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A logic based protection scheme for six phase transmission system against shunt and series faults

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Abstract. Multiphase transmission system is a serious contender to the conventional Three Phase System. The fault analysis of Six Phase system is studied and adequate protection scheme is developed. A Logical protection scheme of Six Phase Transmission System against shunt and series faults using Logic Based Detection of negative sequence currents is presented in this paper. World First Six Phase Transmission Line is operating between McCalmont bus and Springdale bus of Allegheny Power System (APS),USA. A few amount of work had been reported on protection of Six Phase Transmission System in literature. This paper bridges the gap and paves the way to boost the research in Protection of Six Phase Transmission System. The Proposed Protection Scheme is a Novel approach as it doesn't require any special algorithms and using logical approach. Because of this the fault will be cleared with in one cycle and also the previous history of the healthy wave form just few cycle before occurrence of the fault can be traced for further investigation. The voltages and currents under fault for various types of fault had been taken from earlier studies of fault analysis of Six Phase Transmission line of Allegheny Power System. The proposed Logic based protection scheme is simulated to get a Logic 1 for fault conditions and Logic '0' for healthy conditions by using MATLAB/SIMULINK for shunt and series faults of both Unsymmetrical and Symmetrical faults on different phases of Six Phase Transmission system.

Keywords: six phase protection, negative sequence currents,multi phase system, series and shunt faults

1 Introduction

Six Phase Transmission System meets the demand for electric power which is increasing day by day and the resources are decaying in the same proportion. Erecting of Six Phase Transmission Line requires additional transmission corridor which is difficult to acquire in addition to additional cost of other components required. As an alternative the feasibility of converting the existing Three Phase Double Circuit lines into Six Phase lines of the same phase voltage had been studied and reported in the literature[2, 12, 13]. Conversion of existing Three Phase Double circuit lines into Six Phase Lines leading to additional advantages like increased power transmission capacity to $\sqrt{3}$ times for the same line with greater efficiency, regulation and reliability[2] is gaining ground on economic considerations. Compared to Electro Magnetic Relays and Static Relays, Digital Relays are preferred as they act quickly and can be used in Real Time Control of Power System. Digital relaying requires additional calculations and Algorithms. The effect of variation in fault inception angle and fault distance location has been investigated reported on the performance of the proposed protection scheme develop by MATLAB/SIMULINK by using Artificial Neural Networks Technique[6, 7]. On the other hand use of Logic based Protection[10] has the advantage of instant action as in hardware and the use of simulation eliminates development of special Algorithms. Stability analysis and fault analysis of Six Phase Transmission

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line is achieved in past decade and Protection of Six Phase Transmission line is becoming prominent in Now-a-days. The Protection Scheme proposing in this paper is a Novel approach as logical signal is being considered to analyze the different types of faults. Negative sequence currents are considered to distinguish faulty and healthy condition, because except symmetrical fault all types of faults possess negative sequence currents. This scheme is applicable to both Three Phase and Six Phase System, because Six Phase Transmission line is the combination of two Three Phase double circuit lines. The method proposed in this paper paves the way in the direction of implementation of Six Phase Transmission line by converting Existing Three Phase Double Circuit lines to compact Six Phase Transmission line with in the existing Right-Of-Way to meet the power demand in future.

This paper was categorized into 7 sections. Section 2 covers the importance of Negative sequence currents to be considered in developing the protection scheme. Section 3 describes the comparative study of six phase transmission line. Section 4 explains about the complete protection scheme of Six Phase transmission line and is validated by taking real time values to analyze different types of shunt faults, whereas series faults are discussed in Section 5 and proceeds to conclusion and references.

2 Absence of zero sequence currents in ground fault of six phase system

Literature on fault analysis of Six Phase System reported that in certain cases of Six Phase faults involving ground and opposite phases, the zero sequence currents were found to be absent which prevents the operation of earth fault relays[11] and Protection fails. Except for symmetrical faults all other faults do possess negative sequence currents which can be used for protection. Hence the logic based detection of negative sequence currents plays an important role in protection of Six Phase System. This scheme was simulated using MATLAB for all possible types of faults of both Symmetrical and Unsymmetrical.

The Highlight of the scheme is that the present Current wave form is being compared with the previous history of the corresponding wave form for a few cycles continuously just before the disturbance, so that when fault occurs the faulted current wave form is compared with the corresponding previous healthy wave form for further analysis and investigation.

3 Comparative studies of six phase transmission line

The method to determine the stability in terms of critical clearing angles for both three and six phase line faults is reported in literature[9]. This method has been validated by applying it first for the faults on a 132kV three phase double circuit line of a given practical power system and comparing the results with those obtained through the symmetrical component method. Then it has been applied for the faults on the same line but considered to have been converted into a 132kV six phase single circuit line.

A new method of fault location and phase selection with the help of long line equation, the fault currents can be calculated from the location of fault and electrical signals gained from the end of transmission lines. And the characteristics of amplitude for fault currents can be used for phase selection. Theoretical analysis and MATLAB simulation shows that this method is not affected by distributed capacitance and transition resistance, which locates exactly. And it has the ability of adaptive adjustment on settings of phase selection as operation mode operating mode identification. So it can provide effective fault phase selection logic for distance relay protection of six-phase transmission lines[1].

By using load-point and system indices Six Phase Transmission line have been studied for composite system reliability. The worth of employing the six-phase transmission line is expressed in terms of the reduction in the customer interruption cost[15].

ANN based protection scheme against phase to phase faults of six phase transmission line by sing MATLAB. Fundamental components of six phase voltages and currents have been used as inputs for training of the Artificial Neural Network for detection and classification of faulted phase using neural network toolbox of MATLAB? A sample 138kV system of 68 km length, the model of Allegheny Power System has been selected[3].

The technology of high phase order electric power transmission, especially the Six Phase Transmission system because of its advantage of more power transfer capability within the existing Right-Of-Way promises the demand in future. Different techniques of symmetrical components by using filters to measure symmetrical components of voltages and currents have been proposed for analyzing the Six-phase power system under unbalanced condition[5].

The Six Phase Transmission line can be protected by using Phase Comparison protection using Six Phase Sequence components and differential protection using pilot wire[4].

Construction of UHV power grid is the fundamental guarantee to the growing demands of electricity in the future. Six phase transmission lines can evidently improve power transmission density, and many countries pay attention to it. The motivation of writing this article arises from the question: Why Protection of Six Phase Transmission line is not given complete attention? Of course the number of faults that occurs in Six Phase line are 120. Even though these faults can be reduced to 13 distinct groups[13], and makes developing the protection system is simpler. This article is proposed to bridge the gap in developing the compete protection scheme so that the Six Phase Transmission line may implement in future.

4 Protection of six phase transmission system

Six Phase Transmission Line can be considered as two mutually coupled Three Phase Systems. Negative sequence detection plays an important role in designing the protection scheme[10, 16]. The scheme presented makes use of amplitude and phase comparators and necessary logic gates. Fault currents are compared with healthy wave for both amplitude and phase by using Relational operator block and Complex Phase Difference Block respectively available in simulink library. The 138kV Six Phase Transmission line of Allegheny Power System(APS),USA located between McCalmont and Springdale bus, given in Fig. 1 is considered to simulate the proposed protection scheme. The single line diagram with necessary relay locations is depicted in Fig. 2. The simulation diagram of the proposed protection scheme is shown in Fig. 3.

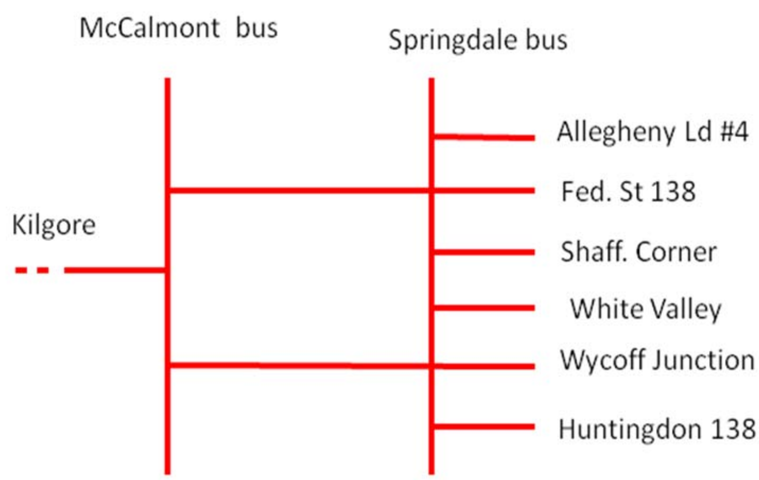

Fig. 1: Single line diagram of six phase transmission line between McCalmont and Springdale buses of APS, USA

The operation of different relays including backup protection are tabulated in Tab. 1 for shunt faults. The Proposed protection scheme is simulated for different possible kinds of shunt and series faults of both Symmetrical and Unsymmetrical faults occurring at McCalmont bus. This scheme works for Symmetrical, Unsymmetrical, Open circuit faults and simultaneous faults. Initially fault current is fed to "Complex Phase difference" and "Relational operator" blocks for comparison of healthy wave form and fault wave forms. Here, only one wave form is used to represent the healthy and fault wave forms because in actual practice there will

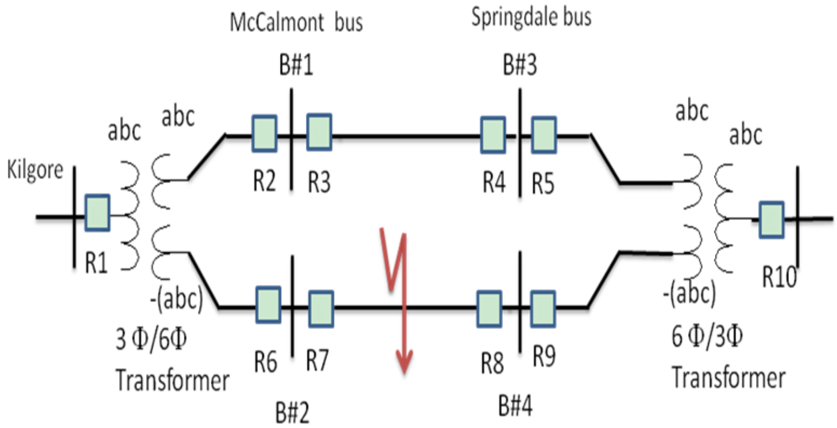

Fig. 2: Single line diagram of APS with relay locations

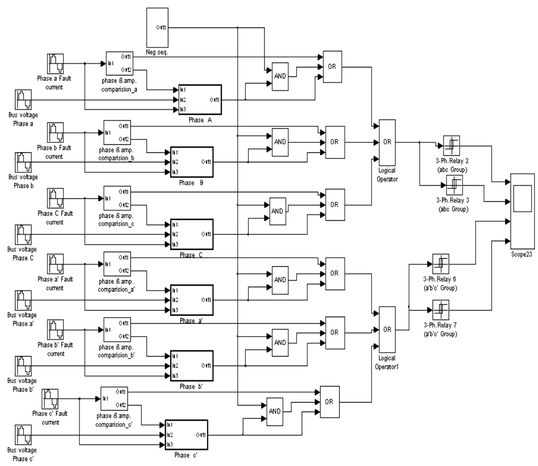

Fig. 3: Simulation diagram of protection scheme of six phase line with 3-Φ Relays

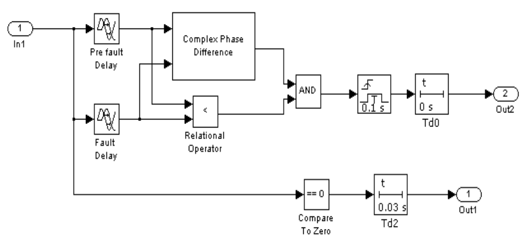

Fig. 4: The simulation diagram of subsystem "phase & amp. comparision" block

be only one wave form. The healthy wave form is obtained for comparison by delaying the input wave form by a few cycles. The same input wave form becomes the faulty wave form on occurrence of fault.

So, the same input wave form represents both, the healthy wave form as in the case of normal conditions and faulty wave form as in the case of fault conditions. To create the conditions for comparison two Time Delay Blocks are used, one to make the healthy wave form available for comparison and the other to simulate the faulty wave form because definitely there will be a time difference between prefault and fault conditions. These time delays are Prefault delay (Pd) and Fault delay (Fd). The proposed protection scheme will give the trip signal as Logic 1 only for fault condition and Logic 0 for normal condition. To simulate the normal condition the time delays Pd and Fd are set to be same value so that the difference between two time delays is zero. Similarly to simulate the fault condition the time delays Pd and Fd is set to be different values so that

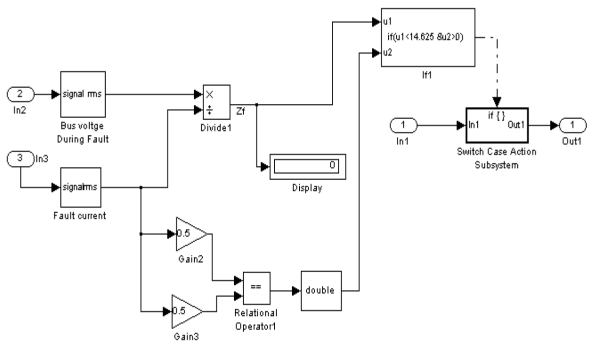

Fig. 5: Simulation diagram to measure fault impedance

there will exist the time difference between prefault and fault and during this time period the previous history of the fault wave form can be traced.

Table 1: The operation of different relays for the Faults occurring at McCalmont bus

	Type of Fault	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Main	Shunt Fault at Bus♯1	×	√ Td1	√ Td1	×	×	×	×	×	×	×
Protection	Shunt Fault at Bus♯1	×	×	×	×	×	√ Td1	√ Td1	×	×	×
	Shunt Fault at Bus♯1 & ♯2	×	√ Td1	√ Td1	×	×	√ Td1	√ Td1	×	×	×
	Series fault between Bus ♯2 & ♯4	×	×	×	×	×	×	√ Td1	√ Td1	×	×
Backup Protection	Case 1 (If R2 Fails to trip)	√ Td2	×	√ Td2	√ Td2	×	×	×	×	×	×
	Case 2 (If R3 Fails to trip)	×	√ Td1	×	√ Td2	×	×	×	×	×	×
	Case 3 (If both R2 & R3 Fails to trip)	√ Td2	×	×	√ Td2	×	×	×	×	×	×
	Case 1 (If R6 Fails to trip)	√ Td2	×	×	×	×	×	√ Td1	√ Td2	×	×
	Case 2 (If R7 Fails to trip)	×	×	×	×	×	√ Td1	×	√ Td2	×	×
	Case 3 (If R6 & R7 Fails to trip)	√ Td2	×	×	×	×	×	×	√ Td2	×	×

The comparison method is depicted in the subsystem "phase & amp. comparison" Block for each phase and is shown in Fig. 4 for the phase 'a' which is the same for all phases. The fault is assumed to occur at t =0.03 sec. The time delay Fd is set for 0.03 sec. The Prefault delay Pd is set for 0.02. The output of "Complex Phase difference" block and "Relational Operator" block is fed to AND gate, because both phase and amplitude difference will exit between prefault and fault wave forms. For better illustration of trip signal a "Discrete Mono stable" block is used. The delay Td0 is taken as zero, because the relay will give trip signal based on logic and hence the maloperation of the relay for momentary faults is neglected.

The fault impedance is calculated by using "Divide" block and is fed to "If" block to incorporate the condition of fault impedance is less than the line impedance. The simulation diagram to calculate the fault impedance is given in Fig. 5. Earlier studies of Fault analysis on the above mentioned system is considered

Table 2: The faults currents for all Significant faults on McCalmont bus

S.No	Type of fault &Phase current (kA/Degrees)						
		a	c'	b	a'	c	b'
1	abc a'b'c'	15.7 ∠−81	15.7	15.7	15.7	15.7	15.7
2	abca'b'c'∠−n	15.7 ∠−81	15.7	15.7	15.7	15.7	15.7
3	bca'b'c'	0	17.5	14.4	12.6	14.4	17.5 ∠−30
4	bca'b'c'∠−n	0	16.9	15	13.7 100	14.6	16.6 ∠−2.8
5	aba'c'	17.1	10.4	10.4 140	17.1	0	0
6	aa'b'c'	11.8 ∠−81	14.1	0	19.6	0	14.1 ∠−7
7	aa'b'c'∠−n	13.4 80	14.4	0	18	0	14.9 ∠−13
8	aa'c'	13.8	10.5	0	18.9 85	0	0
9	aa'c'∠−n	14.8 ∠−71	13	0	16.9	0	0
10	a'b'c'	0	15.4	0	15.7	0	15.7 ∠−21
11	aa'	15.7 ∠−81	0	0	15.7	0	0
12	aa'∠−n	15.7 ∠−81	0	0	15.7	0	0
13	a∠−n	11.5 ∠−77	0	0	0	0	0
14	b'c'	0	13.6 ∠−189	0	0	0	13.6

Table 3: The fault Voltages at McCalmont bus for all Significant faults on McCalmont bus

S.No	fault Type	Phase current (kA/Degrees)					
		a	c'	b	a'	c	b'
1	a b c a'b'c'	0	0	0	0	0	0
2	a b c a'b'c'−n	0	0	0	0	0	0
3	bca'b'c'	147.7∠0	29.5∠180	29.51∠180	29.5∠180	29.5∠180	29.5∠180
4	bca'b'c'−n	164.8∠0	0	0	0	0	0
5	aba'c'	63.9∠−90	63.9∠−90	63.9∠−90	63.9∠−90	14.7∠−120	14.7∠−60
6	aa'b'c'	36.9∠0	36.9∠0	147.7∠240	36.9∠0	147.7∠120	36.9∠0
7	aa'b'c'−n	0	0	156.2∠233	0	160.3∠126	0
8	aa'c'	49.2∠−60	49.2∠−60	147.7∠240	49.2∠−60	147.7∠120	14.7∠60
9	aa'c'−n	0	0	134.8∠232	0	169.9∠118	162.6∠66
10	a'b'c'	147.7∠0	0	147.7∠240	0	147.7∠120∠120	0
11	aa'	0	147.7∠300	147.7∠240	0	147.7∠120	147.7∠60
12	aa'−n	0	147.7∠300	147.7∠300	0	147.7∠120	147.7∠60
13	a−n	0	128.4∠−71	160.5∠229	179.2∠178	170.9∠128	141.1∠73
14	b'c'	147.7∠0	73.8∠0	147.7∠240	147.7∠180	147.7∠120	73.8∠0

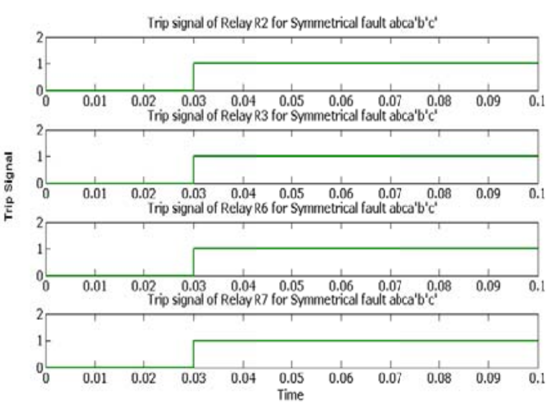

Fig. 6: Trip signal of the relays for symmetrical fault abca'b'c' or abca'b'c'-n

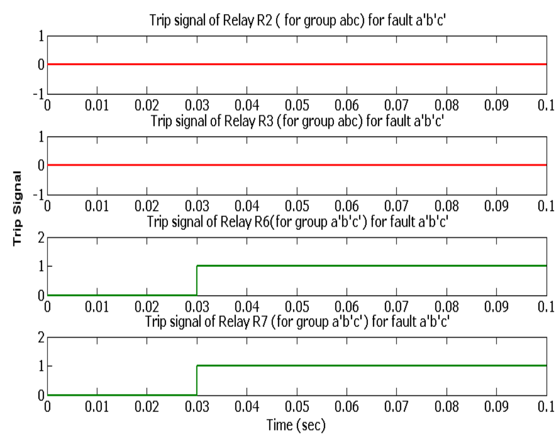

Fig. 7: Trip signals of the relays for Unsymmetrical faults occurring in Group a'b'c'

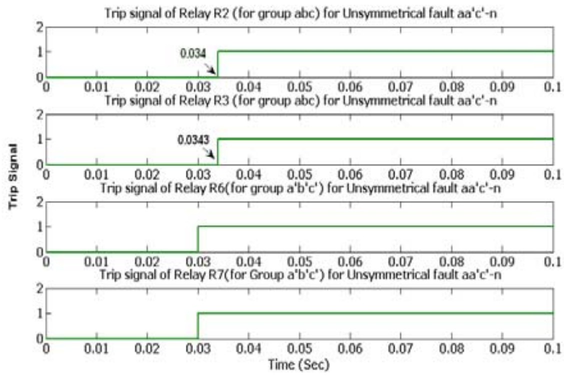

Fig. 8: Trip signal of the relays for Unsymmetrical fault aa'c'-n

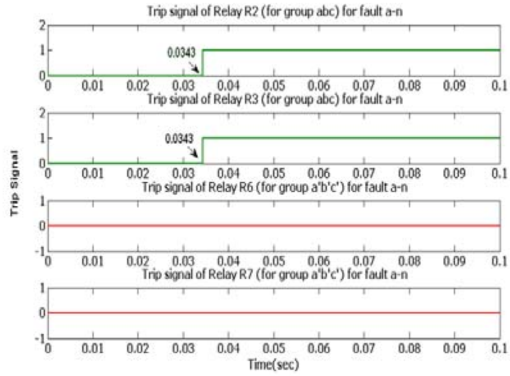

Fig. 9: Trip signals of the relays for Unsymmetrical fault a-n

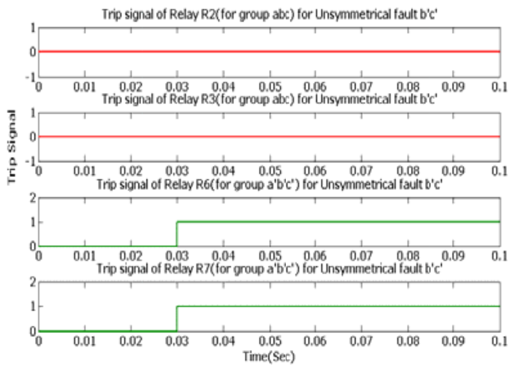

Fig. 10: Trip signals of the relays for unsymmetrical fault b'c'

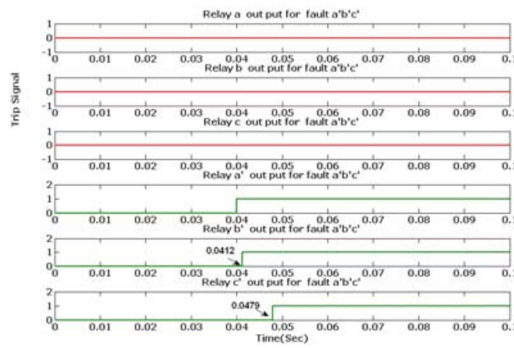

Fig. 11: Trip signals of the relays in faulty lines for unsymmetrical fault a'b'c'

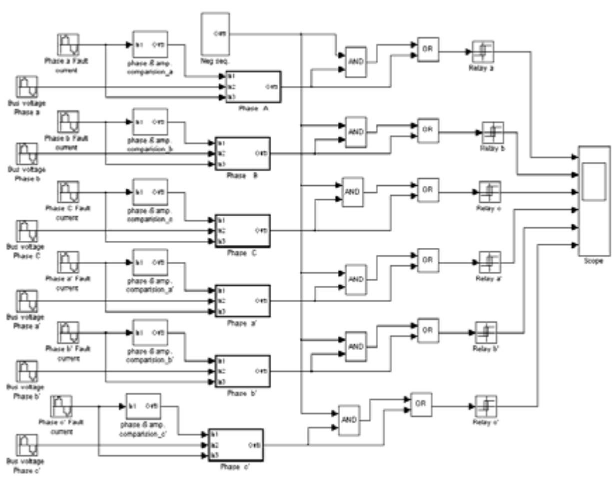

Fig. 12: Simulation diagram to isolate only the faulty lines

to check the performance of the scheme and the fault currents and fault voltages for all significant faults on McCalmont Six Phase Bus of Allegheny Power System, USA of Fig. 1 are given in Tabs. 2 and 3[10].

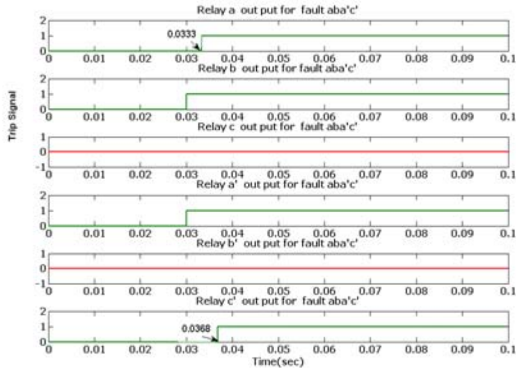

Fig. 13: Trip signals of the relays in faulty lines for unsymmetrical fault aba'c'

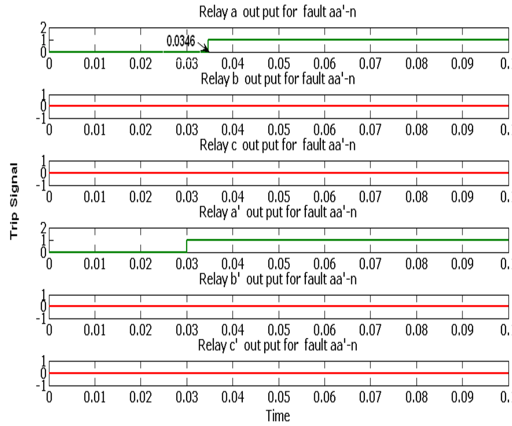

Fig. 14: Trip signals of the relays in faulty lines only for Unsymmetrical fault aa'-n

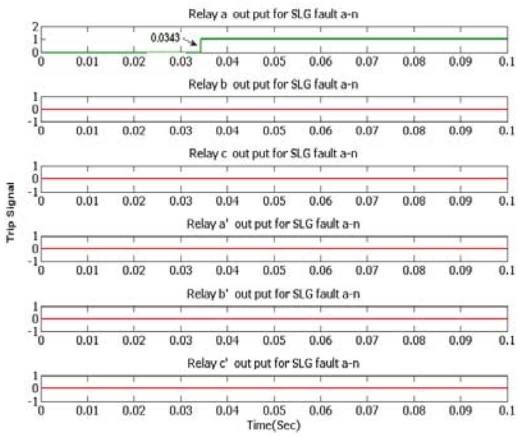

Fig. 15: Trip signals of the relays in faulty lines only for unsymmetrical fault a-n

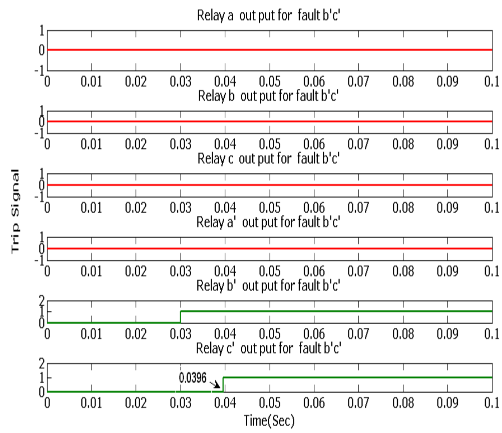

Fig. 16: Trip signals of the relays in faulty lines only for Unsymmetrical fault b'c'

4.1 Analysis of shunt faults to trip only the faulty group

On occurrence of fault the detection by relays in the faulty line can cause operation of any one or both the Relays (for groups abc & a'b'c') depending on the fault conditions so as to provide continuity of supply through the healthy Three Phase Group in the case of shunt faults.

Alternatively only the faulty lines can be isolated so as to provide continuity of supply in all the remaining healthy lines in the case of shunt faults.

In this section the operation by one or more relays to isolate all the three lines of the group (abc or a b c) in which they are placed causing simultaneous tripping of all the three lines of the group in which the fault occurs is being considered for few kinds of shunt faults (i)abca'b'c' or abca'bc'-n ii) a'b'c' iii) aa'c -n iv) a-n v) b'c'.

The fault currents and voltages given in Tabs. 2 and 3 of the faults abca'b'c' or abca'b'c -n are fed to the proposed protection scheme given in Fig. 3 and the trip signal of the relays are plotted in Fig. 6 to Fig. 10 respectively. In this scheme the fault is assumed to occur at 0.03sec, and the relays have given the trip signal either immediately fault occurs or within $1/4^{th}$ of the cycle.

4.2 Analysis of shunt faults to isolate only the faulty lines instead of faulty groups

The scheme of protection given in Fig. 3 has been suitably modified so as to make only the faulty line to trip as given in Fig. 12. In this scheme only the faulty lines are isolated so as to provide continuity of supply in all the remaining healthy lines in the case of shunt faults since the Six Phase System can operate stably with even as many as four lines out.

In this section the operation by one or more relays to isolate only the faulty phase of either group in which fault is to be simulated. The faults being considered for few kinds of shunt faults are i)a'b'c' ii)aba'c' iii)aa'-n iv)a-n v)b'c'.

The fault currents and voltages given in Tabs. 2 and 3 are fed to the proposed Protection scheme given in Fig. 12 and the tripping signals of the respective relays are depicted in Fig. 11 to Fig. 16. In all the cases only the faulty phases have given the trip signal. In the case of the fault aa'-n even though it is a ground fault occurs in similar phases of two groups the relay a and relay a have given the trip signal.

5 Analysis of series faults

In case of Six Phase System one line open circuit fault is equivalent to five line to ground fault and Two line open circuit fault is equivalent to four line to ground fault and so on[14]. According to this even though there is fault in one line only because of by fault or by external means it is required to open all the Six Phases. A few open circuit faults of Allegheny Power System, USA are discussed for the proposed protection scheme shown in Fig. 12 and the respective fault currents[14] are tabulated in Tab. 4. Series faults are simulated only by considering the current value which is zero in case of series fault. The protection scheme is developed in such a way that the relay will give trip signal whenever current flowing through the line is zero. The values of the Bus voltages does not matter in the analysis of series faults. To simulate the series fault the time difference between Prefault delay and fault delay is to be created in subblock "phase & amp. comparison" of Fig. 4 of the protection scheme for all phases.

5.1 Analysis of one line open series fault on phase a

The fault currents given in Tab. 4 of one line series fault on phase a are fed to the proposed protection scheme given in Fig. 12 and the trip signal of the relays are plotted in Fig. 17. The fault is assumed to occur at t =0.03 sec and it is observed that the relay b and Relay c s have given the trip signals at t =0.0315 sec and t =0.0375 sec respectively and the rest of the relays have given the trip signal at t =0.03sec.

Table 4: The faults currents for all types series faults of Allegheny Power system

S.No	Type of series fault	Phase current (kA/Degrees)					
		a	c'	b	a'	c	b'
1	Single phase series fault(a)	0	481.32 $\angle -134.2$	437.23 $\angle 164.3$	410.24 $\angle 99.05$	431.65 $\angle 32.49$	473.64 $\angle -26.5$
2	Single phase series fault (a-c')	0	0	470.41 $\angle 172.5$	385.43 $\angle 109.6$	378.52 $\angle 30.25$	495.45 $\angle -34.7$
3	Single phase series fault (a-b)	0	504.34 $\angle -142.5$	0	433.78 $\angle 106.5$	403.76 $\angle 38.96$	429.36 $\angle -28.2$
4	Single phase series fault (a-c'-b-a')	0	0	0	0	366.28 $\angle 55.88$	346.93 $\angle -32.8$
5	Single phase series fault (a-c'-b-a'-c)	0	0	0	0	0	346.47 $\angle -18.9$

5.2 Analysis of inter group series fault on phase ac’ of the six phase system(two lines open fault of inter group)

The fault currents given in Tab. 4 of two line series fault on phase ac are fed to the proposed protection scheme given in Fig. 12 and the trip signal of the relays are plotted in Fig. 18. The fault is assumed to occur at t =0.03 sec and it is observed that the relay b have given the trip signal at t =0.032 sec and the rest of the relays have given the trip signal at t =0.03sec.

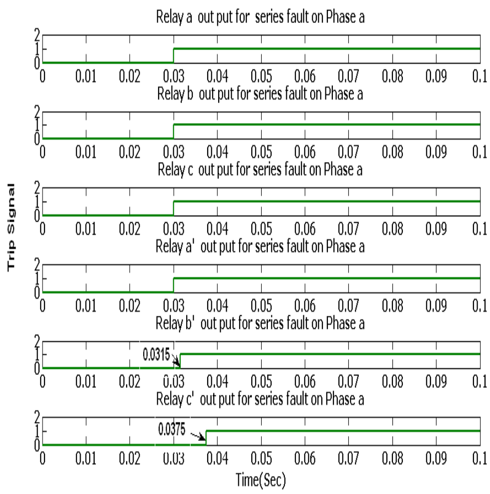

Fig. 17: Trip signals of the relays for one line series fault on phase ‘a’

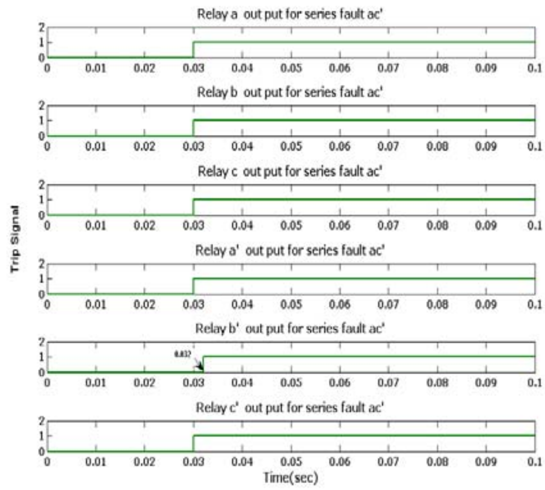

Fig. 18: Output response of protection scheme for the series fault ac’

5.3 Analysis of series faults in the same three phase group like phases ‘a’ and ‘b’ of the six phase system (two lines open fault of same group)

The fault currents given in Tab. 4 of two line series fault on phase ab are fed to the proposed protection scheme given in Fig. 12 and the trip signal of the relays are plotted in Fig. 19. The fault is assumed to occur at t =0.03 sec and it is observed that the relay b’ and Relay c’ s have given the trip signals at t =0.032 sec and t =0.038 sec respectively and the rest of the relays have given the trip signal at t =0.03sec.

5.4 Analysis of inter group series faults like phases aba’c’ of the six phase system (four lines open fault of inter group)

The fault currents given in Table No.4 of two line series fault on phase aba’c’ are fed to the proposed protection scheme given in Fig. 12 and the trip signal of the relays are plotted in Fig. 20. The fault is assumed to occur at t =0.03 sec and it is observed that the relay ’b have given the trip signal at t =0.032 sec and the rest of the relays have given the trip signal at t =0.03 sec.

6 Conclusions

The protection scheme not only works for Six Phase System, but also works for existing Three Phase System. Because it has been designed based on the negative sequence components which exists in both Six Phase and Three Phase system under fault conditions. Negative sequence currents play a major role in the protection of six phase transmission system, because for certain types of faults involving ground ,the zero sequence currents are found to be absent in the case of six phase system and leads to the failure of ground

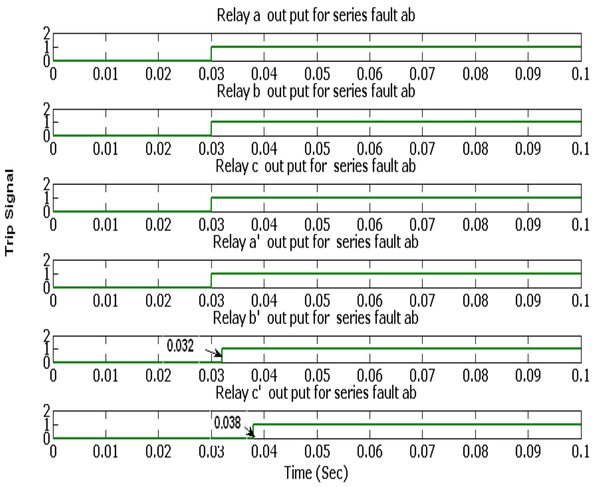

Fig. 19: Output response of protection scheme for the series fault ab

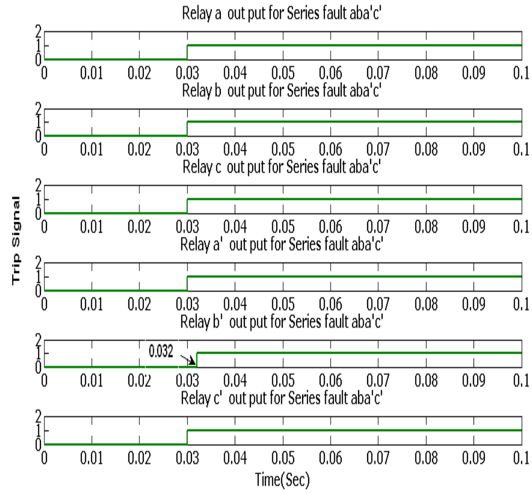

Fig. 20: Output response of protection scheme for the series fault aba'c'

relay. The proposed complete Protection scheme for Six Phase system is simulated for both shunt and series faults, and in all the cases trips signals of the relays are Logic 1 for fault condition and Logic 0 for healthy conditions. The protective scheme has given the trip signal in less than one cycle from the time of occurrence of fault for all types of faults such as shunt and series faults. It will make the circuit breaker to trip the faulty section as early as possible to reduce the damage to healthy section. Except symmetrical faults all types of faults possess Negative sequence components, and hence this scheme works for all types of faults including symmetrical faults, because a special logic has been applied for symmetrical faults in Simulink Model. This Novel concept of Logical approach to Protect Six Phase Transmission System will work for all types of faults such as Symmetrical and Unsymmetrical faults. And also this Scheme can be extended to provide backup protection as occasionally the relay may fail to give trip signal whenever the fault occurs. This novel approach of Protection of Six Phase Transmission System by using Negative Sequence currents bridges the gap between the Three Phase System and Six Phase System leads to the development and implementation of Six Phase system in future with in the existing Right-Of-Way. The Proposed Scheme is simulated for the faults occurring on similar phases of both groups viz., aa', bb' and cc' where the zero sequence components are absent. The simulation results are satisfactory and up to the expectations.

References

[1] S. hmed, M. Tawrit, et al. Novel adaptation of the critical clearing angle formula for faults on a three phase and a six phase line. *Electric Power Systems Research*, 2002, **61**(2): 119–126.

[2] H. Barnes, L. Barthold. High phase order power transmission. *Electra*, 1973, **24**: 139–153.

[3] R. Billinton, S. Faried, M. Fotuhi-Firuzabad. Composite system reliability evaluation incorporating a six-phase transmission line. **in:** *Generation, Transmission and Distribution, IEE Proceedings-*, vol. 150, IET, 2003, 413–419.

[4] M. S. Farghaly, E.-N. A. Ibrahim. Two three-phase symmetrical component filters of 6-phase electrical power systems. *Electric Power Components and Systems*, 2006, **34**(11): 1231–1242.

[5] T. Khodiyar, E. Koley, A. Yadav, A. Thoke. Protection of six phase transmission line against phase to phase faults. *UACEE International Journal of Advancements in Electronics and Electrical Engineering*, **1**(1-2012).

[6] E. Koley, A. Yadav, A. S Thoke. Artificial neural network based protection scheme for one conductor open faults in six phase transmission line. *International Journal of Computer Applications*, 2014, **101**(4): 42–46.

[7] E. Koley, A. Yadav, A. S. Thoke. A new single-ended artificial neural network-based protection scheme for shunt faults in six-phase transmission line. *International Transactions on Electrical Energy Systems*, 2015, **25**(7): 1257–1280.

[8] K. R. Reddy, P. Subramanyam, T. K. Parandhama. Series faults on six phase transmission system. *Proc. Ninth National Convention of Electric Engineers*, 1993, 218–332.

[9] K. R. Reddy, P. Subramanyam, T. K. Parandhama. Fault analysis through fault impedances on six phase transmission system. *Proc. Tenth National Convention of Electric Engineers*, 1994, 32–42.

[10] F. G. C. Sekhar, S. P. Subramanyam, T. B. S. Ram. Logic based design of protection scheme for six phase system using detection of negative sequence currents. *Int. J. on Recent Trends in Engineering and Technology*, 2011, **6**(2).

[11] G. C. Sekhar, P. Subramanyam, B. S. Ram. Logic based detection of negative sequence currents for six phase system. *International Journal of Applied Engineering Research*, 2011, **4562**: 1311–1322.

[12] J. Stewart, D. Wilson. High phase order transmission–a feasibility analysis part i–steady state considerations. *Power Apparatus and Systems, IEEE Transactions on*, 1978, (6): 2300–2307.

[13] P. Subramanyam. *Contributions to the analysis of six phase system*. Ph.D. Thesis, Ph. D. Thesis, IIT, Madras, March 1983, 1983.

[14] S. Venkata, W. Guyker, et al. 138-kv, six-phase transmission system: fault analysis. *Power Apparatus and Systems, IEEE Transactions on*, 1982, (5): 1203–1218.

[15] Y. Wang, D. Zhou, et al. Fault location and phase selection for uhv six-phase transmission lines. **in:** *Power and Energy Engineering Conference (APPEEC), 2011 Asia-Pacific*, IEEE, 2011, 1–3.

[16] Y. Wang, D. Zhou, S. Xu. Study on phase comparison pilot protection for six-phase transmission lines based on six-sequence transformation. **in:** *Advanced Materials Research*, vol. 433, Trans Tech Publ, 2012, 2394–2399.