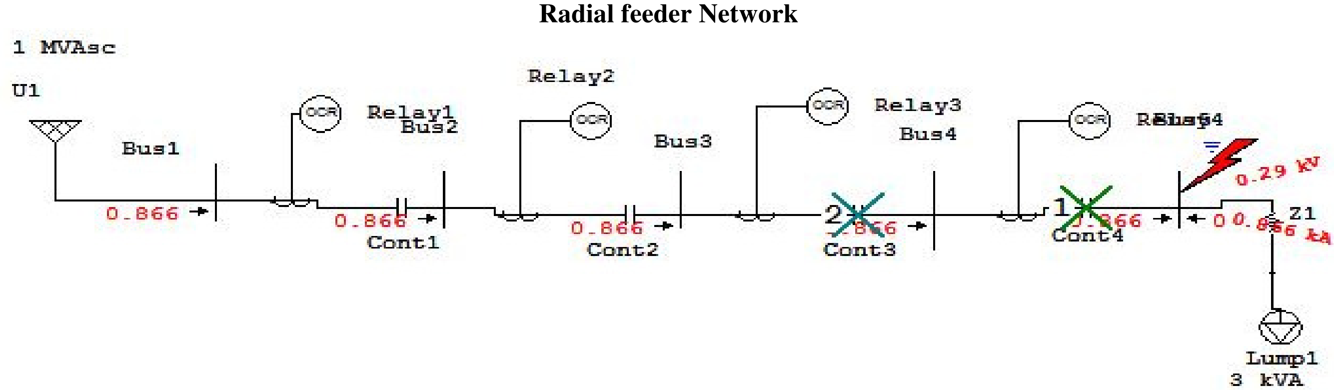

Figure-2
Fault insertion at Bus5 showing fault current 0.866kA and tripping of the respective devices

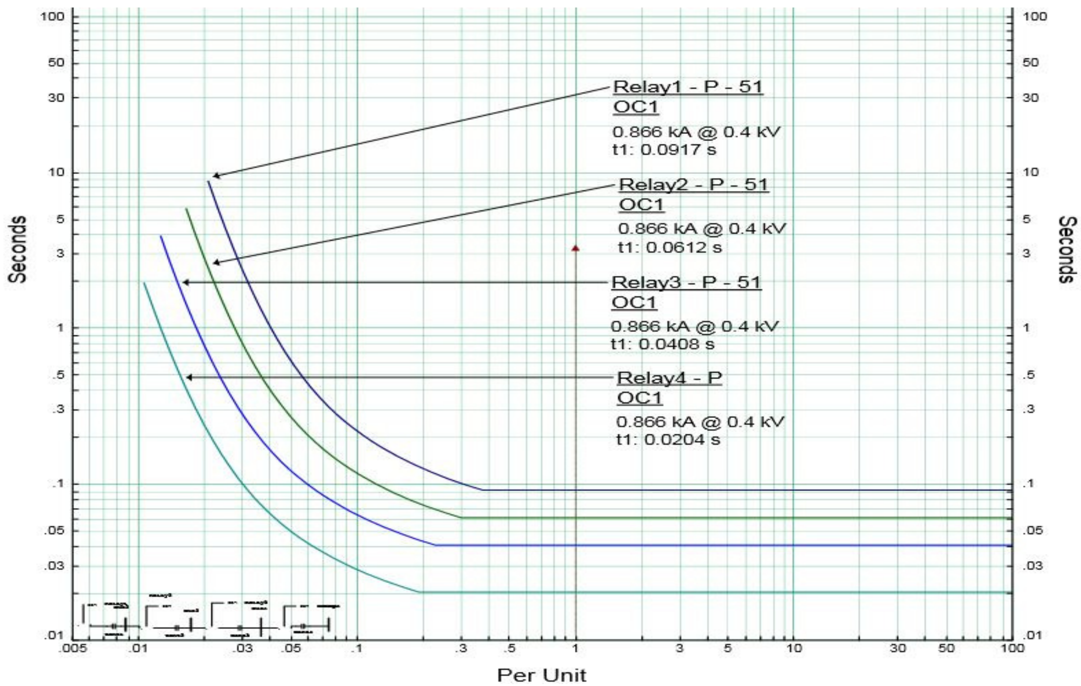

Figure-3

Coordination of the overcurrent relays for the radial feeder networks

Table-1

Sequence of timing operations for overcurrent relays and the contractors for radial feeder network

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
20.4	Relay4	0.866	20.4		Phase - OC1 - 51
30.4	Cont4		10.0		Tripped by Relay4 Phase - OC1 - 51
40.8	Relay3	0.866	40.8		Phase - OC1 - 51
50.8	Cont3		10.0		Tripped by Relay3 Phase - OC1 - 51
61.2	Relay2	0.866	61.2		Phase - OC1 - 51
71.2	Cont2		10.0		Tripped by Relay2 Phase - OC1 - 51
91.7	Relay1	0.866	91.7		Phase - OC1 - 51
102	Cont1		10.0		Tripped by Relay1 Phase - OC1 - 51

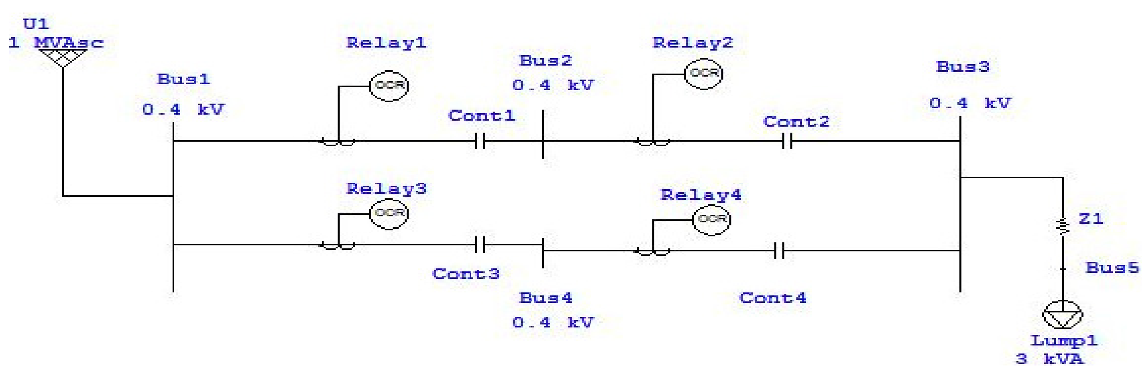

Figure-4

Parallel Feeder Network

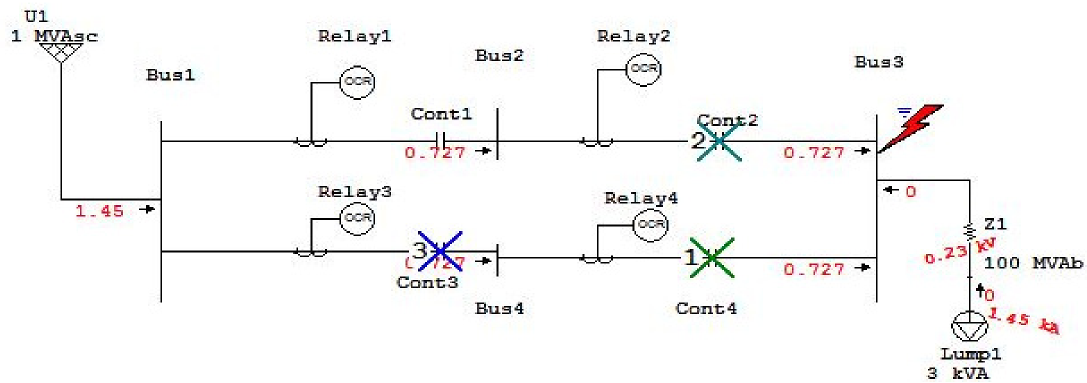

Figure-5
Fault insertion at Bus5 showing fault current 1.454kA and tripping of the respective devices

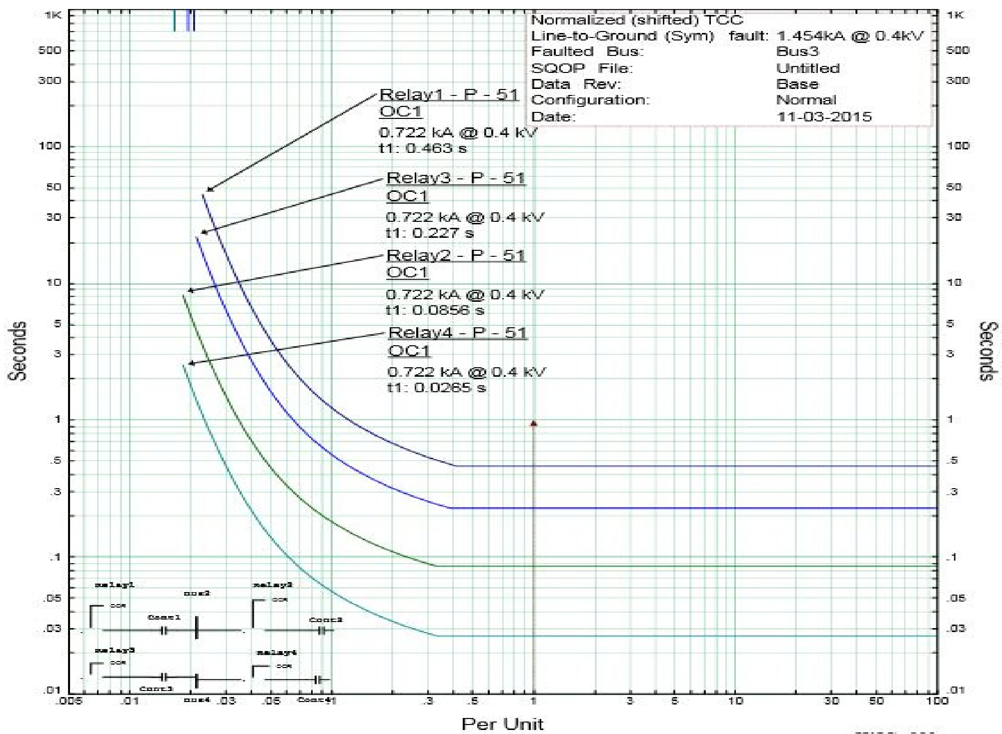

Figure-6
Coordination of the overcurrent relays for the parallel feeder networks

Table-2
Time of operation for overcurrent relay at different values of time dial setting for radial feeder

S.N.	OCR4		OCR3		OCR2		OCR1	
	TD	Time(ms)	TD	Time(ms)	TD	Time(ms)	TD	Time(ms)
1	0.2	19.87	0.4	36	0.6	60	0.8	89
2	0.4	39.3	0.6	66.2	0.8	83.9	0.9	109.8
3	0.6	69.4	0.8	89.5	0.9	106.5	0.95	580.8
4	0.8	92.6	0.9	102.3	0.95	592.4	1	1150

Table-3
Sequence of timing operations for overcurrent relays and the contractor for parallel feeder network

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
26.5	Relay4	0.722	26.5		Phase - OC1 - 51
36.5	Cont4		10.0		Tripped by Relay4 Phase - OC1 - 51
85.6	Relay2	0.722	85.6		Phase - OC1 - 51
95.6	Cont2		10.0		Tripped by Relay2 Phase - OC1 - 51
227	Relay3	0.722	227		Phase - OC1 - 51
237	Cont3		10.0		Tripped by Relay3 Phase - OC1 - 51
463	Relay1	0.722	463		Phase - OC1 - 51
473	Cont1		10.0		Tripped by Relay1 Phase - OC1 - 51

Table-4
Time of operation for overcurrent relay at different values of time dial setting for Parallel feeder

S.N.	OCR4		OCR2		OCR3		OCR1	
	TD	Time (ms)	TD	Time (ms)	TD	Time (ms)	TD	Time (ms)
1	0.05	20.2	0.1	80.3	0.05	195	0.1	460.5
2	0.05	20.2	0.2	550	0.1	460.2	0.2	590
3	0.1	80.3	0.2	552.6	0.2	587.1	0.25	634.2
4	0.2	556	0.25	663	0.25	660	0.3	756.8
5	0.3	755	0.4	986.5	0.3	750	0.4	994.2.5

Conclusion

The overcurrent relay protection provided the clearance of the faulty part by detecting alteration in current values of the radial and parallel feeder lines. Coordination of the relay is observed to be crucial for minimizing the fault. The use of the overcurrent protection in power system is achieved for radial or parallel feeder which required proper coordination of settings, operating times and its characteristics. IMDT relays, its specifications and their time current characteristics are analyzed and observed in ETAP simulations. The observed characteristics resulted that coordinating time interval between the overcurrent relays and the protective devices is effective enough to carry the fault clearance. The relay pick-up values, PSM and TD setting adjusted according to the fault current in the feeders showed the inverness characteristics of the overcurrent relay. Fault insertion in the buses of the feeders helped in the study of fault current simulation and proper time setting of the protective relays and devices. Backup protections to the primary devices are achieved though the study of time-current characteristics and the operating time of the protective devices.

Experimental observations for the radial and parallel feeder in the electrical laboratory are carried out to study the real scenario of the operation time of the overcurrent relays. Different observations were noted for the change in pickup values and time dial settings in the laboratory which revealed that higher the step of fault current, operation time is directly proportional to it. The obtained time of operation from the experiment were compared with the simulations from the software.

This research work does not analyze the characteristics of overcurrent relays which could be further expanded by detailed review of these properties and selection of reverse power relay or directional relay for reverse current flow in parallel feeders on the load side.

Abbreviations: ETAP: Electrical Transient Analysis Program, FLA: Full Load Ampere, IDMT: Inverse definite minimum time, OCR: Overcurrent Relay, PSM: Plug Setting Multiplier, TDS: Time Dial Setting.

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