A Transient Current Based Bus Zone Protection Scheme Using Wavelet Transform

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***Abstract*--This paper deals with application of wavelet transform to detect busbar faults and to provide backup protection for external faults. The detail coefficients of a source CT current, feeder current and Zone-2 current are obtained over a narrow moving window. The fault indexes of differential and source CT current signals obtained are compared with their respective threshold values to detect the internal faults. In the event of feeder and Zone-2 faults, the d-coefficients of differential current have a time shift compared to that of source current. Further the external fault is located by comparing the polarities of peak d-coefficient of source, feeder and Zone-2 currents. The scheme is tested for different types of external and internal faults with variation in incidence angles and fault impedance. The proposed scheme detects internal faults and locates external faults even in the presence of current transformer saturation.**

***Index Terms*--Busbar protection, backup protection, wavelet transforms, threshold**

I. INTRODUCTION

Busbar is one of the most important elements of a power system connecting a variety of elements like generators, transmission lines and loads. A fault on a busbar leads to loss of all the elements connected to it. The protection scheme of a busbar should be fast, reliable and stable. The reliability and stability of a system depends to a great extent on the efficiency of the busbar protection scheme. A simple current differential scheme works satisfactorily for busbar protection. But this scheme is likely to mal-operate due to CT error, ratio mismatches and saturation of one of the CTs in the event of external fault. A percentage biased differential scheme can restrain from false tripping but it reduces the sensitivity of the relay [1]. Failure to trip for an internal fault or false tripping due to external faults can both have disastrous effects on the stability of a power system and may even cause a complete blackout [2]. A considerable amount of literature is available for various types of digital relays employing microprocessors, microcontrollers, and digital signal processors (DSPs), most of which were developed along the lines of traditional differential relays [3].

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The wavelet transforms (WT) has been proposed for busbar protection, which has feature extraction capabilities due to their Multi Resolution Analysis [4]. Various WT based techniques have been proposed in literature for tackling the problems associated with the busbar protection namely CT error, CT saturation and ratio mismatch. A Continuous Wavelet Transforms based method, making use of operating and restraining signals similar to percentage biased differential protection scheme was proposed in [5]. ME Mohammed has proposed a scheme in [6], which makes use of Wave Packet Transforms (WPT). However there is always a need to develop innovative and efficient methods for busbar protection.

This paper presents a WT based busbar protection scheme that utilizes detail decomposition of differential current to detect internal faults. The time shift in transients between differential current and source current is used to discriminate external faults from internal faults. The external faults are then classified based on polarities of peak d-coefficients obtained from Multi Resolution Analysis of Source, Feeder and Zone-2 current signals to provide backup protection. The details of the proposed scheme are described in the following sections.

II. WAVELET ANALYSIS

Wavelet transform (WT) is an efficient means of analyzing transient currents and voltages. Unlike DFT, WT not only analyzes the signal in frequency bands but also provides non-uniform division of frequency domain, i.e. WT uses short window at high frequencies and long window at low frequencies. This helps to analyze the signal in both frequency and time domains effectively. A set of basis functions called Wavelets, are used to decompose the signal in various frequency bands, which are obtained from a mother wavelet by dilation and translation. Hence the amplitude and incidence of each frequency can be found precisely.

Wavelet Transform is defined as a sequence of a function {h(n)} (low pass filter) and {g(n)} (high pass filter). The scaling function $\varphi(t)$ and wavelet $\psi(t)$ are defined by the following equations

$$\varphi(t) = \sqrt{2}\sum h(n)\,\varphi(2t-n)$$
$$\psi(t) = \sqrt{2}\sum g(n)\,\varphi(2t-n)$$

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Where $g(n)=(-1)^n h(1-n)$

A sequence of {h(n)} defines a Wavelet Transform. There are many types of wavelets such as Haar, Daubachies, and Symlet etc. The selection of mother wavelet is based on the type of application.

In the following section a novel method of detection and discrimination of faults using multi resolution analysis of the transient currents associated with the fault is discussed.

III. BUSBAR PROTECTION

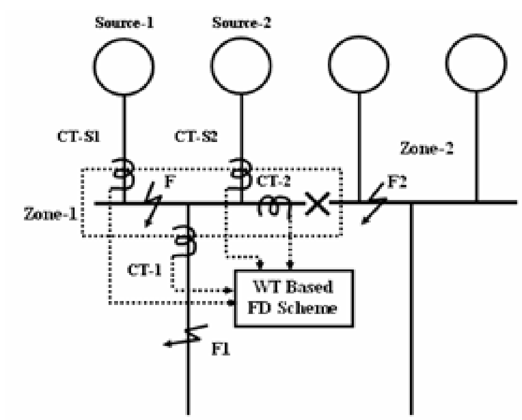


Figure.1. System considered for Studies

Figure-1 shows a typical system considered for present studies. The four generators are connected to two 220KV busbar sections. The busbar has two Zones. The CT ratio is 1250A/1A with knee voltage of 300V. Generators are rated 110MW, 50Hz.

The current signals of Source-1 (I_{s1}), Feeder (I_1), Zone-2 (I_2) CTs and the differential current (I_d) obtained are sampled at a frequency of 5kHz. Four moving windows of 6-sample length are used to collect the signal for WT analysis. Detail coefficients of single level decomposition of these windowed signals are obtained with Bior3.3 wavelet. The narrow window enhances the speed of protection scheme. The fault indexes I_{fs1} and I_{fd} of the source current I_{s1} and differential current I_d are defined as

$$\mathbf{I_{fs1}} = \text{MAX}\ \{\text{ABS}\ [d1\_I_{s1}]\}$$

$$\mathbf{I_{fd}} = \text{MAX}\ \{\text{ABS}\ [d1\_I_{d}]\}$$

[$d1\_I_{s1}$] and [$d1\_I_d$] are d1-coefficients of current signals I_{s1} and I_d respectively obtained over a window length. Fault Indexes $\mathbf{I_{fs1}}$ and $\mathbf{I_{fd}}$ are compared with their Threshold values Th_I_{s1} and Th_I_d respectively to detect the fault.

In the event of an internal fault (at F), there will be a sudden change in the source current I_{s1} and differential current I_d as shown in Figure.2. Hence the detail coefficients appear in both the windows simultaneously. This is illustrated in Figure.3 When Fault indexes of these two signals exceed their respective thresholds a trip signal is given to all circuit breakers.

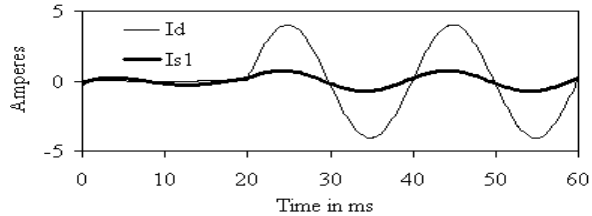


Figure.2. Current signals for a fault at F

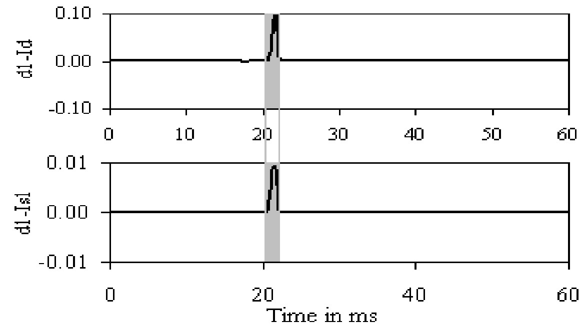


Figure.3. Variation of d1-coefficients for Internal Fault (F)

The variations of Fault Indexes I_{fd} and I_{fs1} of current signals I_d and I_{s1} are presented along with their threshold values in Figures 4 & 5 for a 3-phase busbar fault for different fault incidence angles.

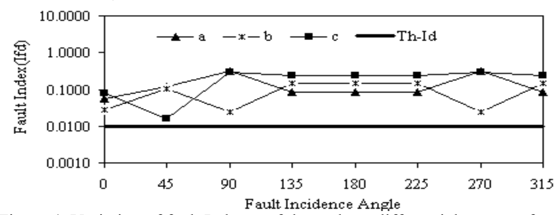


Figure.4. Variation of fault Indexes of three phase differential currents for a 3-phase busbar fault (F)

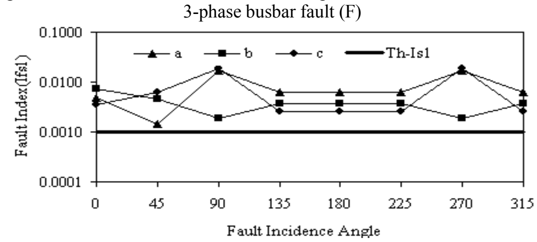


Figure.5. Variation of fault Indexes of three phase source currents for a 3-phase busbar fault (F)

Since this scheme is based on the transient features of differential current its performance is not affected by fault impedance. Figures 6 and 7 show the performance of the scheme for a 3-phase busbar fault with a fault impedance of 100 Ω.

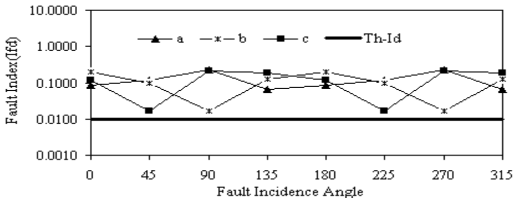


Figure.6. Variation in fault index of I_d for busbar fault with Z_f =100 □

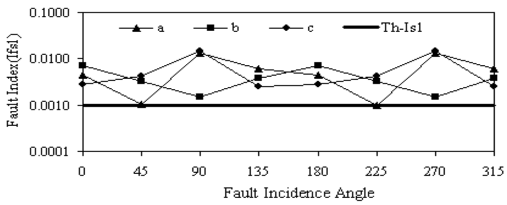


Figure.7. Variation in fault index of I_{s1} for Z_f =100 Ohms

The proposed scheme is tested for all types of ground and phase faults of busbar and the corresponding Fault Indexes are plotted in the Figures 8 and 9. It can be seen that the faulty phases have their Fault Indexes greater than or equal to their Threshold values. This provides detection of faulty phases and hence fault classification.

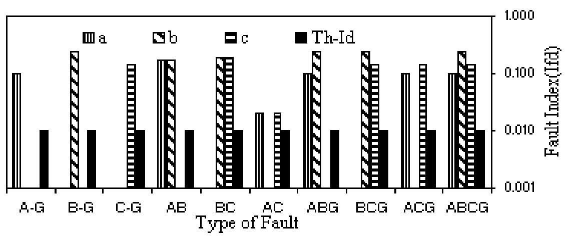


Figure8. Variation of fault Index with type of busbar fault (F)

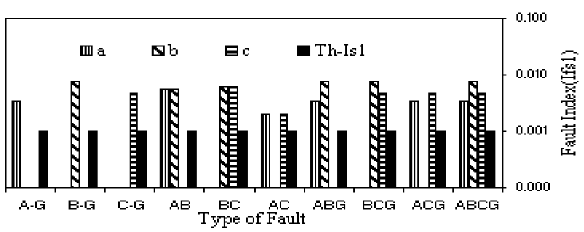


Figure 9. Variation of fault Index with type of busbar fault (F)

In the event of external faults i.e. Feeder faults (at F_1) and Zone-2 faults (at F_2) the differential current should remain zero since the sum of incoming currents is equal to sum of outgoing currents. However a feeder fault (at F_1) causes total fault current to flow through CT-1, resulting in saturation. This causes a change in differential current from its null value and this in turn makes differential current fault index I_{fd} to reach its threshold. The same is valid for a Zone-2 fault also. The variation of Fault Index I_{fd} of differential current I_d for feeder fault and Zone-2 fault is shown in Figures 10 and 11 respectively for various incidence angles.

The transients associated with the source current I_{s1} and the fault index $I_{fs1}$are independent of location of fault (internal or external). Hence I_{fs1} reaches its threshold value as in the case of internal fault. This leads to maloperation of the protection scheme.

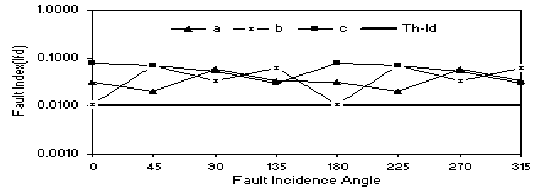


Figure.10. Variation in I_{fd} of three phases currents for feeder fault with fault incidence angle

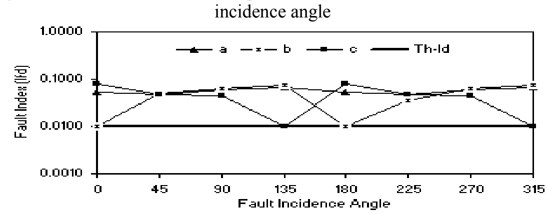


Figure.11. Variation in I_{fd} of three phases currents for Zone-2 fault with fault incidence angle

As the components connected to busbar i.e. generators, transmission lines etc. are highly inductive in nature, the differential current cannot reach its saturation level instantaneously. Hence the change in differential current I_d appears with a delay compared to change in source current I_{s1} as shown in the Figure 12. This leads to a time shift in the instants where the individual Fault Indexes I_{fs1} and I_{fd} reach their thresholds.

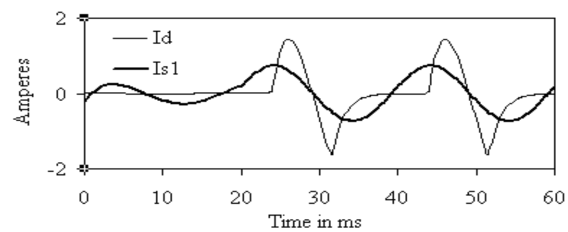


Figure.12. Variation in source current and differential current for a Feeder fault (at F_1)

Since the scheme is designed to derive trip signal if the Fault Indexes I_{fd} and I_{fs1} reach their threshold values during the same window, tripping is blocked. This is illustrated in Figures 13 and 14.

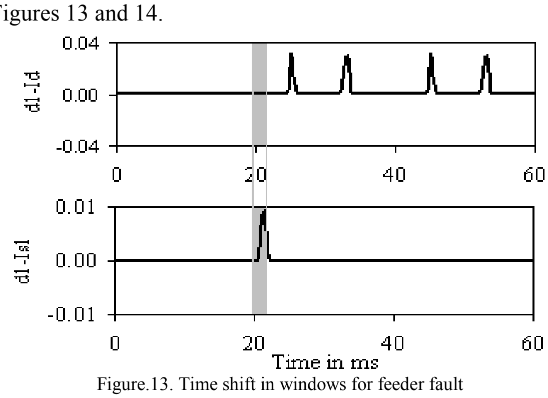


Figure.13. Time shift in windows for feeder fault

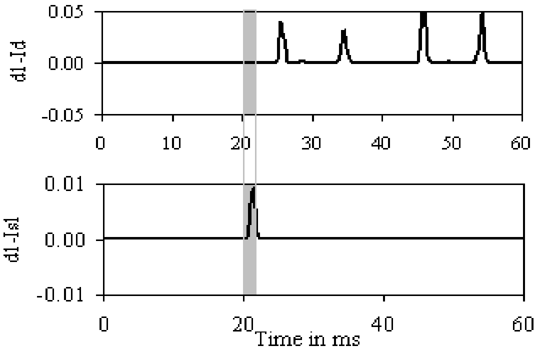


Figure.14. Time shift in windows for Zone-2 fault

IV. BACK UP PROTECTION

In case of external fault backup protection is to be provided for the feeder faults and Zone-2 faults with appropriate delay. For this purpose the polarities of peak d-coefficients of source, feeder and Zone-2 currents are compared. This is achieved by defining polarity indexes as follows.

If (abs($Is1\_d1_{max}$) > abs($Is1\_d1_{min}$))

$I_{PPS1}=1$

else

$I_{PPS1}=0$

If (abs($I1\_d1_{max}$) > abs($I1\_d1_{min}$))

$I_{PP1}=1$

else

$I_{PP1}=0$

If (abs($I2\_d1_{max}$) > abs($I2\_d1_{min}$))

$I_{PP2}=1$

else

$I_{PP2}=0$

Where $Is1\_d1_{max}$, $I1\_d1_{max}$, $I2\_d1_{max}$, $Is1\_d1_{min}$, $I1\_d1_{min}$ and $I2\_d1_{min}$ are the maximum and minimum values of d1-coefficients of the source currents Is1, feeder current I1 and Zone-2 current I2 are defined below

$$Is1\_d1_{max} = \text{Max}\left[d1 - Is1\right]$$
$$Is1\_d1_{min} = \text{Min}\left[d1 - Is1\right]$$
$$I1\_d1_{max} = \text{Max}\left[d1 - I1\right]$$
$$I1\_d1_{min} = \text{Min}\left[d1 - I1\right]$$
$$I2\_d1_{max} = \text{Max}\left[d1 - I2\right]$$
$$I2\_d1_{min} = \text{Min}\left[d1 - I2\right]$$

Where $[d1 - Is1]$, $[d1 - I1]$ and $[d1 - I2]$ are d1- coefficients of current signals Is1, I1 and I2 respectively obtained over a window length.

Feeder Fault

In the event of feeder faults the transients associated with feeder current are similar to those of source current and opposite to those of Zone-2 current. This is illustrated in Figure 15. Thus the peak polarity of d1-coefficients is obtained from feeder current I1 is similar to that of source current Is1 and opposite to that of Zone-2 current I2 as illustrated in Figure 16. Hence the trip signal is issued to feeder breaker with appropriate delay to provide backup protection.

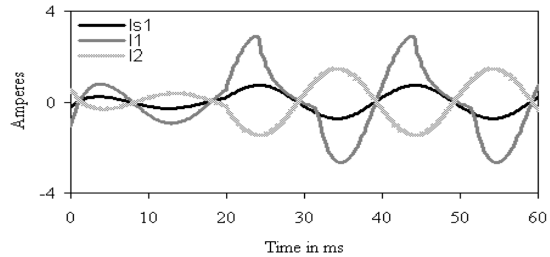


Figure 15. Current signals for a fault at F1

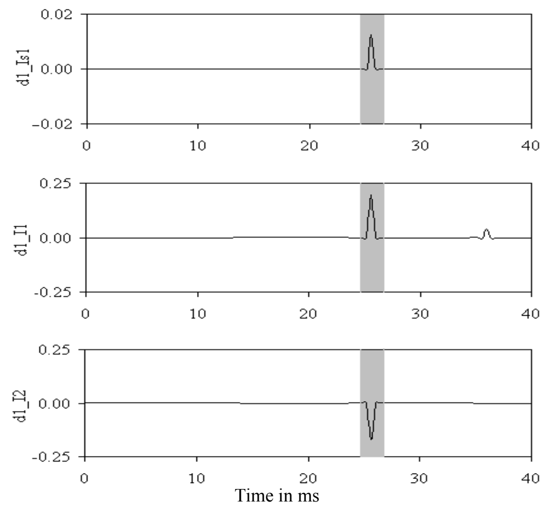


Figure 16. Variation of d1-coefficients for feeder faults

Zone-2 Fault

In the event of Zone-2 faults the transients associated with Zone-2 current are similar to those of source current and opposite to those of feeder current. This is shown in Figure 17. Thus the peak polarity of d1-coefficients are obtained from Zone-2 current I2 is similar to that of source current Is1 and opposite to that of feeder current I1 as illustrated in Figure 18. Hence the trip signal is issued to Zone-2 breaker with appropriate delay to provided backup protection.

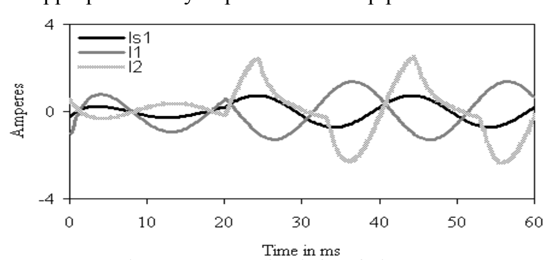


Figure 18. Current signals for a fault at F2

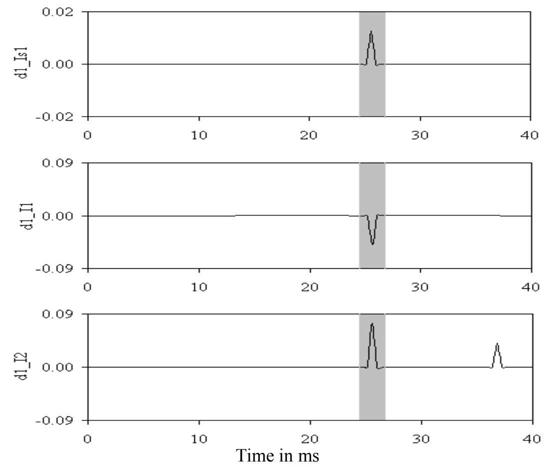
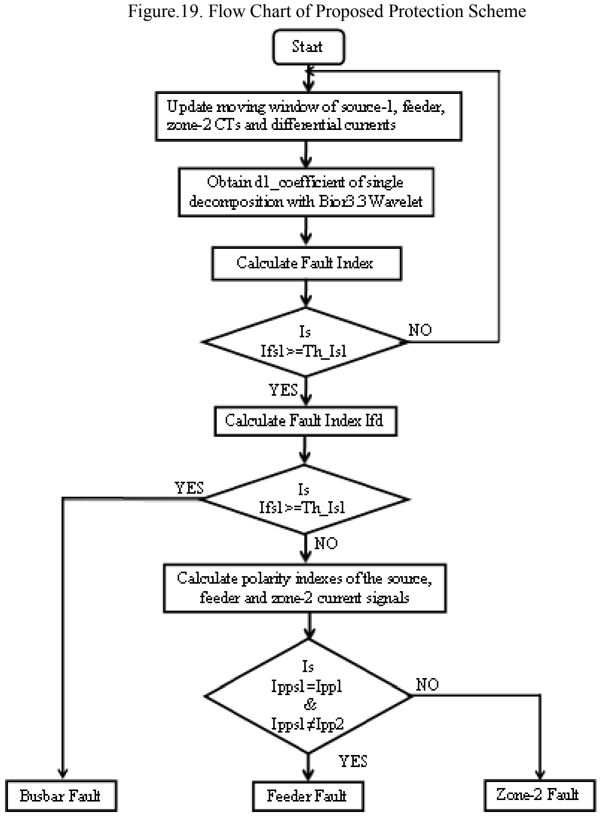


Figure 19. Variation of d1-coefficients for Zone-2 faults

Thus the scheme effectively discriminates external faults from internal faults and provide backup for external faults. Since the proposed method is based on the changes in differential current, its operation is not affected by the problems associated with the conventional busbar protection such as CT errors and ratio-mismatches. The flow chart for the proposed algorithm is shown in Figure 19.

Figure.19. Flow Chart of Proposed Protection Scheme



V. Conclusions

The proposed Wavelet Transforms based scheme is effective in detecting busbar faults and to discriminate the same from external faults. This scheme also provides effective backup protection for feeder and zone-2. CT error and ratio-mismatch have no effect on the proposed scheme. The proposed scheme is proved to be simple, fast, reliable and stable under various conditions.

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