S-transform based directional bus-bar protection

Samantaray, S. R. Tripathy, L. N. Dash, P. K. Panda, G.
National Institute of Technology, Rourkela, INDIA

This paper appears in: **TENCON 2008 - 2008, TENCON 2008. IEEE Region 10 Conference**

Publication Date: 19-21 Nov. 2008
On page(s): 1 - 6
Number of Pages: 1 - 6
Location: Hyderabad, India
ISBN: 978-1-4244-2408-5
http://dx.do.org/10.1109/TENCON.2008.4766745

S-Transform based Directional Bus-bar protection

S. R. Samantaray, L. N. Tripathy, P. K. Dash, G. Panda

***Abstract*— The directional protection of bus-bars using time-frequency transform such as S-transform is presented in the paper. S-transform is used to estimates the phase and amplitude of the fault current signals during fault situations. The difference in phase angle between positive sequence component of the current during fault and pre-fault conditions distinguishes internal faults (bus-bar faults) from external fault and load change situations. The estimated phase difference is positive for outgoing feeders for internal fault, but the same is negative for external and load change conditions. Thus a simple rule base is formulated for bus-bar protection depending upon the difference in phase information of the current signal of the outgoing feeder. The proposed method is tested for different fault situations in bus-bar as well as external fault and loading conditions, and provides accurate results.**

***Index Terms*— Bus-bar protection, S-transform, phasor estimation, phase change.**

I. INTRODUCTION

The performance of a power network is frequently affected by the bus-bar faults, which give rise to disruption in power flow. Bus bar fault may cause excessive damage in the system and the power network becomes completely interrupted. Bus-bars, the connection nodes of multiple power circuits, must have very secure protection since tripping of a bus-bar usually has widespread power interruptions. The risk of an unnecessary trip must be kept to a minimum. This immediately brings stability into consideration for a fault just beyond the zone of bus-bar protection, commonly known as through faults, which has similar fault levels to the bus that causes a mistrip of the bus-bar protection relay. The protection must be stable for these through faults. Thus unwanted tripping must be avoided to ensure operation of the protection scheme.

Generally, differential protection scheme has been found suitable for bus-bar protection. But differential protection suffers due to CT saturation and ratio mismatch. This problem can be solved to a certain extent by biased differential protection scheme. Several protection schemes are available [1-3] based on differential scheme for bus-bar protection employing microprocessor and digital signal processor. Recently, a directional protection scheme based on wavelet packets [4] has been presented where the decomposed fault current signal features are used for tripping decision. Another proposed technique extracts the energy spectrum of the transient fault current to distinguish between internal and external fault [5]. Another technique uses wavelet transform for direction estimation of the fault situation for bus-bar protection by finding out the power signal derived from current and voltage signal [6]. Although wavelets provide a variable window for low and high frequency currents in the voltage and current waveforms during faults, their capabilities are often significantly degraded owing to the existence of noise riding high on the signal [7]. In particular, as the spectrum of the noise coincides with that of the transient signals, the effects of noise cannot be excluded by means of some kinds of filters without affecting the performance of the wavelet transform.

The proposed technique uses time-frequency transform known as S-transform [8-9] for phasor estimation of the fault current signals, which in turn is used for direction estimation. The S-transform is an invertible time-frequency spectral localization technique that combines elements of wavelet transforms and short-time Fourier transform. The S-transform uses an analysis window whose width is decreasing with frequency providing a frequency dependent resolution. This transform may be seen as a continuous wavelet transform with a phase correction.

The phase difference in positive sequence component of the pre-fault and fault current is found out in internal fault and external fault, load change situations for both incoming and outgoing feeders. S-transform accurately estimates the phase of the respective current signals from which the phase difference is calculated. The phase difference in pre-fault and fault current becomes positive for internal fault and negative for external fault/load change situations in outgoing feeders. But the phase difference is negative for internal and external fault/load change situations for incoming feeders. Thus a simple rule base distinguishes the internal and external fault taking the phase difference information of the outgoing feeder current signals only, reducing the cost of voltage sensors and related elements. Thus an effective directional protection scheme for bus-bar is built up using the proposed technique.

II. S-TRANSFORM AND PHASOR ESTIMATION

The S-transform [8] is an invertible time-frequency spectral localization that combines elements of Short-time Fourier transform and wavelet transform. The S-transform has an advantage in that it provides multiresolution analysis, which retaining absolute phase of each frequency. This has led to its application for time series analysis and pattern

---

S.R.Samantaray and G. Panda are with National Institute of Technology, Rourkela, INDIA, E-mail: sbh_samant@yahoo.co.in

L. N. Tripathy and P. K. Dash are with Silicon Institute of Technology, Bhubaneswar, INDIA

recognition in power networks and other engineering systems. The expression for S-transform of a continuous signal $x(t)$ is given as

$$S(\tau,f)=\int_{-\infty}^{\infty}x(t)\left\{\frac{|f|}{\alpha\sqrt{2\pi}}\right\}.\exp\left(\frac{-f^2(\tau-t)^2}{2\alpha^2}\right).\exp(-2\pi ift)dt \qquad (1)$$

Here f is the frequency, t is the time and τ is a parameter that controls the position of the Gaussian window on the t-axis.

The factor 'α' controls the time and frequency resolution of the transform and lower 'α' means higher time resolution. The converse is true if higher value of 'α' is chosen for the analysis. A suitable value of 'α', however, lies between $0.2 \le \alpha \le 1$.

Also $$\int_{-\infty}^{\infty}S(\tau,f)d\tau = X(f) \qquad (2)$$

where $X(f)$ is the Fourier transform of $x(t)$.

The discrete version of the continuous S-transform is obtained as

$$S(j,n)=\sum_{m=0}^{N-1}X(m+n).\exp\left(\frac{-2\pi^2m^2\alpha^2}{n^2}\right).\exp(i2\pi mj) \qquad (3)$$

and j=1……..N-1, n=0, 1…N-1.

Here j and n indicate the time samples and frequency step, respectively and

$$X(n)=\frac{1}{N}\sum_{k=0}^{N-1}x(k).\exp(-i2\pi nk) \qquad (4)$$

where n=0, 1………,*N-1*

Computation of $X(m+n)$ is done in a straight forward manner from equation (4). The Fourier spectrum of the Gaussian window at a specific n (frequency) is called a voice Gaussian and for a frequency $f_1(n_1)$, the voice is obtained as

$$S(j,n_1)=A(j,n_1).\exp(j\phi(j,n_1)) \qquad (5)$$

Hence the peak value of the voice is

$$\max(S(j,n_1))=\max(A(j,n_1)) \qquad (6)$$

and

$$\phi(j,n_1)=a\tan\left\{\frac{imag(S(j,n_1))}{real(S(j,n_1))}\right\} \qquad (7)$$

From the above analysis it is quite evident that not only S-transform localizes the faulted event but also peak amplitude and phase information of the current signals can be obtained, which are used for direction estimation. To reduce calculations only the fundamental voice of the S-transform can be used.

Fig. 1(a) shows the magnitude (pu) versus sample (time) estimated using S-transform as per (6) and the phase using (7) at fundamental frequency voice. The normalized frequency versus magnitude (pu) plot in Fig.1 (b) (2nd window) shows the frequency content information in the fault current signal. Thus when the magnitude is highest, corresponding frequency voice (position) is selected and at that particular frequency voice, the phase in calculated as per (7). This provides the absolute phase position of the corresponding pre-fault and fault current signal. Fig 1(b) provides the phase (radian) comparison estimated using S-transform for fault current signal without noise and with SNR up to 20 dB. It is observed that the estimated phase does not change significantly in case of noisy environment.

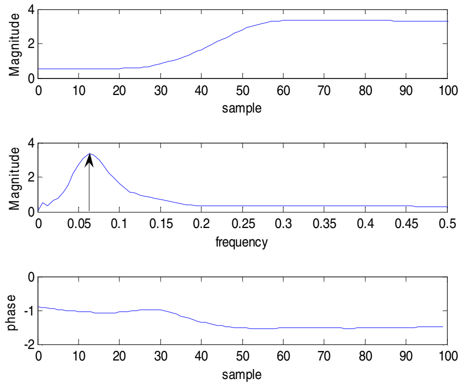

Fig.1 (a) Magnitude, frequency and phase estimation using S-transform

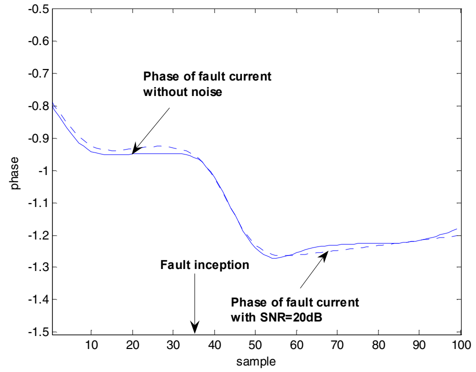

Fig.1 (b) Variation in phase with pure signal to signal with SNR=20dB

III. System Studied

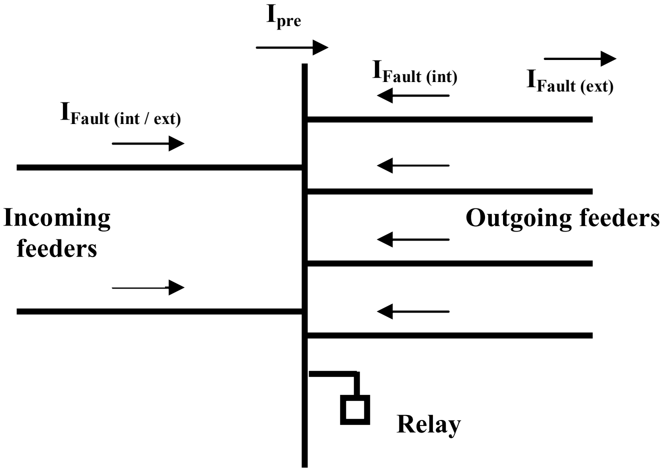

Fig.2 Bus-bar with incoming and outgoing Feeders

The system studied is shown in Fig. 2 has been developed using PSCAD/EMTDC. The system voltage is 400 kV with two incoming feeders and four outgoing feeders. The lines modeled as π sections of 100 km each. The current transformers are modeled as saturabale transformer available in PSCAD/EMTDC. CTs are selected as per the standards mentioned in [10, 11].The model is simulated with a sampling frequency of 1.0 kHz on a 50Hz base frequency. The relaying point is as shown in the figure for the selected bus. The figure also shows the direction of internal fault current, external fault current and pre-fault current seen by the relay.

IV. DIRECTION ESTIMATION USING PHASE CHANGE IN CURRENT SIGNAL

The proposed method estimates the phase change in the current signal for direction estimation for different fault situations using S-transform. The current (pu) in case of pre-fault, internal fault and external fault are shown in Fig. 3. The fault currents for incoming and outgoing feeders are calculated as follows.

Let the fault current in the incoming and outgoing feeders are I_{F1} and I_{F2} respectively for internal fault situation as shown in Fig. 4(a). But before the fault inception, there exists a pre-fault current in both incoming and outgoing feeders. The directions of the fault and pre-fault currents are shown in Fig. 4(a) for internal fault. Let the pre-fault current be I_{pre} . Now during internal fault situation the current seen by the relay at the bus for incoming feeder is

$$I_{in} = I_{pre} + I_{F1} \tag{10}$$

and similarly the current seen by the relay at bus for outgoing feeder will be

$$I_{out} = I_{pre} - I_{F2} \tag{11}$$

But in case of external fault situation, the fault current direction in the outgoing feeders gets changed, but that of incoming remains same as shown in Fig. 4(b). In this condition, the current seen by the relay at bus for the incoming feeder is

$$I_{in} = I_{pre} + I_{F1} \tag{12}$$

and the current seen by the relay at bus for outgoing feeder will be

$$I_{out} = I_{pre} + I_{F2} \tag{13}$$

The phasor relationship can be drawn for the fault and pre-fault situations as shown in Fig. 5(a) and 5(b) for internal and external fault, respectively. The direction of fault current can be found out from the fault phasor position with respect to the pre-fault phasor position. Thus change in phase from pre-fault condition to fault condition will provide the information regarding the direction of fault seen by the relay at the bus-bar.

As shown in Fig. 5(a), the phase angle between I_{out} and I_{pre} is positive and the phase angle between I_{in} and I_{pre} is negative for internal fault situation. Similarly for external fault situation, as shown in Fig.5 (b), the phase angle between I_{out} and I_{pre} is negative, and the phase angle between I_{in} and I_{pre} is also negative.

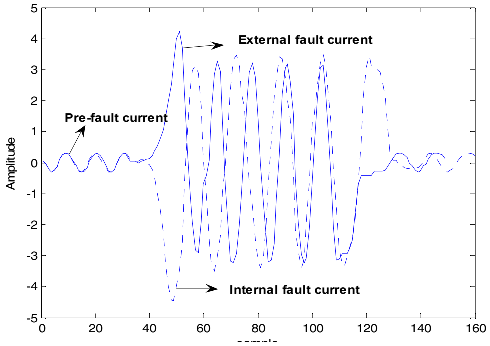

Fig.3 Pre-fault, internal fault and external fault currents retrieved at the relaying end

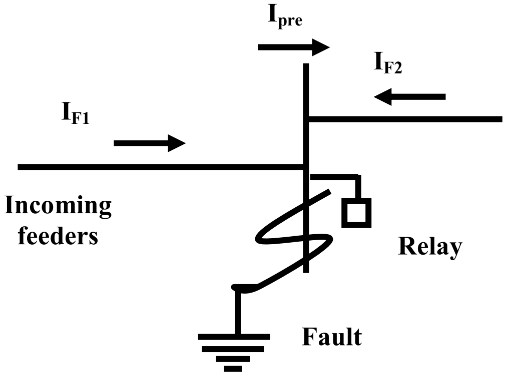

Fig.4 (a) Fault and pre-fault currents during internal fault (bus-bar fault)

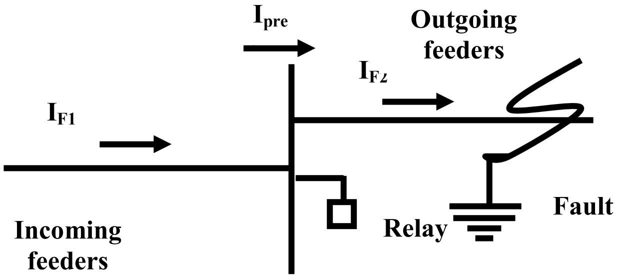

Fig.4 (b) Fault and pre-fault currents during external fault

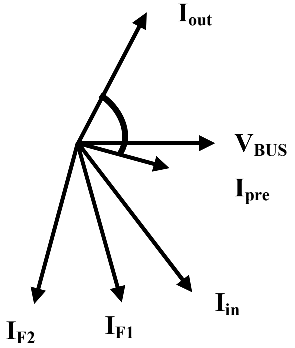

Fig. 5(a) Phasor representation in case of internal fault

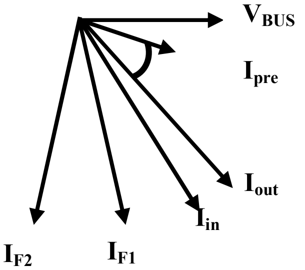

Fig. 5(b) Phasor representation in case of external fault

As seen from the above analysis, the phase difference of the positive sequence component of the fault and pre-fault current of the incoming feeder is negative for both internal and external fault situation. But the phase difference in the outgoing feeder is positive for internal fault and negative for external fault. Thus the phase difference information of the outgoing feeder is used to distinguish between internal (bus-bar fault) and external fault conditions. A simple rule base with a positive phase difference detects the internal fault and negative phase difference as external fault.

V. RESULTS AND DISCUSSION

The results are depicted in Table-I through Table-IV. Table-I depicts the phasor information for the incoming feeders for internal fault (bus bar fault) at 0.04 second. As seen from the table, the phase difference between pre-fault and fault current is negative for all fault conditions. Similarly Table-II depicts the phase difference information for incoming feeders for external fault situation at 0.06 second. It is observed that the phase difference is also negative for different fault situation. Thus the phase difference is negative for internal and external fault for incoming feeders.

Table-III shows the phase difference for outgoing feeders for internal fault. It is found that the phase difference between pre-fault and fault current is positive for internal fault situation. But the phase difference is negative for external fault as depicted in Table-IV. Thus the phase difference is positive for internal fault and negative for external fault for outgoing feeders.

The phase-angle difference of fault and pre-fault phasor may exceed the limits of $-\pi$ to $+\pi$. Thus 2π should be added if the phase difference is more $-\pi$ and 2π should be subtracted if the phase difference is more than $+\pi$. In Table-I, 5th and 6th row results, phase difference is more than the limit π and thus 2π is subtracted from the result and final values of phase differences are -2.28 and -2.42, respectively.

As seen in the results, the phase difference is negative for incoming feeders for internal and external faults, but same is positive for internal fault and negative for external fault for outgoing feeders. Thus the phase difference for incoming feeders is not considered for decision making process of the proposed directional relay. Only the phase difference for outgoing feeders is included in the decision process and a simple rule base work satisfactorily for issuing the tripping signal. When the phase difference is positive in all outgoing feeders, trip signal is issued, otherwise no trip signal is generated.

The logic for tripping signal generation is given in Fig. 6. This includes ANDing operation of all outputs (phase difference) of outgoing feeders. The issue of tripping signal with phase difference (radian) for all outgoing feeders with respect to sample (time) for a-phase is shown in Fig 7(a). The fault inception is at 0.027 second and the tripping signal is issued at 0.042 second. Similar result for a-phase with fault inception at 0.04 second is shown in Fig. 7(b), where the tripping signal is issued at 0.055 second. It is observed that the tripping signal is issued after 0.015 second (3/4th cycle) after fault inception, which shows the speed of the proposed technique. Thus a directional protection scheme is designed which distinguishes internal and external fault in case of bus-bar protection, and found to be effective with respect to speed and accuracy.

The proposed method has also been tested under sudden changed in loading conditions. During sudden load change, the phase difference of positive sequence components of the pre-load and changed load current of outgoing feeders are estimated and the results are depicted in Table-V. It is found that the phase difference for different loading conditions is negative and thus prevents issuing the tripping signal. The test cases and corresponding tripping conditions are given in Table-VI. It is found that in case of internal fault, the tripping conditions are 149 out of 150 cases studied. But in case of external fault, for 2 cases it malfunctions as tripping signal is generated instead of no-tripping. Similarly, for 1 case in load change condition, the tripping signal is generated instead of no-tripping. It is found that the accuracy is more than 99% taking all conditions into consideration. The flow chart for distinguishing internal fault and external fault/load changes are shown in Fig. 8. Thus the proposed technique is found to be suitable for directional protection of bus-bar which is highly effective with respect to speed and accuracy.

TABLE I
PHASOR INFORMATION FOR INTERNAL FAULT (BUS-BAR FAULT) AT 0.04 SEC FOR INCOMING FEEDERS

Fault		Pre-fault		Difference	
Mag (pu)	Phase (rad)	Mag (pu)	Phase (rad)	Mag (pu)	Phase (rad)
4.15	-1.28	0.4	-1.21	3.75	-0.07
5.62	-1.89	0.4	-1.21	5.22	-0.68
4.87	-2.58	0.4	-1.21	4.47	-1.37
3.89	-1.57	0.4	-1.21	3.49	-0.36
5.12	2.79	0.4	-1.21	4.72	-2.28
6.14	2.65	0.4	-1.21	5.74	-2.42
5.12	-1.52	0.4	-1.21	4.72	-0.31

TABLE II

PHASOR INFORMATION FOR EXTERNAL FAULT AT 0.06 SEC FOR INCOMING FEEDERS UNITS FOR

Fault		Pre-fault		Difference	
Mag (pu)	Phase (rad)	Mag (pu)	Phase (rad)	Mag (pu)	Phase (rad)
3.89	1.31	0.5	1.56	3.39	-0.25
4.56	-0.77	0.5	1.56	4.06	-2.33
5.14	1.11	0.5	1.56	4.64	-0.45
4.58	0.24	0.5	1.56	4.08	-1.32
4.89	-0.68	0.5	1.56	4.39	-2.24
5.01	0.65	0.5	1.56	4.51	-0.91
5.45	0.89	0.5	1.56	4.95	-0.67

TABLE III

PHASOR INFORMATION FOR INTERNAL FAULT (BUS-BAR FAULT) AT 0.04 SEC FOR OUTGOING FEEDERS

Fault		Pre-fault		Difference	
Mag (pu)	Phase (rad)	Mag (pu)	Phase (rad)	Mag (pu)	Phase (rad)
3.89	0.28	0.4	-1.21	3.49	1.49
4.12	-0.77	0.4	-1.21	3.72	0.44
5.27	1.58	0.4	-1.21	4.87	2.79
4.99	-0.57	0.4	-1.21	4.59	0.64
5.01	1.52	0.4	-1.21	4.61	2.73
4.98	0.57	0.4	-1.21	4.58	1.78
5.21	0.98	0.4	-1.21	4.81	2.19

TABLE IV

PHASOR INFORMATION FOR EXTERNAL FAULT AT 0.06 SEC FOR OUTGOING FEEDERS

Fault		Pre-fault		Difference	
Mag (pu)	Phase (rad)	Mag (pu)	Phase (rad)	Mag (pu)	Phase (rad)
4.25	-1.31	0.5	1.56	3.75	-2.87
5.21	-2.77	0.5	1.56	4.71	-4.33
4.89	-1.58	0.5	1.56	4.39	-3.14
5.36	0.57	0.5	1.56	4.86	-0.99
3.14	-0.98	0.5	1.56	2.64	-2.54
4.56	0.65	0.5	1.56	4.06	-0.91
5.14	0.72	0.5	1.56	4.64	-0.84

TABLE V

PHASOR INFORMATION FOR LOAD CHANGE CONDITIONS FOR OUTGOING FEEDERS

Load-change		Pre-load change		Difference	
Mag (pu)	Phase (rad)	Mag (pu)	Phase (rad)	Mag (pu)	Phase (rad)
1.22	1.21	0.5	1.56	0.72	-0.35
1.52	-0.65	0.5	1.56	1.02	-2.21
1.47	-0.88	0.5	1.56	0.97	-2.44
1.17	0.74	0.5	1.56	0.67	-0.82
1.45	-0.38	0.5	1.56	0.95	-1.94
1.28	0.95	0.5	1.56	0.78	-0.61
1.46	1.09	0.5	1.56	0.96	-0.47

TABLE VI

TEST CASES VERSUS TRIPPING

Events	No of cases studied	Trip signals generated
Internal Fault	150	149
External Fault	150	2
Load changes	50	1

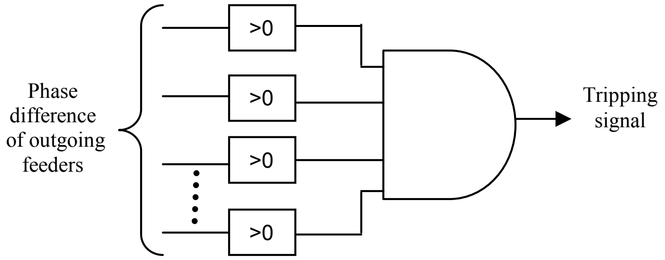

Fig. 6 Tripping logic for proposed system

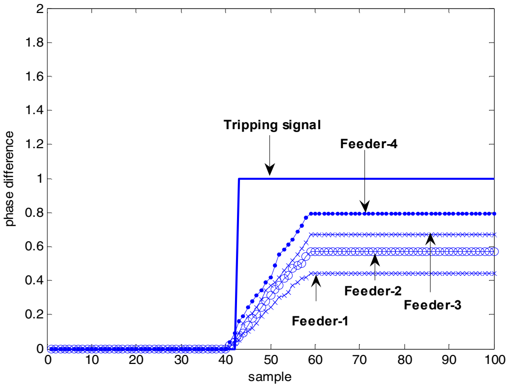

Fig. 7(a) Tripping signal generated for a- phase with fault inception at 0.027 second

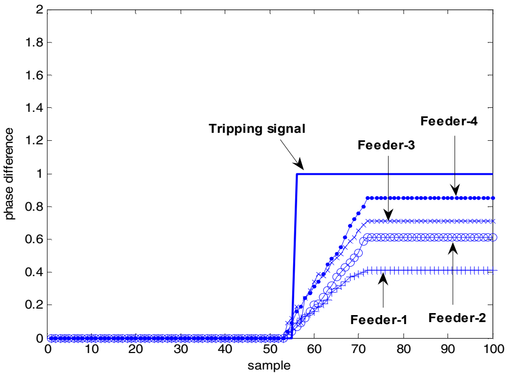

Fig. 7(b) Tripping signal generated for a- phase with fault inception at 0.04 second

VI. CONCLUSIONS

The proposed technique uses time-frequency transform such as S-transform for directional protection of bus-bar. S-transform is used to estimate the phase and amplitude of the fault and pre-fault current signals. The phase difference of positive sequence component of the pre-fault and fault current signal is the indicator for direction estimation for bus-bar protection. The tripping signal is issued when the phase difference of all the outgoing feeders goes positive, otherwise not. The tripping signal is issued just after 3/4th cycle from fault inception showing the fastness of the proposed technique. Thus a fast and robust directional protection scheme for bus-bar protection is designed using the phase information of the current signal only, thus reducing the cost of voltage sensors and related elements.

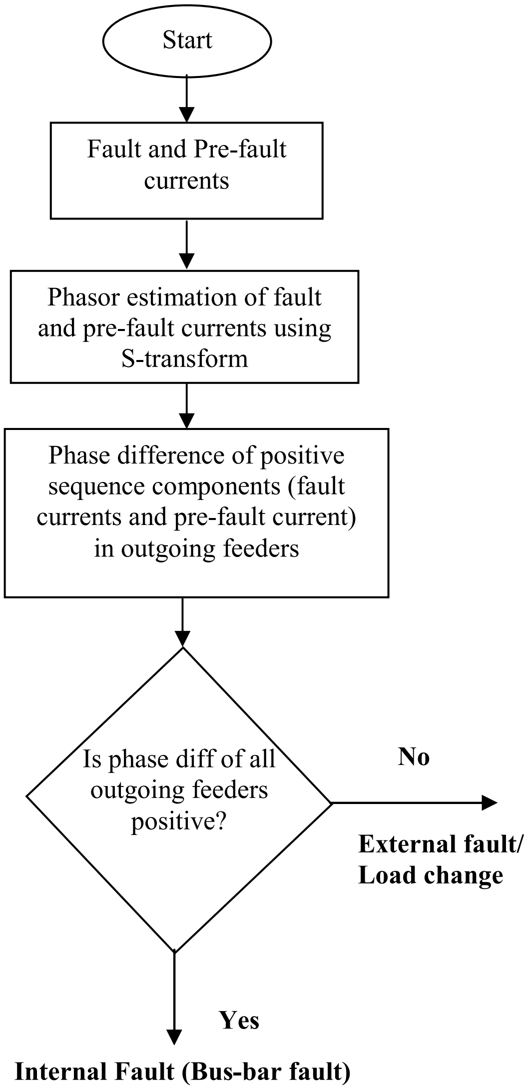

Fig. 8 Flowchart for distinguishing internal and external fault/load change

VII. REFERENCES

[1] J. M. Wheatley, "A microprocessor based current differential protection" in *Proc. 4th Int. Conf. Developments in Power Protection*, Apr.1989, pp. 116–120.

[2] B.-L. Qin, A. Guzman-Casillas, and E. O. Schweitzer, III, "A newmethod for protection zone selection in microprocessor-based bus relays" *IEEE Trans. Power Del.*, vol. 15, no. 3, pp. 876–887, Jul. 2000.

[3] C. Li-jun, "The research of the sampling method for CT saturation for numerical busbar protection," in *Proc. 8th Inst. Elect. Eng., Int. Conf. Developments in Power System Protection*, Apr. 2004, vol. 1, pp. 384–386.

[4] Mohammed, M.E., "High-speed differential busbar protection using wavelet packet transform," *Proc. Inst. Elect. Eng., Gen., Transm. Distrib.*, vol.152, no. 6, pp. 927–933, Nov. 2005.

[5] F. Jiang, Z. Q. Bo, M. A. Redfern, G.Weller, Z. Chen, and D. Xinzhou, "Application of wavelet transform in transient protection-case study: Busbar protection," in Proc. 7th Inst. Elect. Eng., *Int. Conf. Developments in Power System Protection*, Apr. 2001, pp. 197–200.

[6] S. P. Valsan and K, S. Swarup, "Computationally efficient wavelet-transform based digital directional protection for bus bars", *IEEE Trans. On power delivery*,vol.22, no.3, pp.1342-1350, July 2007.

[7] Hong-Tzer Yang, Chiung-Chou Liao, "A de-noising scheme for enhancing Wavelet-based power quality monitoring system", *IEEE. Transaction on Power Delivery*, Vol.16, No.3, pp.353-360, July 2001.

[8] Stockwell, R. G., Mansinha, L., and Lowe, R.P., "Localization of the complex spectrum: The S-transform", *IEEE Trans. on Signal Processing*, 44, pp. 998-1001, 1996.

[9] Pinnegar, C.R and Mansinha, Lalu, "The S-transform with windows of arbitrary and varying window", *Geophysics*, vol-68, Geophysics, vol-68, pp.381-385, 2003.

[10] Requirements of Instrument Transformers, *ANSI/IEEE Std.. C.57.13*,1978

[11] IEEE Guide for the application of Current Transformers used for protective relaying purposes, *IEEE Std.C37.110,*1996.