Numerical Relay Algorithm for Blackout Prevention

Shanker Warathe
Department of Electrical Engineering
Govt. Polytechnic Durg, India
sb.govt@gmail.com

R N Patel
Department of Electrical and Electronic Engineering
SSCET Bhilai Durg, India
ramnpatel@gmail.com

Abstract- The serious electric grid disturbance was occurred in the Northern part of India on 30th and 31st of July 2012, this led to low voltages at the Gwalior end in the event of high line loading causes major shutdown of power in eight States. The reason was unnecessary tripping of distance relay due to load encroachment, weak inter-regional corridor and number of feeders was disconnected for maintenance purpose. To prevent occurrence of such situation a new algorithm is proposed for numerical relay to protect national or regional grid during load encroachment and power swing. The new algorithm is tested using the PSCAD software and it gives the results as we desired to prevent the unforeseen blackout in electricity grid. This paper describes the algorithm for distance relay to protect the transmission line from load encroachment. In electrical power transmission network detection of load encroachment and power swing is very useful for transmission line protection; using these variable parameters the protective system can be improved. In this work the load encroachment, angular separation and power swing were produced by two ways, first one was by increasing the load in the northern region and another was due to loss of generation in northern as well as western region. Modern protective relays built up with digital signal processor are fast in calculation and decision making, improve the protective scheme of transmission line during load encroachment.

Keywords- Power Swing; Numerical Relay; Synchro-phasors; Load Encroachment; Disturbance Fault Recorder; Phasor Data Concentrator; Phasor Measurement Unit; Global Time Reference.

INTRODUCTION

Numerical relays are Intelligent Electronics Devices (IED) embedded with digital signal processor (DSP of series TMS320F2812). This DSP is suitable for precise calculation and having high accuracy for the numerical algorithm used in protection of power swing, transmission line protection [1]. The numerical relay having an ability to performe fast calculation with greater accuracy for complex signal. Modern Digital Signal Processors are excellent configuration with the protective devices, and performance is very good for control applications. The static relays having a number of demerits, such as inadaptability, inflexibility and not suitable for continueously changing power system conditions and complecity [1, 2]. Microprocessor-based relays for protection were widely used in power system [1–3]. The continuously increasing performance and reduced costs have made the micro-processor relays the solution of choice[4, 5]. The digital relays are more suitable because of it, easy to programme and maximum merits over conventional relays [6]. The old microprocessors based digital relays having minimum processing capacity for the same signal [2, 5]. The DSP processor has higher processing capability [5-7]. The modern numerical relay is made of digital signal processor (DSP), whereas a microprocessor was used in digital relay [8]. Modern numerical relay protection scheme offers multi-function and multiple characteristics, and other several advantages[9]. Desired relaying characteristics can be obtained by using the same interface [8-10]. Now a day for automation of electrical power substation a newly international standard IEC 61850 is used and this standard is one part of IEC committee 57. To modernizing the electrical power system the trend of automation of substation using numerical relay know as intelligent electonic devices are increasing, this advance device reduce the complecity of system. A DSP from Texas Instruments, TMS320F2812 is suitable for detection of power swing in power system. The processor of TMS320F2812 is working at frequency of 150.0MHz [12, 13]. The high amount of data can be processed by advance architecture of TMS320F2812. This DSP processor can perform precise numerical calculation for the algorithm used in the IED [14]. the relay using DSP as processor, is suitable for meeting the all basic protective requirements such as high speed, more sensitivity, more selectivity and more reliability [3, 4]. Therefore, the new automation of substation using numerical relays will replace all previous protective technology. The Digital Signal Processor used in numerical relays technology process the signal in real-time [1]. So the numerical relay is more suitable for detecting the disturbance and fault condition in power system by processing the signal, fast and more accurately as compared to old relay technology[15-21].

LOAD ENCROACHMENT

The power flowing through a transmission line to feed the load also increases the line current in transmission line and due to variation in load the current magnitude also varies. The impedance relay used for distance protection of transmission line also measuring this apparent impedance of load called as load-impedance. The magnitude of this apparent impedance of load varies with the variation in load. As the load on power system increases, the apparent impedance for the transmission line through which power is flowing, decreases and vice versa. During the stress condition or normal condition of power system some times the value of apparent impedance of load so low as compared to fault impedance and relay measure the value which is inside the relay's characteristics shape. As a result, the distance relay, see the value of impedance below the pre set value of impedance and consequently issue the trip command to circuit breaker. This is a highly undesirable operation of relay because a heavily loaded line has been taken out of service causes heavy power swing and other disturbances, when there is no real fault exists and this condition lead to black out situation. The apparent impedance varies with the power flow in transmission line and depends on angular separation between two buses as explained below.

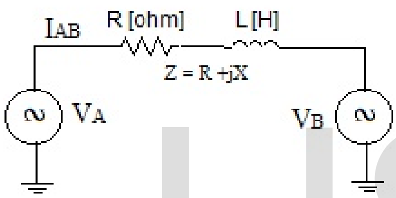

Fig. 1. Two interconnected voltage source buse.

In this fig.1, there are two equivalent voltage sources are connected with tie line whose impedance is $Z = R + jX$ and voltage at sending end $V_A = |V_A|\angle\delta_A$ and at receiving end voltage $V_B = |V_B|\angle\delta_B$

The current I_{AB} is flowing in the circuit is calculated by

$$I_{AB} = \frac{|V_A|\angle\delta_A - |V_B|\angle\delta_B}{R+jX} = \frac{|V_A|\angle\delta_A - |V_B|\angle\delta_B}{|Z|\angle\gamma^\circ} = \frac{|V_A|}{|Z|}\angle\delta_A - \gamma^\circ - \frac{|V_B|}{|Z|}\angle\delta_B - \gamma^\circ \quad (1)$$

So the apparent power flowing from sending end to receiving end is given by $S_{AB} = V_A I_{AB}^* = |V_A|\angle\delta_A \left[\frac{|V_A|}{|Z|}\angle\gamma - \delta_A - \frac{|V_B|}{|Z|}\angle\gamma - \delta_B\right] = \left[\frac{|V_A|^2}{|Z|}\angle\gamma - \frac{|V_A||V_B|}{|Z|}\angle\gamma + \delta_A - \delta_B\right]$ (2)

Thus the real power P_{AB} and reactive power Q_{AB} are given by

$$P_{AB} = \frac{|V_A|^2}{|Z|}\cos\gamma - \frac{|V_A||V_B|}{|Z|}\cos(\gamma + \delta_A - \delta_B) \quad (3)$$

$$Q_{AB} = \frac{|V_A|^2}{|Z|}\sin\gamma - \frac{|V_A||V_B|}{|Z|}\sin(\gamma + \delta_A - \delta_B) \quad (4)$$

In long transmission line the value of resistance R is very low as compared to line reactance X, then assume R=0 and $Z = |Z|\angle 90^\circ$ =X∠90° , put $\gamma = 90^\circ$ in above equation they becomes

$$P_{AB} = \frac{|V_A|^2}{X}\cos 90^\circ - \frac{|V_A||V_B|}{X}\cos(90^\circ + \delta_A - \delta_B) \quad (5)$$

$$P_{AB} = \frac{|V_A||V_B|}{X}\sin(\delta_A - \delta_B), \quad \& \quad (6)$$

$$Q_{AB} = \frac{|V_A|^2}{X}\sin 90^\circ - \frac{|V_A||V_B|}{X}\sin(90^\circ + \delta_A - \delta_B)$$

$$Q_{AB} = \frac{|V_A|^2}{X} - \frac{|V_A||V_B|}{X}\cos(\delta_A - \delta_B) \quad (7)$$

It means the real power flow from *A* to *B* depend upon angular separation $\delta = \delta_A - \delta_B$, small change in δ will significant change in real power P_{AB} the direction of power flow will depend whether voltage V_A leading with V_B or lagging with V_B by a angle δ, if the V_A leading with V_B the flow of power is forward direction and V_A lagging with V_B the flow of power is reverse. That means the large flow of power means large value of δ, it is possible when there is large angular separation between V_A and V_B. So the value of current in a particular tie line depends upon δ, if load continuously increase in area B, the angular separation between V_A and V_B also increases that means the power flow P_{AB} also increases. The current loading increases in tie line due power increase so the apparent impedance of line decreases as increase in line current. Sometimes the values of apparent impedance *Z* is so low and relay assuming that there is virtual fault in line of zone 3 protection and issuing the trip command to the circuit breaker this condition called load encroachment. Outage of lines due to unnecessary tripping causes power swings in the system and the results are cascading tripping of lines become the cause of islanding. This is a highly undesirable operation of relay because a heavily loaded line has been taken out of service causes heavy power swing and other disturbances, when there is no real fault exists and this condition lead to black out situation. The impedance of large load is low as compared to impedance of faulty line. So the protective relay must be made so selective to discriminate between impedance of higher load and the impedance of fault condition. The equivalent load resistance is decreases as the load increases, so that the impedance Z_L, of load decreases and sometimes the value of Z_L is low as compared to fault impedance Z_f and due to this reason the impedance distance relay issue the trip command and circuit breaker get operate. The following fig.2 shows the load encroachment phenomena as the load increases the load impedance decreases and encroached the area of zone 3 of mho relay characteristics.

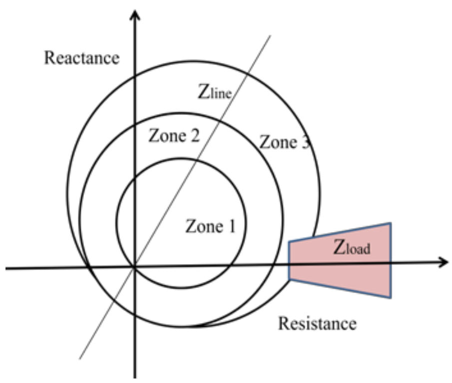

Fig. 2. Mho relay characteristics for load encroachment.

INDIAN NATIONAL GRID

The Indian national grid is consists of five regional grids namely, Northern grid, Eastern grid, North East grid, Western grid and Southern grid. Four of them, NEW grid synchronously inter connected and Southern grid asynchronously connected with Western and Eastern grids and each having regional load dispatch centre. The all India total installed capacity is 228.5 GW and total transmission length is 293852.0 km (including 765kV, 400kV, 220kV and HVDC +/- 500kV). The backbone of the transmission grid is formed by the 400 kV transmission system and the upcoming 765 kV lines [16]. The synchronously connected Indian national grid is shown in fig.3, it consists of NEW Grid comprising of the Northern, Eastern, Western and North-Eastern Grids are meeting a demand of about 75.0 - 80.0 GW and the Southern Grid which is connected to NEW Grid asynchronously, is meeting a demand of about 30.0 GW [16]. In the month of July 2012, due to failure of monsoon and high electrical loading in the Northern region of India was the main cause of over drawing bulk amount of electrical power from the neighbouring regional grids like Western and Eastern as shown in fig.4 by blue colour import bar, the illustration show the plot of real data on the incident day. The electrical power demand was less in the Western and Eastern region due to sufficient rain and it was under drawing condition as clearly shown in fig.4 by blue colour export bar. The major grid disturbance in month of July 2012 was occurred due to heavily loaded tie lines between East to North and West to North grid of India to feed the over draw power and skewed power generation balance among the regional grids as shown in fig.4, by generation and demand bar. This disturbance causes blackout in the entire Northern region of India covering neighboring eight states. The NEW grid frequency prior to the incident was 49.68 Hz. The National demand prior to the incident was nearly 99.70 GW and the demand being met in the Northern Region of India was 38.0 GW [16].

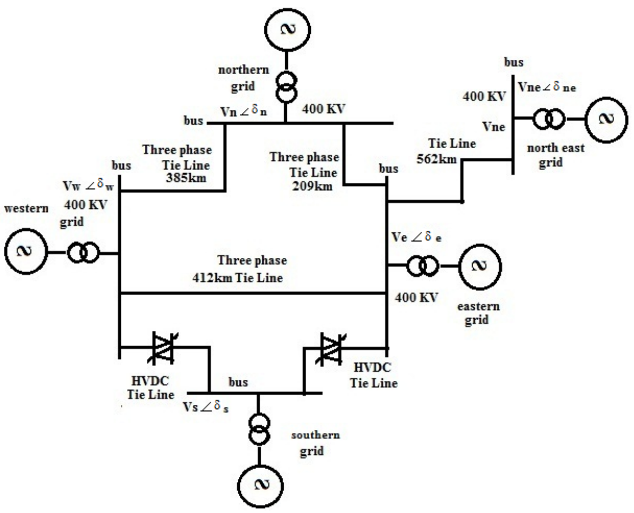

Fig. 3. Equivelent model of a nation grid.

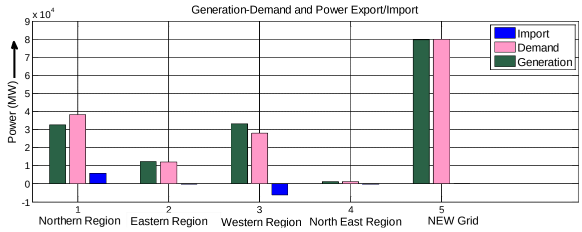

Fig. 4. Generation, demand and power export.

The fig.4 clearly shows the demand is more than the generation in the Northern regional grid and power is imported from the neighboring Western regional grid, in the Western region generation is more than the demand in the region so power is exported as shown by blue bar from the Western region to the Northern region and interconnected lines are over loaded. On the day of incedence the power generatio in the Eastern regional grid and North East region grid was just meeting the demand of power demad [16]. The voltage profile of the Indian grid before the grid disturbance on the 30th July and 31st July 2012 is shown by fig.5, the voltage in kV is shown on the *y* axis and region wise bus is shown on *x* axis. On both the day the voltage pattern for Northern region is similar except one node voltage is high and the range is 380-415.0 kV, but bus voltages in Eastern region above the rated voltage and it shows the Eastern region is lightly loaded. In the Western region the voltage profile on both days are just opposite to the each other and voltage range is wide, this shows at some buses the load is lightly connected and on other buses the load is heavily connected. It shows imbalance power generation among the region and inter region. The voltage profile also shows the inadequate reactive power compensation in the grid [16].

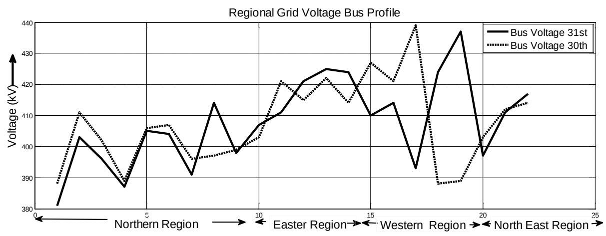

Fig. 5. Voltage profile in four regions on 30th and 31st July 2012

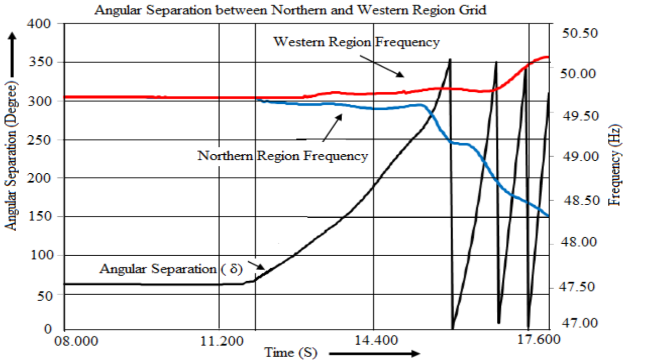

Fig. 6. Angular separation between Northern and Western regions during disturbance

The frequency profile and angular separation of the Northern region and the Western region is shown in fig.6, on the day of grid disturbance the frequency of both the region is nearly 49.68 Hz and constant before the incident occurred at 13.00hrs [16]. After the incident the frequency of Northern region is decrease as shown by the blue curve, this shows there was heavy loading and reduction in power generation but simultaneously the frequency in Western region shown by red curve increases it shows more generation in the region and lightly loaded regional grid. Same time it clearly shows the angular separation between Western and Northern region is increases linearly shown by the black curve and responsible for tripping of number of generators in Northern region causes blackout at time 15.40hrs.

Simulation Model and Result

The simulation model shown in fig.7; were design on PSCAD plate form and parameters were taken from the report of the Power System Operation Corporation LTD, POWERGRID, National Load Dispatch Centre and Regional Load Dispatch Centre [16]. The simulation model was run for the period 5.0 second. Here the Western regional grid represented by thevenin's equivalent source of 220.0 KV, 50.0Hz and generated power 33024.0 MW is feeding to the national grid. Similarly the Northern region grid, Eastern grid and North East grids are represented by thevenin's equivalence source of 220.0 KV, 50.0Hz and feeding the electrical power 32636.0MW, 12452.0 MW and 1367.0 MW to the national grid. The inter regional tie lines are 385.0km from Northern region to Western region, 209.0km East region to Northern region, 562.0km North East to East region and between Western region to east region is 412.0km.

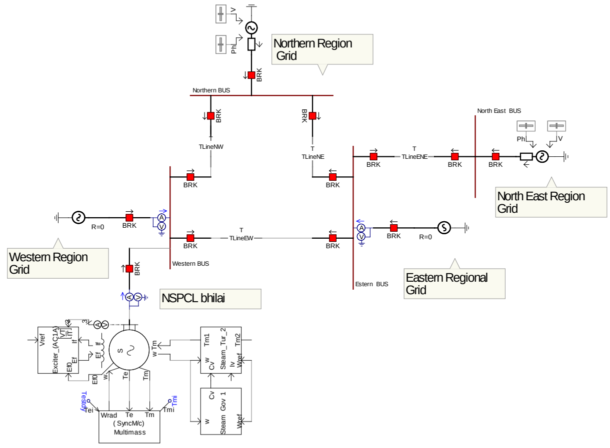

Fig. 7. Simulation model of a NEW Indian grid.

The above designed model were simulated for following cases,

a) The simulation for to observe the impact of rise of load on system and load encroachment.

b) The simulation for to evaluate the performance of numerical relay algorithm during three phase to ground fault.

c) To evaluate the performance of algorithm for load encroachment during increase in demand and loss of generation in Northern and Western region.

Impact of rise of load on load angle

The impact of rise of electrical load in a particular region of electrical grid can be observed by the simulation of above model. In this simulation the electrical load was changed in the Northern region of Indian grid and for the rise of particular load the value of load angle was noted. The observations are tabulated in table 1 for the simulation period of 5.0 second.

Table 1 Load and voltage phasor angle of grid buses

Load in Northern Grid (MW)	V_{north} Angle(θ^o)	V_{weast} Angle(θ^o)	V_{east} Angle θ^o
794.2	31.49	31.80	31.67
1255.0	32.28	31.88	30.69
1705.0	33.06	31.97	30.73
2154.0	33.84	32.07	30.75
2597.0	34.70	32.15	30.77
3034.0	35.39	32.24	30.79
3466.0	36.15	32.33	30.84

ISSN 2229-5518

In the first case the electrical load in MW was changed in step from 794.2MW to 3466.0MW as tabulated in first column of table 1 and observation for bus voltage angle at North, West and East Grid was tabulated in other columns. It clearly shows from the fig.8 the northern angular separation increases with increase in load with respect to Western and Eastern bus grid as shown by point *A*, *B* and *C*. that means the load angle is depend upon the electrical load.

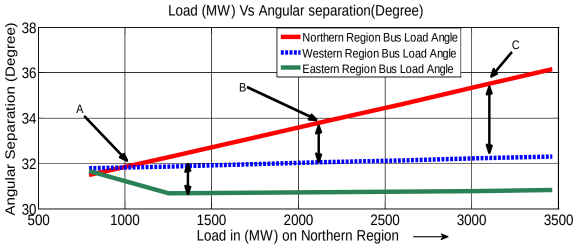

Fig. 8. Relationship between load(MW) verses angular separation(degree).

The following fig.9 shows the relationship between north bus angle to west and east bus angle. During the simulation period of 5.0 second the angular separation increases with time and become wide between northern regions to other regions. During this simulation the northern region is heavily loaded and western regions was disconnected.

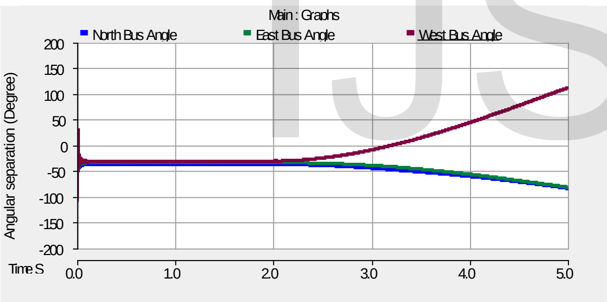

Fig. 9. Angular separation between regional grids during loss of generation in western grid.

Proposed Numerical Relay Algorithm for load encroachment with distance protection

The numerical relay algorithm shown in fig. 10, is proposed for the distance protection as well as load encroachment protection during stressed condition of power system. The proposed algorithm based on the theory of line impedance measurement and angular separation measurement of two end of transmission line. World larggest Indian national grid is very complx system and build up of number of generating station, number of buses and five regional grids are interconnected with tie lines. Now a day the syncro phasor technology is suitable for large power system to measure the wide area bus parameters. At each bus the real time voltage magnitude and phase angle are measured according to globle time.

The merits of measuring phase angle with a global reference time are helpful in capturing the snap shot of the large power system at real time. This technology is very helpful in more stressed system to prevent leading blackouts situation and examine the real time behavior of the big power system. Assume that the power grid system is consist of *N* number of buses, then on the basis of above observation and illustration the algorithm for DSP based numerical relay is developed and line diagram shown in fig. 10 and logical model is shown in fig. 11.

The model with algorithm for distance protection was simulated during three phases to ground fault and for highly stressed condition to demonstrate the effect of load encroachment condition; the simulation time is 5.0 second. The simulated model with algorithm gives the expected result during three phases to round fault applied at the time 1.0 second and load encroachment condition by judging the angular separation more than the pre set load angle. The trip command issued for three phase to ground fault and the block command issued to prevent unnecessary tripping of circuit breaker during load encroachment.

Load angle between bus *ij* and *ps* is given by

$$\delta = (\theta_{ij} - \theta_{ps}) \quad (8)$$

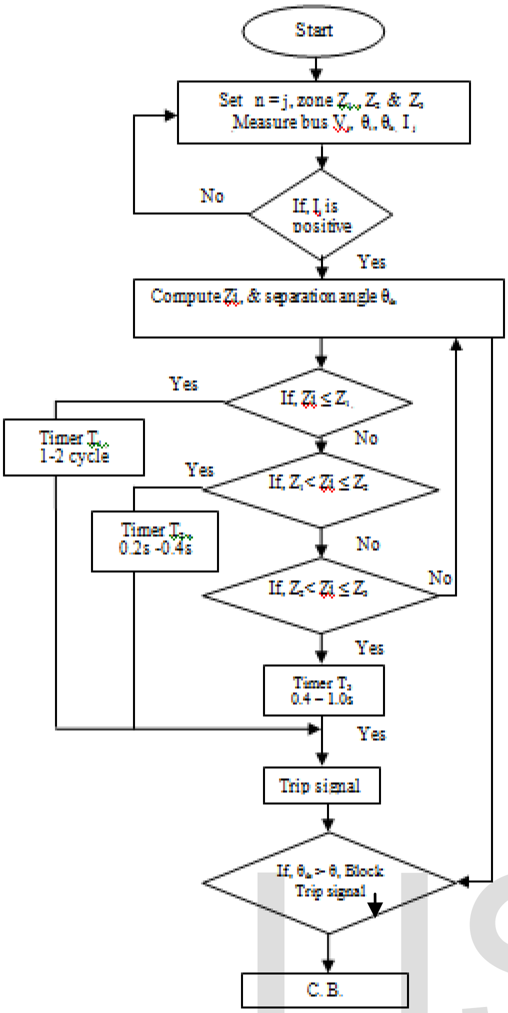

Fig. 10. Algorithm for numerical relay

Numerical relay algorithm response during three phase to ground fault

The three phases to ground fault applied at the time of simulation 1.0 second by a fault logic control in the mho distance protected tie line between West Region to North Region. The three phase fault is clearly shown in fig.12 and mho relay characteristics is shown in fig. 13, for this condition the measured value of impedance is laying in the protected zones and relay issued a trip command to isolate the faulty line as shown by fig.14.

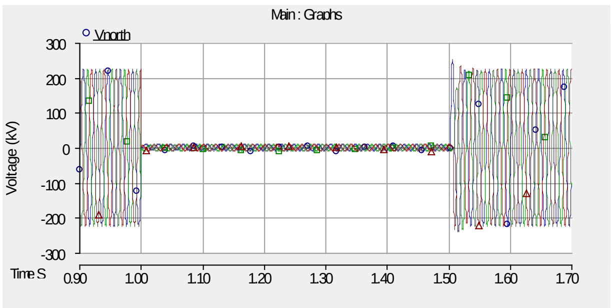

Fig. 11. Three phase to groun fault at time 1.0 second

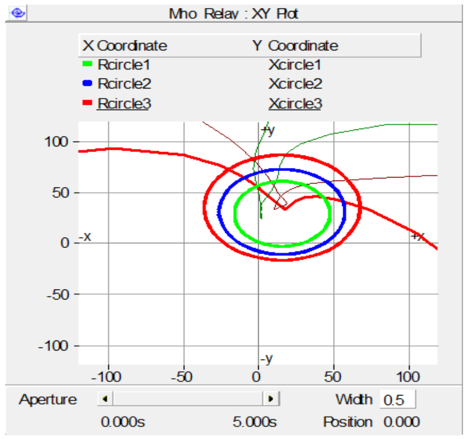

Fig. 12. Mho characteristics of numerical relay for three zone protection during three phase to ground fault.

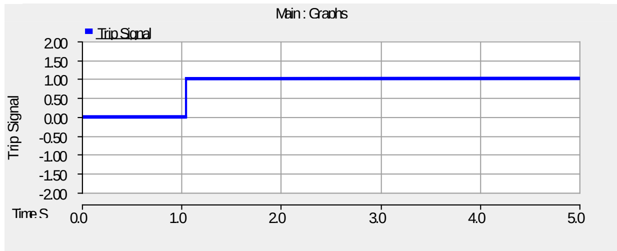

Fig. 13. Trip signal during three phase fault

Numerical relay algorithm response during load encroachment

The load encroachment condition is detected by numerical relay after 2.0 second. The load in the northern region is gradually increases and it reflected by increase of angular separation between regional grids as in shown in fig.15 and impedance measured by mho relay characteristics is shown in fig. 16, for this condition the measured value of impedance is laying in the protected zones three and relay try to issued a

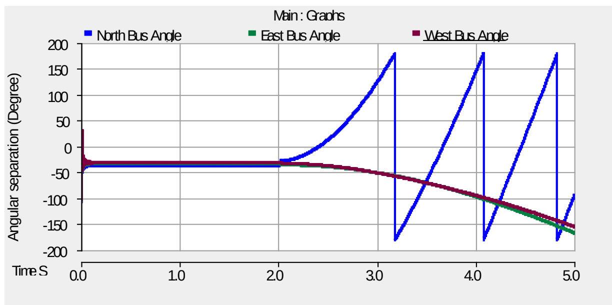

Fig. 14. Angular separation between regional grids during loss of generation in northern grid.

ISSN 2229-5518

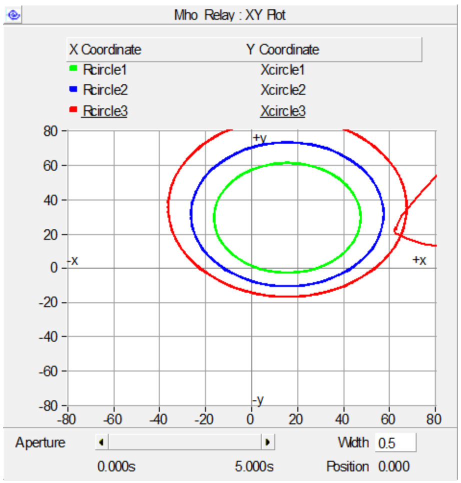

Fig. 15. Mho characteristics of numerical relay for three zone protection during load encroachment.

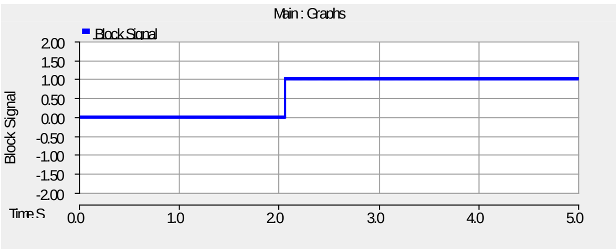

Fig. 16. Block signal during load encroachment

tripping command to circuit breaker to isolate the faulty line but after detection of load encroachment the relay logic issued a blocking command to prevent the unnecessary tripping during load encroachment as shown by fig.17. On the basis of above observation the proposed numerical relay algorithm is working properly in both the cases and clearly discriminating the faulty situation and load encroachment situation and issuing the trip signal and block signal based on logic of algorithm. So we can save the time and loss of the grid.

Conclusion

In this paper the equivalent Indian regional grids connected with tie lines is taken for blackout case study and the model simulated for 5.0 seconds and the effect of rise of load in northern regional grid was observed. In the observation it is clearly shows by angular separation that any change in demand of northern grid was shared by other regional grids. When the load in northern region increases the the angle separation between the regional grids are also increases as shown in table I. it is observed that the loss of generation in western region, increases the load on other region and angular separation increases in large amount. When angular separation increases as in the above case the proposed new algorithm for numerical relay to protect grid during load encroachment by issuing the block command to the circuit breaker and discriminate with fault condition and avoid the unforeseen blackout. The new algorithm is simulated for numerical relay and gives the expected result and prevents the leading of blackout in electricity grid.

References

[1] Goh YL, Ramasamy AK, Nagi FH, Abidin. AZ (2011) Evaluation of DSP based Numerical Relay for Over current Protection, International Journal Of Systems Applications, Engineering & Development 5(3): 396-403.

[2] Apostolov A, Tholomier D, Richards S (2006) Zone 3 Distance Protection –Yes or No?", 60th Annual Georgia Tech Protective Relaying Conference.

[3] Jonsson M, Daalder JE(2003) An adaptive scheme to prevent undesirable distance protection operation during voltage instability, Power Delivery, IEEE Transactions 18(4): 1174-1180.

[4] Farid A, Abidin, Mohamed A, Ayob A(2009) A New Method to Prevent Undesirable Distance Relay Tripping During Voltage Collapse, European Journal of Scientific Research, 31(1): 59-71.

[5] Lim S, Liu CC, Lee SJ, Choi MS, Rim SJ (2008) Blocking of Zone 3 Relays to Prevent Cascaded Events, IEEE Transactions on Power Systems, 23(2): 747754.

[6] Machowski J, Bialek JW,. Bumby JR(2008) Power System Dynamics: Stability and Control , 2nd Edition, John Wiley & Sons Ltd: 121.

[7] Zhang N, Kezunovic M (2005) A study of synchronized sampling based fault location algorithm performance under power swing and out-of-step conditions," Power Tech, 2005 IEEE Russia : 1-7.

[8] Phadke AG, Thorp JS (2008) Synchronized Phasor Measurements and Their Applications, Springer : 213.

[9] POSOCO (2012), Report on the Grid Disturbances.

[10] Muller C(2010) Introduction to PSCAD/EMTDC X4, Manitoba HVDC Research Centre Inc., Canada.

[11] Darwish HA, and Fikri M (2007) Practical considerations for recursive DFT implementation in numerical relays, IEEE Trans. on Power Delivery 22: 42–49.

[12] IEEE Standard for Synchrophasors for Power Systems (2005) IEEE C37.118

[13] Kesunovic M, and Chen Q (1997) A novel approach for interactive protective system simulation, IEEE Trans. On Power Systems, 12(2): 668-694.

[14] Dommel HW (1969) Digital Computer Solution of Electromagnetic Transient in Single- and Multiphase Networks, IEEE Transactions on Power Apparatus and Systems, 88(4): 388-399.

[15] Jamali S (2001) A fast adaptive digital distance protection in Proc Developments in Power System Protection, Conference Publication IEE: 149-152.

[16] Goh YL, Ramasamy AK, Nagi FH, Abidin AZ (2011) Evaluation of DSP based Numerical Relay for Over current Protection, International Journal Of Systems Applications, Engineering & Development 3(5): 396-403

[17] Jingxuan H, McLaren PG, Dirks E, Wang P, and Bisewski B (2002) A graphical block platform for real-time DSP-based digital relay development, Power System Technology, Proceedings. Power Con 2002. International Conference 1: 265 – 269.

[18] Kim CH, Lee MH, Aggarwal RK, Johns AT (2000) Educational Use of EMTP MODELS for the Study of a Distance Relay Algorithm for Protecting Transmission Lines, IEEE Transactions on Power Systems, 15(1)

[19] Jonsson M, Daalder JE (2003) An adaptive scheme to prevent undesirable distance protection operation during voltage instability, Power Delivery, IEEE Transactions 18 (4): 1174-1180

[20] Biswas B, Bhattacharya KD, Purkait P, and Das JK(2009) Design of a Numerical Adaptive Relay Based on Memory Mapped Technique, Proceedings of the International MultiConference of Engineers and Computer Scientists, 2: 1484-1488