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Review Article

DEVELOPMENT OF NUMERICAL RELAY FOR POWER SYSTEM PROTECTION LABORATORY

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Abstract
In Power systems there are different types of Protection relays and one of types is Overcurrent relays. Overcurrent relay protection could be designed in an easy and cost-effective way. That is the reason why the Overcurrent relays are mostly used in electrical motors, generators, power transformers, distribution system and transmission line system protections etc. When the fault current occurs in a power system or in an any electrical equipment crosses the predefined or threshold value, it generates a trip signal to the Electrical Circuit Breaker. This paper mainly concentrates on IDMT relay through the software model. In that model single-phase to ground, line to line and three phase faults are taken as the fault for examining the relay sub-system.

Keywords: Electrical protection, IDMT relay, Transmission line, Over current relay, MATLAB Simulink model of overcurrent relay.

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INTRODUCTION

The Electrical power system mainly consists of generators, motors, distribution, transformers, transmission line etc. All these to be protected while many electrical or mechanical faults occurs in the power system. So, whenever the fault is occurred at any part due to different conditions in the power system, that fault part should be removed from the healthy part of the power system, so that the power system long lasts and the remaining part will be protected. There are many types of protection schemes used in power system for different types of faults, in that over current relay protection is one of the protection schemes. Over current relay system is used whenever the current in the system exceeds its threshold or predefined value, the relay generates the trip signals to the circuit breakers or other protection system. Overcurrent relays are one among the best smooth relays and they are used in power system and its equipment protection. The main backup protection for 66KV,132Kv and 220KV lines are Overcurrent relays. Overcurrent relays are also mostly used in the different industrial applications. Overcurrent relays are mostly used for backup protection. Traditional relays have much more complications with compared to Controller based relays.

Relay control techniques are mainly divided into three main categories, they are static, numerical and Electro-mechanical. Numerical relays have more supremacy compared to Static relays and Electro-mechanical relays because it have self-checking facilities reliability and compactness etc. The advantages of using numerical relays are no mechanical actions, easily controllable by the codes, accuracy, compact size, flexibility, reliability, multi-function capability, can be communicated etc.

The working of numerical relay is explained by using the MATLAB Simulink model by considering a different types of faults like single phase to ground fault, line to line fault[19], three phase to ground fault. Also, the model can be analyze for different test cases by changing the current settings and time settings depends on the application of the relay.

WORKING OF OVER CURRENT RELAY

Over current relays are classified into different types based on the time of operation (TOP) of the relay. The time of operationdefines that the time required to generate the trip signal to the circuit breaker when the fault event is occurred. Based on the TOP the over currents relays are inverse definite minimum time over current relay, inverse time over current relay, very inverse time over current relay, extremely inverse time over current relays are classified. In Inverse definite minimum time over current relay, the relay will generate the trip signal with the fixed time delay when ever the current crosses the threshold or predefined value. Inverse time over current relays generates the trip signal when the fault is sensed and the time of operation is inversely proportional to the fault magnitude. Similarly, very inverse and extremely inverse time over current relays generates the trip signals when the fault is occurred and the time of operation is inversely proportional to the square and cube of the fault current magnitude respectively. The time of operation for the inverse definite minimum time over current relay can be calculated by using the below formula.

Time of Operation of Relay: $\left(\frac{a}{(PSM^b)-1}\right)TSM$

Where, a & b are constants.

PSM means Plug Setting Multiplier and it is the ratio of fault current magnitude to the pickup current magnitude. It can be calculated by using the formula,

PSM = Fault Current / Current Setting

Pickup current = CT rated secondary current x Current setting

Current setting of an over current relay can be varied from 50% to 200% in levels of 25%.

TSM means Time Setting Multiplier, its value can be varied from 0 to 1 in levels of 0.05. So, when the TSM is 0.2, the time of operation of relay is 0.2 times the total time required to operate the relay.

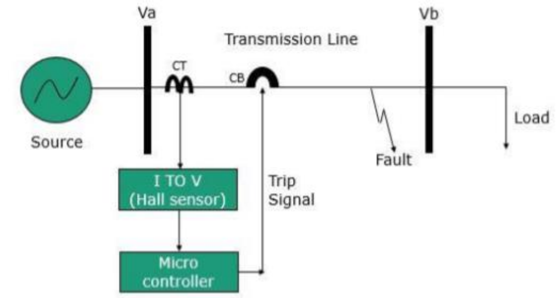


Fig. 1 Schematic diagram Numerical Relay in power system

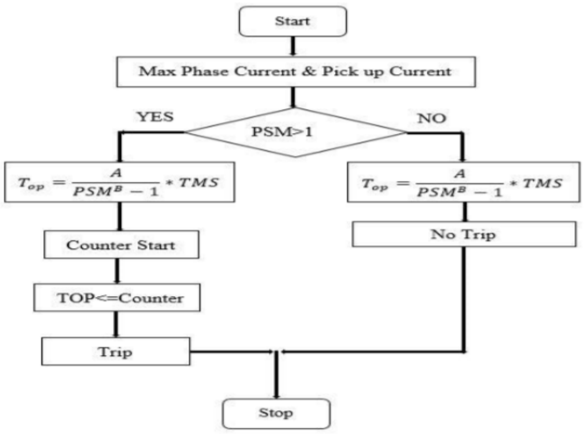


Fig. 2 Flow chart for Numerical relay

The Fig. 1 shows the working of numerical relay in power system. By using the CT (Current Transformer), current is scaled down from kilo amperes to 1/5 amp. The sampled current is sensed by the sensor and that value is given to the micro controller. In micro controller all the plug setting, time setting and other parameters are predefined in the program. The current sensed from the sensor is compared with the plug setting pick up value. If the fault is occurred, the micro controller calculates the time [20]-[21] of operation and generates the trip signal to the circuit breaker accordingly. The step by step working of numerical relay is shown in fig. 2.

MATLAB Modeling Of Numerical Relay

The numerical relay[15] can be modeled using MATLAB as shown in the Fig. 3. The model is formed by using different matlab blocks like 3-phase voltage source, circuit breaker, 3-phase VI measurement, 3-phase fault, transmission line, 3-phase load and other block for output and relay modeling.

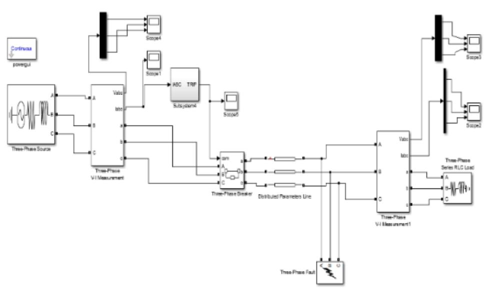


Fig. 3 Simulink model of Transmission line system and protection system using numerical relay

TABLE I Values of a & b for Different Relays

Relays	a	b
Inverse	0.14	0.02
Very Inverse	13.5	1
Extremely Inverse	80	2
Long time Inverse	120	1

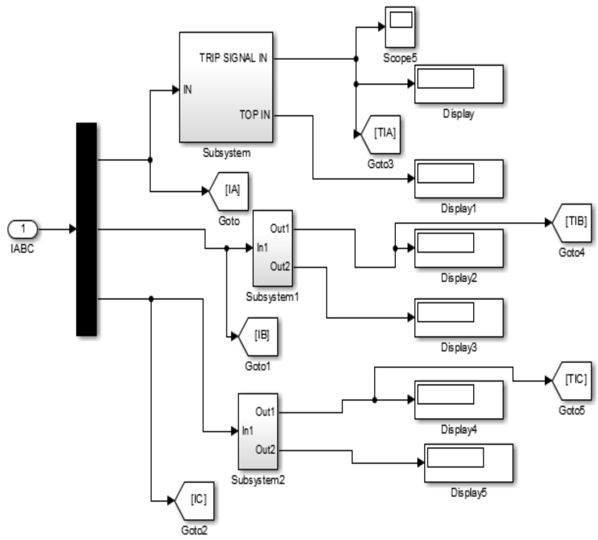


Fig. 4 Three-phase over current relays

Fig. 4 shows the three over-current relay sub-systems for phase faults. Each subsystem takes phase current as input from the VI measurement block and generates the trip signal and calculate the time of operation for the respective fault according to the setting value.

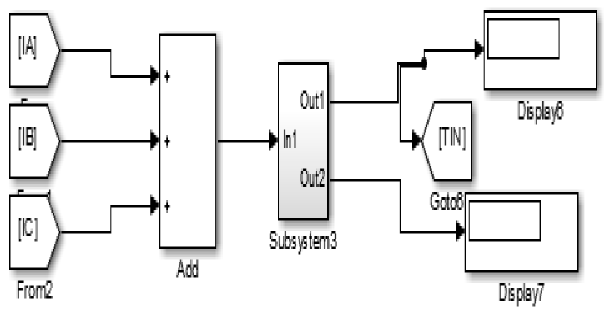


Fig. 5 MATLAB model of earth relay

Fig. 5 shows the earth relay subsystem, where all the phase currents are added and given as an input to the earth relay system. The earth relay subsystem compares the input current signal with the pickup value and generates trip signal and time of operation as per the given setting when the fault event is occurred[17].

Fig. 6 shows the matlab modeling of numerical over current relay. The phase current is the input of the system and then rms value is calculated. The rms value of current is scaled down to 1 amp by using the CT ratio. According to the plug setting value, the pickup value is generated. The sampled current value is compared with the pickup value and then it checks the fault is occurred or not. If fault is occurred it calculates the time of operation with the time setting value and generates the trip signal.

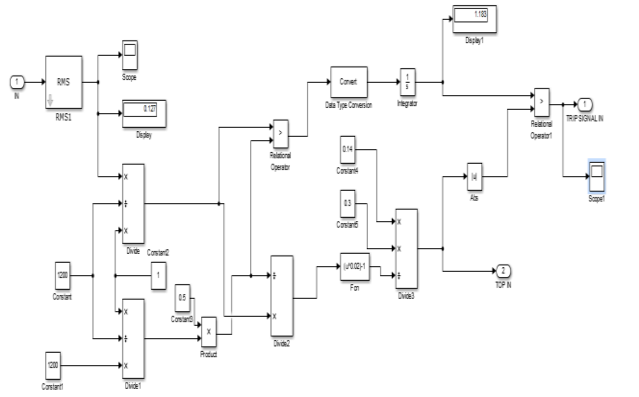


Fig. 6 MATLAB model of over current relay subsystem

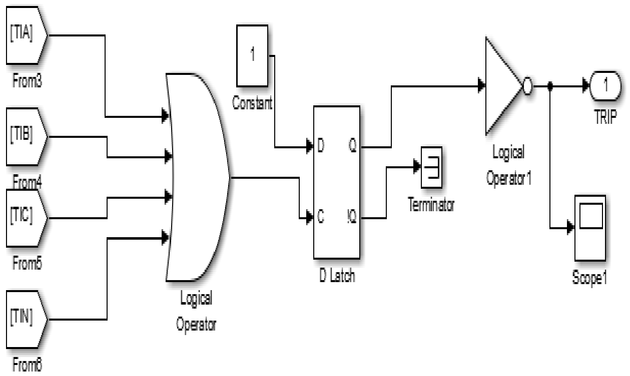


Fig. 7 MATLAB model of trip circuit

Fig. 7 shows the matlab model of trip circuit. The working of trip circuit is, if any of the phase relays or the earth relay generates the trip signal, the trip circuit generates the trip signal to the circuit breaker. This is done by the logical OR gate. Once the three-phase circuit breaker gets the trip signal, the circuit breaker isolates the load from the source.

In this system the fault is created by the three-phase fault block, where we can create any type of faults like single phase, line to line and three phase fault in the power system.

The below parameters are used for simulation model that are mentioned in the table II and the overcurrent relay settings are mentioned in the table III as shown below. From table III, it briefs that the parameters which are phase to phase voltage (vrms), frequency, +ve sequence resistance (r1), -ve sequence resistance (r0), and same as inductance and capacitance, line length of the transmission line, active and reactive power of the system parameters are selected in the three phase source block that is developed in the numerical overcurrent relay matlab Simulink model.

TABLE II Model Parameters

Parameters	Values
Phase to Phase voltage	220KV
Frequency	50Hz
+ve Sequence resistance	0.0748746 Ω/km
-ve Sequence resistance	0.2199746 Ω/km
+ve sequence inductance	0.00127085 H/km
-ve sequence inductance	0.00426289 H/km
+ve sequence capacitance	2.33471e-09 F/km
-ve sequence capacitance	1.46429e-09 F/km
Line length	100km
Active power	159.9 MW
Reactive power	120.1 MVAR

Table III Over Current Relay Settings

Relays	PS	TSM
Phase Relays	1.25	0.2
Earth Relay	0.5	0.2

The Over current relay subsystem has four divide blocks, when the divide 1 block parameter is greater than the product block threshold value, then the integrator block which is counter will start and later whenever the product block value and divide 1 block gets equal then the counter will be stop. The parameters in table III shows the plug setting and the time setting of the phase relay and earth current relays. These plug setting and time setting values are different for different types of relays. The time setting value used to set the different time of operation values.

From Table III, it shows that overcurrent relay settings can be kept for different values depending upon whether it is a phase relay or an earth relay. For phase relay, the plug setting and time setting multiplier is 1.25 and 0.2. Wherein, for an earth relay, it is 0.5 and 0.2 respectively. Based upon these parameters the overcurrent relay subsystem will be set and the overcurrent relay subsystem which is developed in matlab model will operate as accordingly.

SIMULATION RESULTS

The developed MATLAB model of overcurrent relay is tested on different test cases by creating a fault over individual phases and for three phases.

Case 1: Applying single phase to ground fault by varying the Time multiplier setting and resistance of the fault and the results are mentioned below.

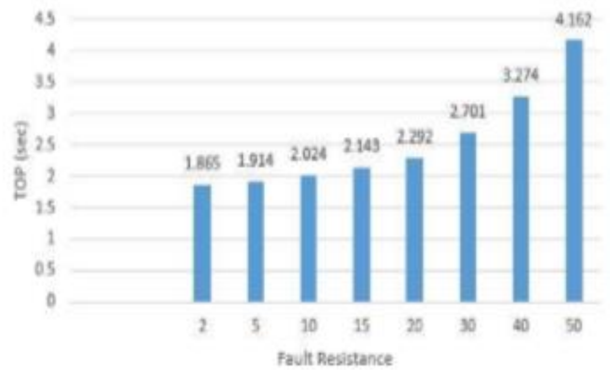
Table Iv Variation Of The Tsm

TMS	Rf (ohm)	If Phase (A)	TOP (sec) 1.25 PS		If Earth (A)	TOP (sec) 0.5 PS	
			Calculated	Practical		Calculated	Practical
0.1	2	1888	3.035	3.040	1274	0.922	0.936
0.2	2	1888	6.071	6.079	1274	1.845	1.858
0.3	2	1888	9.107	9.117	1274	2.767	2.785
0.4	2	1888	12.143	12.150	1274	3.690	3.715
0.5	2	1888	15.178	15.190	1274	4.613	4.636

TABLE V VARIATION OF THE FAULT RESISTANCE

S. No	Rf (ohm)	If earth (A)	TOP (sec) (TMS=0.2, PS=0.5)	
			Calculated	Practical
1	2	1274	1.845	1.865
2	5	1247	1.899	1.914
3	10	1200	2.005	2.024
4	15	1152	2.132	2.143
5	20	1103	2.285	2.292
6	30	1007	2.690	2.701
7	40	919	3.269	3.274
8	50	840	4.147	4.162

TABLE VI Variation of the fault resistance



The table IV shows that the Matlab Simulink model outcome by varying the time multiplier setting, the different values of phase current, time of operation of the relay (TOP) and earth current can be observed. The calculated values and practical values are almost equal. So, the result of the Simulink is accurate.

The outcomes of the above case are, if time multiplier setting is more in the relay, then the relay will take more amount of time given to the trip signal and from the table V, if the resistance of the fault is high then it can reduce the fault current as it will propagates the time of operation of the overcurrent relay. As, from the table, when the resistance of the fault is 2 ohms and fault current is 1888A, the time of operation of the relay observed as 3.0 as per simulation model and by calculating it is observed as 3.03 which is almost equal. But when considering the tripping signal, it will be initialize after the one sec. Therefore, the tripping signal can be occurred after one sec i.e. (1+1.15 = 2.5S), this will be shown in fig 9.

The table V shows that by varying the fault resistance the different parameters of Rf, earth current and time of operation of the relay can be observed for time multiplier setting of 0.2 and plug setting of 0.5 in this case. The table VI determines the variation in the fault resistance vs time of operation of the relay can be observed. By increasing the faut resistance, the time of operation of the relay will be increasing. By which it can says that the resistance fault is directly proportional to the time of operation of the relay.

Case 2: The different types of plots can be observed by changing the fault event type and increasing the switching time of the three-phase fault block in MATLAB model. When single phase to ground fault applied with switching time period is from 0.2 to 0.5s. The load current of phase a, b and c is shown in below Fig 8.

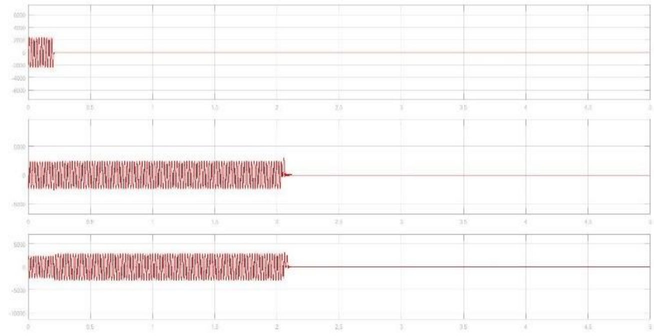


Fig. 8 Load phase currents for LG fault

From the above Fig 8, the fault is applied to single phase and the relay should sense the fault and should send the signal to the three phase circuit breaker. So, three phases should be tripped from the line as per given delay that is mentioned in relay subsystem. The tripping signal can be done after certain delay as per mentioned in the setting in the relay subsystem by doing certain calculations as per required. In this case the delay will be 2.15S, it can be observed from the below Fig 9.

Fig. 9 The trip signal

When fault is applied to double line ground (LLG) fault, the load current for the applied fault is shown in below Fig 10.

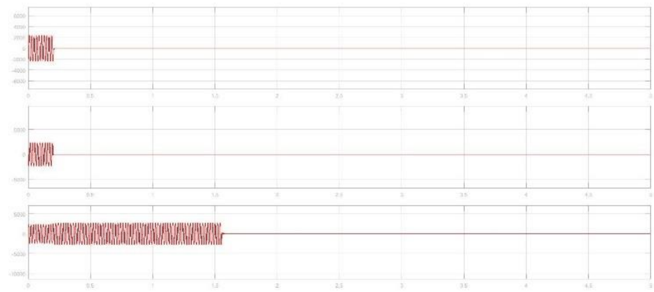


Fig. 10 Load phase currents for LLG fault

From the above fig 10 it can be observed that the double line ground is applied to the system with switching time from 0.2s to 5s and tripping of the line can be observed. The RMS fault phase current for the above mentioned fault can be observed in below figure.

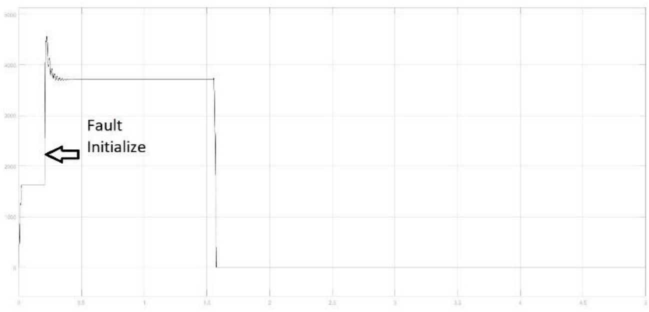


Fig. 11 RMS phase current for LLG Fault

When three phase line to ground fault is applied, the numerical relay which is developed in matlab Simulink model can sense the fault and sends the signal to the three phase circuit breaker as this is the basic principle of the working of the relay in the power system protection. In the above case, the different load currents for the individual phases can be observed in the below figure.

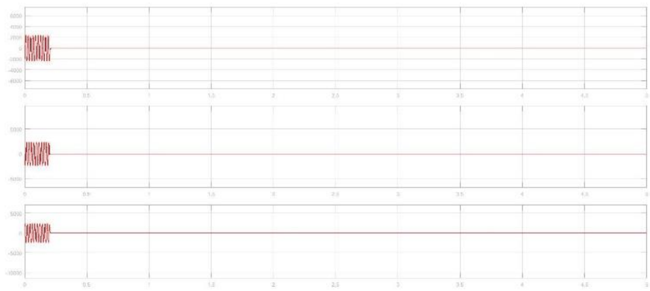


Fig. 12 Load phase currents for LLLG fault

From all the above faults, the most severe fault is symmetrical fault that is three phase line to ground fault (LLLG). From the above figure, it can be seen that the fault is applied to all three phase lines. Therefore, relay will send the signal and circuit breaker will trips the all three lines in the power system.

This is another test case by which it can bale to analyze the numerical overcurrent relay by changing the resistance of the fault from 2 ohms to the 50 ohms. The fault current of the phase, fault current of the earth and tripping signal can be observed by showing different figures

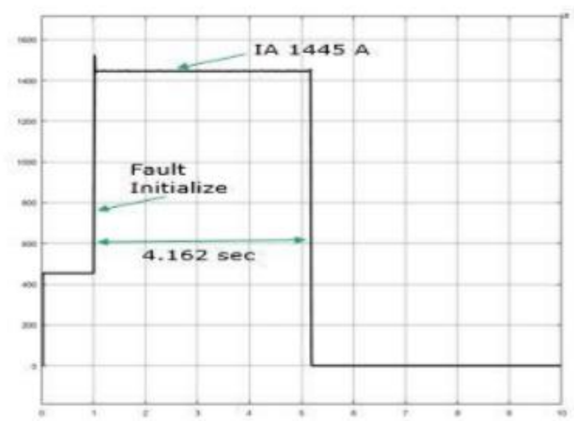


Fig. 13 RMS phase current for 50 ohms

By observing the above figure, the fault resistance of the system is changed to 50 ohms, then fault current of the A phase is 1445A, and it is taking tripping time of 4.162S.

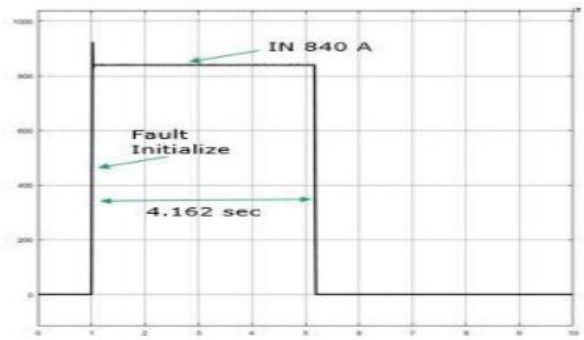


Fig. 13 RMS earth fault current for 50 ohms

The above figure shows that the fault current of the earth is observed as 840A and tripping time is 4.162S.

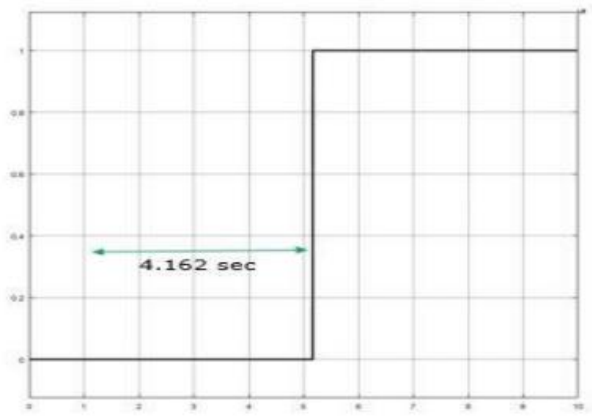


Fig. 14 Tripping signal

CONCLUSION

This paper introduces the use of numerical relays namely over current relays as a criterion to operate in real time conditions with more flexible, reliable and more accurate as compared with electromechanical relays mostly in industrial applications. Overcurrent relays are mostly used for backup protection. Traditional relays have much more complications with compared to Controller based relays. the model can be analyzed for different test cases by changing the current settings and time settings depends on the application of the relay. The methodology presented in the paper describes the nondirectional overcurrent relay subsystem in the Matlab simulation model with time of operation of the relay and counter circuit logic modelling. The practical model which is developed in Matlab as an error of +/- (0.7%). The further research work can be done by analyzing with FPGA based overcurrent relays by considering different conditions.

REFERNCES

1. Majumder, Rikta, Sukdev Dolui, Debasis Agasti, and Surajit Biswas. "Micro-controller based over current relay using Hall Effect current sensor." In 2018 Emerging Trends in Electronic Devices and Computational Techniques (EDCT), pp. 1-4. IEEE, 2018.
2. Sandeep Makwana and Vijay Makwana. "Simulation and Hardware Implementation of Overcurrent Relay Used for Transmission Lines". In Third International Conference on Trends in Electronics and Informatics (ICOEI2019).
3. Kunal Jagdale and A.Siddhartha Rao. "Over current protection of transmission line using GSM and Arduino." In internatonal Journal of Engg. Trends & Technology, Vol. 50, Number 1, August 2017.
4. Blackburn, J. Lewis, and Thomas J. Domin. Protective relaying: principles and applications. CRC press, 2006.
5. G. Benmouyal, and M. Meisinger. "IEEE Standard Inverse-Time Characteristic Equations for Overcurrent Relays", IEEE Transaction on Power Delivery, Vol. 14, No. 3, July 1999.

6. H. Hussin, M. H. Idris, M. Amirruddin, M. S. Ahmad, M. A. Ismail, F. S. Abdullah, and N. M. Mukhatar. "Modeling and Simulation of Inverse Time Overcurrent Relay Using Matlab/Simulink", IEEE I2CACIS, 22 October 2016.
7. Campos, David, Edgar Moreno, and Domingo Torres. "Test and evaluation time-inverse over-current protection algorithm using SIMULINK." In Proceedings of the 7th WSEAS International Conference on Signal Processing, pp. 69-74. World Scientific and Engineering Academy and Society (WSEAS), 2008.
8. De Andrade, Virgilio, and Elmer Sorrentino. "Typical expected values of the fault resistance in power systems." In Transmission and Distribution Conference and Exposition: Latin America (T&D-LA), 2010 IEEE/PES, pp. 602-609. IEEE, 2010
9. Bhavesh Bhalja, R. P. Maheshwari, and Nilesh G. Chothani. "Protection and Switchgear" Oxford University Press, New Delhi, 2011.
10. Sourin Bhattacharya, Victor Sarkar, Priyam Sadhukham, and Nirab Majumder. "An Arduino Uno Microcontroller Based Prototype Overvoltage and Overcurrent Protection System", IJERCSE Vol. 4, Issue 10, October 2017.
11. Bhuvanesh A. Oza, Nirmalkumar C. Nair, Rashesh P. Mehta and Vijay H. Makwana. "Power System Protection and Switchgear", Tata McGraw-Hill Education, New Delhi.
12. Al-Nema, Mudhafar A., Sinan M. Bashi, and Abdulhadi A. Ubaid. "Microprocessor-based overcurrent relays." IEEE Trans. Ind. Electron. 33, no. 1 (1986): 49-51.
13. P. Maji, and G.Ghosh. "Designing Over-Current Relay Logic in Matlab", IJSER, Vol. 8, Issue 3, March 2017.
14. [14] R B R Prakash and P. Srinivasa Varma, "Stability Enhancement of Wind Power Plant during Abnormal Conditions with Negative Sequence Components Compensation using STATCOM", Journal of Advanced Research in Dynamical and Control Systems, Vol. 9, Sp. 18, pp. 85-95, 2017. (SCOPUS)
15. Rajesh Reddy, J., Pandian, A.,"Improved ROCOF relay for islanding detection of solar distributed generation", Indonesian Journal of Electrical Engineering and Computer Science, Volume 14, issue no 3, pp. 1105-1113, June 2019, ISSN Number: 2502-4752.
16. SAIDARAO.K1, M.SRIKANTH2 "An Advanced SMPS Converter to Track the Maximum Power from the Thermoelectric Generator" *Journal of Electrical Engineering,* Volume 15/2015-Edition -4 PP 268-276.
17. *A. Prudhvi Krishna, P. Srinivasa Varma, R. B. R Prakash, V. Kiran Babu, "*Prioritization of network transformers in electrical distribution system by considering social welfare index", Indonesian Journal of Electrical Engineering and Computer Science, Vol. 16, No. 1, October 2019, pp. 25-32, DOI: 10.11591/ijeecs.v16.i1.pp25-32
18. K. P. Prasad Rao, P. Srinivasa Varma, RBR Prakash, "Five phase DSTATCOM with fuzzy controller for industrial and domestic applications", International Journal of Innovative Technology and Exploring Engineering (IJITEE), Volume-8 Issue-4, February 2019, pp 500-504.
19. Gokul, C.H.M., Sarada, K, "AC optimal power flow calculation for locational marginal pricing", Indian Journal of Science and Technology,2015
20. D. Narasimha Rao and P. Srinivasa Varma, "Fractional order-PID controlled closed-loop MLI based DP-FC for fourteen-bus system", International Journal of Innovative Technology and Exploring Engineering, Vol.8, No. 4, pp. 622-627, 2019.
21. M. Naga Chaitanya, G. Venkata Siva Krishna Rao and M. Ramamoorty, "Wavelet energy-based stable and unstable power swing detection scheme for distance relay," Turkish Journal of Electrical Engineering & Computer Sciences, vol. 27, no. 4, pp. 2908-2921.
22. K. Mounika Lakshmi Prasanna, J. Somlal, R. James Ranjith Kumar and Amit Jain, "Load Flow Studies for Distribution System with and without Distributed Generation", WATER and ENERGY INTERNATIONAL, Vol.57, No.12, pp.34-38, March-2015.
23. Suresh Palla, Jarupula Somlal, Comprehensive Examination on Solar -Wind Energy Systems Grid Integration and Emerging Power Quality challenges, International Journal of Engineering and Advanced Technology (IJEAT), Vol.8, Issue 6S3, September 2019.