# Differential Bus Bar Protection Scheme Based Modulus Maxima Wavelet Transform and Genetic Algorithm

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## ABSTRACT

**This paper deals with the application of modulus maxima wavelet transform and genetic algorithm (GA) for fault detection and classification of busbar and to discriminate internal faults from external faults. The transients of current signals are analyzed using modulus maxima wavelet based multi resolution analysis to decompose the fault current signals into different frequency bands and to obtain details and approximation coefficients over a narrow moving window. The differential current signals are computed from the decomposed current signals. The information is then fed into GA. Matlab is used for representation of the system and to test the proposed scheme. The proposed algorithm provides more accurate, reliable and fast results in fault detection and classification after one cycle of the fundamental frequency.**

**Keywords: Busbar protection, wavelet transform, modulus maxima, genetic algorithm, differential protection.**

## 1. INTRODUCTION

A bus is one of the most critical power system elements. It is the connecting point of a variety of elements and a number of transmission lines and the occurrence of any fault in causing the loss of all these elements. High speed, reliability and stability of the most important requirements for the protection of the busbar. Failure-to-trip on an internal fault, as well as mal-to- trip of a busbar during service, or in case of an external fault, can both have a strong effect on the stability of the power system, and may even cause complete blackout of the system. So, while designing a busbar protection scheme, precision and reliability are the most important factors to be incorporated [1].

The main problems that affect the reliability of differential busbar protection is the saturation current of the transformer. A percentage biased differential relay can restrain from false tripping while it will reduce the sensitivity of the relay [2]. Some papers have presented busbar protection relays based on fault generated transient currents [3-6].

The Wavelet Transforms (WT) has been proposed for busbar protection, which has feature extraction capabilities due to their Multi Resolution Analysis [7]. Various WT based techniques have been proposed in literature for tackling the problems associated with the busbar protection namely CT saturation. A Continuous Wavelet Transforms (CWT) based method, making use of the operating and restraining signals similar to percentage biased differential protection scheme was proposed in[8]. GA can be used to find an optimal set of feature to improve detection and classification accuracy. This paper presents a modules maxima wavelet transform multi-resolution signal decomposition based busbar protection scheme that utilizes detail decomposition and approximation of differential current to detect internal faults and to discriminate them from external faults. The output signals of modules maxima wavelet transform are then fed into GA, in which the optimized GA output parameters are used to classify the fault. Matlab simulations have been done to verify the proposed scheme. Simulation studies show that the scheme is insensitive to fault type, fault path resistance and current transformer saturation. The proposed relay is fast, reliable and feasible.

## 2. WAVELET MODULUS MAXIMA

The wavelet transform (WT) is a powerful mathematical tool widely used for digital signal processing. WT is useful for the analysis of non-stationary signals such as those associated with faults or switching operations. It has the ability to analyze a localized area of a signal and reveal transitory aspects of data like drift, trends, and abrupt changes. Thus, WT is useful in detecting the onset of a fault and has been widely applied in the field of protective relaying, including fault detection, faulted phase identification, fault location and transformer protection [9] .The function $\psi$ (t) is the base mother wavelet, if it satisfies the finite energy condition

$$\int_{-\infty}^{\infty} \psi \ (t)dt = 0 \tag{1}$$

The function family $\psi_{s,b}$ (t) generated through dilation parameter 's' and translation parameter 'b' is defined as:

$$\psi_{s,b}(t) = \frac{1}{\sqrt{s}} \psi\left(\frac{t-b}{s}\right), s, b \in R, s \neq 0 \tag{2}$$

Where R is a set of real numbers. The wavelet transform of any function x(t) is defined as :

$$W_f(s,b) = \frac{1}{\sqrt{s}} \int_{-\infty}^{\infty} x(t) \psi^* \left(\frac{t-b}{s}\right) dt \tag{3}$$

$\psi^*\left(\frac{t-b}{s}\right)$ is a conjugate of mother wavelet function $\psi \left(\frac{t-b}{s}\right)$.

Wavelet transform Wf(s,b) depends on scale factor and translation factor. Through variation of scale factor, the wavelet transform can be applied to high frequency components where short time intervals are necessary. Therefore, it is a suitable approach to analyze the traveling waves.

If $s = \frac{1}{2^j}\ j \in Z$ (Z is a set of integers) and b$\in$ R (R is a set of real numbers), then it is dyadic wavelet transform. It is a translation invariant and hence used in signal edge detection. When a wavelet transform is applied to a discrete signal x(t),the signal can be decompose into approximation and details .

Wavelet Modulus Maxima (WMM) of wavelet transform are the local maxima of wavelet transform satisfying the following condition:

$$\lfloor W_m x(t) \rfloor \leq A s^{\alpha} \tag{4}$$

Where, $W_m$ x(t) is the WMM of a signal x(t), A is constant, and $\alpha$ is the Lipschitz exponent. Modulus maxima represent the singularity of step signal. The polarity of WMM is identical to the polarity of sudden change of the signal and its magnitude depends on the amplitude and the gradient of the sudden change of the signal.

## 3. GENETIC ALGORITHM

Genetic algorithms (GAs) provide a powerful tool for optimization problems by imitating the mechanisms of natural selection and genetics operation (reproduction, crossover, mutation) which operate on a population of potential solutions (applying the principle of Survival of the Best to produce better and better guesses for the solution) in each generation. New set of approximations is created by selecting the individuals according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genes.

The process starts with random generation of a population. A population consists of a set of strings. The population may be of any size according to the accuracy required. The population size remains constant throughout the whole process. Each string in GAs may be divided into a number of sub-strings. The number of sub-strings, usually, equals to the number of the problem variables. The problem variables are coded using suitable coding system. The strength of an individual is the objective function, Fitness Function, that must be optimized. After evaluation, strings are subjected to three major operators, reproduction, crossover and mutation. Reproduction is Simply a process in which individuals are copied into "mating pool" according to its fitness value. Selecting strings according to their fitness values means that strings with a higher value have a higher probability of contributing offspring to the next generation.

After reproduction, Crossover is performed on two strings at a time that are selected from the population at random. Crossover involves choosing a random position in the two strings and swapping the bits that occur after this position. In one generation the crossover operation is performed on a specified percentage of the population. This is defined at the initialization stage as crossover probability. Mutation, the last Genetic operator, is needed because even though reproduction and crossover effectively search and recombine extant notion, occasionally they may become over-zealous and lose some potentially useful genetic material. In artificial GA mutation protects against such an irrecoverable loss. Mutation operator is performed randomly on less than 5% of the bits. In binary coding system the selected bits are changed from 0 to 1 and vice versa. Mutation process is used to escape from probable local optimum. After mutation the new generation is completed and the procedure begins again with fitness evaluation of strings [10]. The main cycle processes of Genetic algorithm are shown in "Fig. 1".

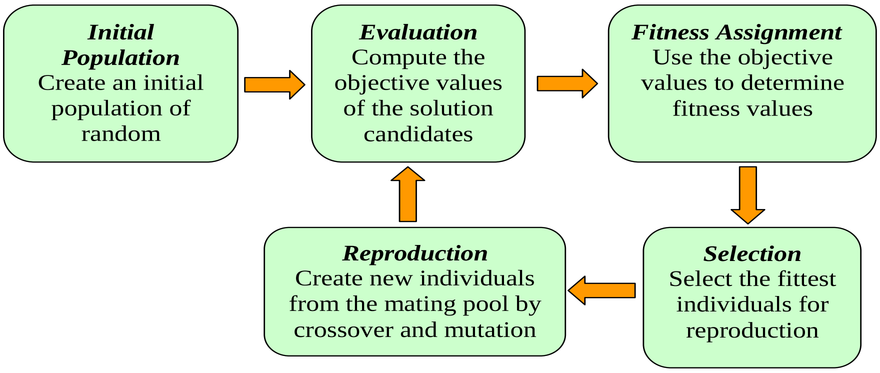

**Figure 1.** Genetic algorithm cycle main processes

## 4. ALGORITHM DESIGN FOR BUS BAR PROTECTION

"Fig. 2", Shows a system considered in the present paper. The five generators (400kv, 5000MVA and X/R=3) are connected to 400KV busbar sections, This busbar protection scheme is based on Kirchhoff's current law that all currents flowing into or flowing out of a point sum to zero at any time.

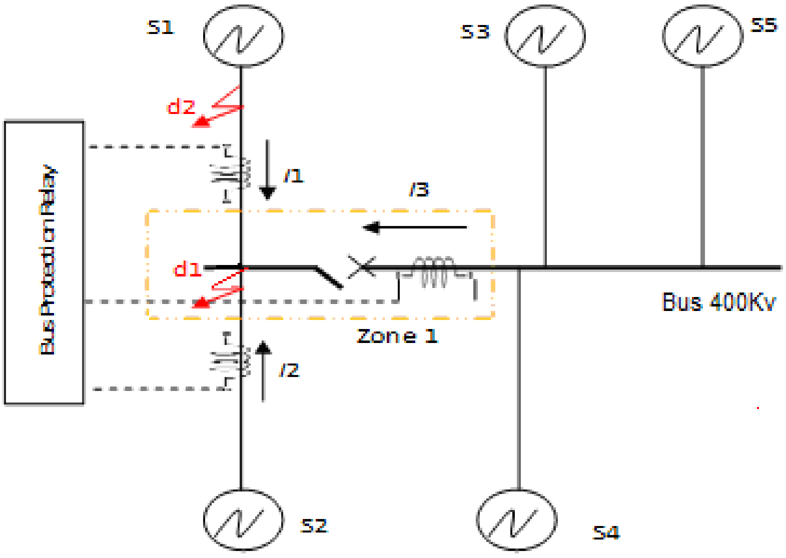

**Figure 2.** 400KV power system for simulation

So the Kirchhoff's current law can be applied to the approximations and details signals current generated by modules maxima wavelet transform. That is, For normal operation or external fault (zone 2) for phase a :

$$\left|\sum WMM_{ia(1,2,3)}\right| \cong 0 \qquad (5)$$

$$\left|\sum WA_{ia(1,2,3)}\right| \cong 0 \qquad (6)$$

While internal fault in phase A is:

$$\left|\sum WMM_{ia(1,2,3)}\right| = \left|WMM^{s}_{i\,fault}\right| \tag{7}$$

$$\left|\sum WA_{ia(1,2,3)}\right| = \left|WA^{s}_{ifault}\right| \tag{8}$$

$WMM^{s}_{i\,fault}$ represents the modulus maxima of discrete wavelet details of fault currents on the scale S. $WA^{s}_{ifault}$ represents the discrete wavelet approximations of fault currents on the scale S.

Fault detection can be obtained from the details of the five decomposition level of the measured current signals using Bior3.3 mother wavelet. This level contains the 7th harmonic component. It was observed that in this level, the wavelet modules maxima related to internal faulted and external faulted currents are well distinguishable .The length of the moving data window used for fault detection is equal to one cycle of the fundamental frequency with sampling rate equal to 10kHz .There is the busbar fault detection scheme:

1-If

$$\sum_{i=1}^{3} WMM^{5th}_{ia} > Th1 \;\;\&\;\; \sum_{i=1}^{3} WMM^{5th}_{ib} > Th1 \;\;\&\;\; \sum_{i=1}^{3} WMM^{5th}_{ic} > Th1 \qquad i=(1,2,3)$$

No, not internal fault.
Yes, Go to step 2.

2-If

$$\left|WMM^{5th}_{ia(1,2,3)}(n_0)\right| > Th2 \;\;\&\;\; \left|WMM^{5th}_{ib(1,2,3)}(n_0)\right| > Th2 \;\;\&\;\; \left|WMM^{5th}_{ic(1,2,3)}(n_0)\right| > Th2$$

No, not internal fault.
Yes, Go to step 3.

3-If

$$\left|\sum_{i=1}^{3} WA^{7th}_{ia}(n_o+50)\right| > Th3 \;\;\&\;\; \left|\sum_{i=1}^{3} WA^{7th}_{ib}(n_o+50)\right| > Th3 \;\;\&\;\; \left|\sum_{i=1}^{3} WA^{7th}_{ic}(n_o+50)\right| > Th3$$

No, not internal fault.
Yes, internal fault.

The first step presents WMM differential currents for three currents (i1,i2,i3) for three phases (a,b,c). The second step presents if all currents (i1,i2,i3) for three phases in protective zone 1 have experienced a singularity at $n_o$, where $n_o$ is one sample point. The third step uses to examine whether the differential currents in sub-band (0-78.125)Hz improve Kirchhoff's low. This sub-band (0-78.125)Hz consist the power frequency current. This step used to avoid C.T saturation during external fault that is take time about a quarter period , we take WA differential currents for three currents (i1,i2,i3) for three phases (a,b,c) on 7th scale at 5ms (50 sample) after the starting moment of fault.

After detecting internal fault based on the steps above, it is classified based on the next step:

4-

$$\left|\sum_{i=1}^{3} WMM^{1th}_{ia}\right| > Th4 \quad \rightarrow \quad fault\ in\ phase\ a$$

$$\left|\sum_{i=1}^{3} WMM^{1th}_{ib}\right| > Th4 \quad \rightarrow \quad fault\ in\ phase\ b$$

$$\left|\sum_{i=1}^{3} WMM^{1th}_{ic}\right| > Th4 \quad \rightarrow \quad fault\ in\ phase\ c$$

This step represents the absolute values of WMM of the first scale of detail of three phases differential currents (i1,i2,i3) are obtained over the same moving data window for the detection of faulty phases.

In order to get various threshold values *Th1*-*Th4*, the GA is used which is trained with the help of training samples. The training sample of

$$\sum_{i=1}^{3} WMM_{ia,b,c}^{5th},\ \left|WMM_{ia,b,c(1,2,3)}^{5th}\right|,\ \sum_{i=1}^{3} WA_{ia,b,c}^{7th}(n_o+50) \text{ and } \left|\sum_{i=1}^{3} WMM_{ia,b,c}^{1th}\right|$$

for different fault types and different fault resistance are given as input data to GA to get the optimized threshold values of *Th1-Th4* respectively. The fitness function is taken to be minimized .To select individuals in the population for the next generations, used the normalized geometic ranking as a selection function. A crossover probability is set to 0.8 using Gaussian function, this parameter gives the probability that a child is generated from parent. A mutation probability is set to 0.2, generally, which is in between {0,1}, this parameter gives the probability that a weight within an individual will be changed. Population size of 200, genome length of 4 is taken for the GA process. GA process is terminated by the pre-specified maximum number of generations of 100.

After training, the optimized threshold values are obtained as Th1 is set to 0.1A,Th2 =0.2A, Th3=1A and Th4 =10A . The flowchart of the proposed algorithm is shown in “Fig. 3”.

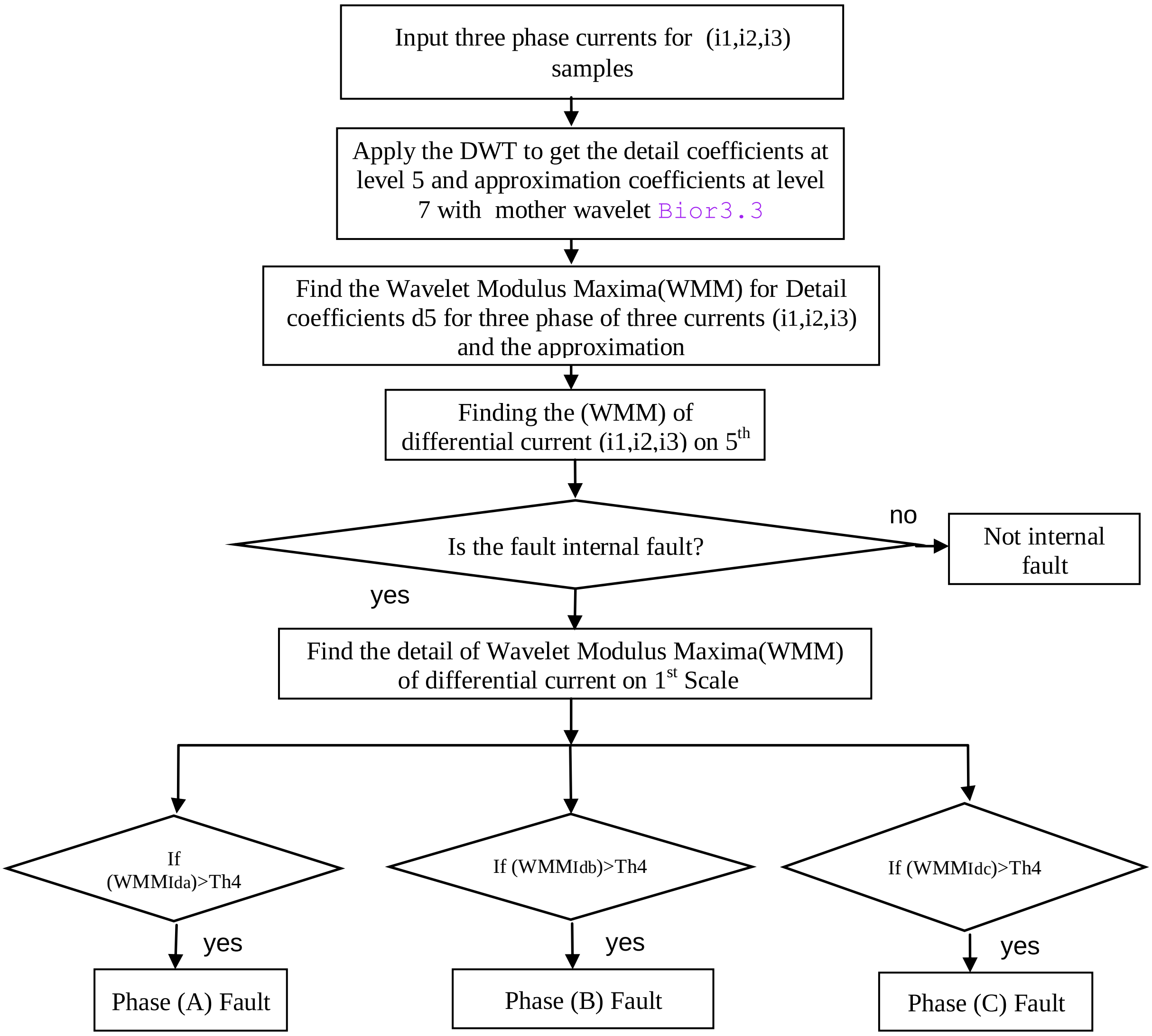

**Figure 3.** **Flow chart of differential Busbar protection**

## 5. COMPUTER SIMULATION TESTS AND VALIDATION

In order to further verify the validity of the proposed wavelet modulus maxima protection algorithm, a simulation of busbar model for different internal and external faults is done. Faults simulations were carried out using MATLAB. The simulated power network is shown in “Fig. 1”.

### A- Internal Fault

A phase A-G fault occurred at location d1 of the busbar as shown in “Fig. 1” the fault resistance 100 ohm. “Fig. 4”shows the wavelet modulus maxima of currents i1,i2,i3 for phase a and differential current $Id_{123}$ on the five scales .In the “Fig. 4” it can be seen that all of the currents in protective zone 1 have a WMM at fault starting moment and the differential current greater than Th1,and $|WA^{7th}|$ = 4.1035> Th3 , Hence a trip signal is issued to all C.B.s.

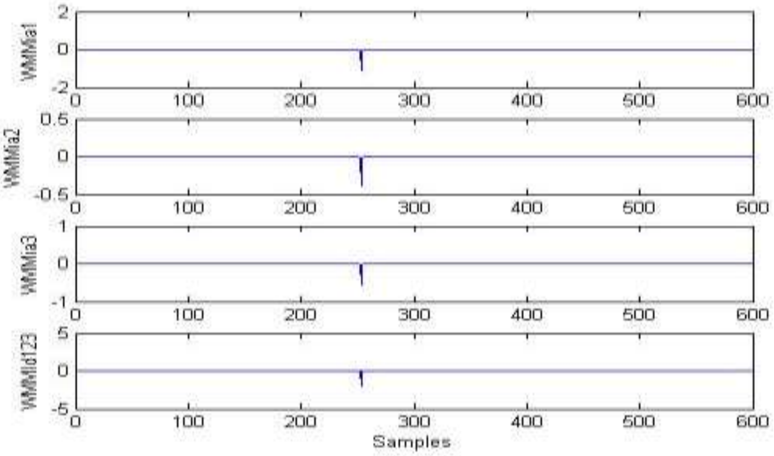

**Figure 4.** WMM of the three currents (phase a) and differential currents for phase A-G Fault with fault resistance equal to 100 ohm

### B- External Fault

A three phase to ground fault occurred at location d2 of the busbar as shown in “Fig. 1”,through resistance fault equal to 100 ohm . “Fig. 5” shows the wavelet modulus maxima of currents i1,2,3 for phase a and differential current Id123 on the five scales .It can be seen that WMM of differential current at the moment of the starting fault equal zero .So the Busbar protection relay will not operate **.**

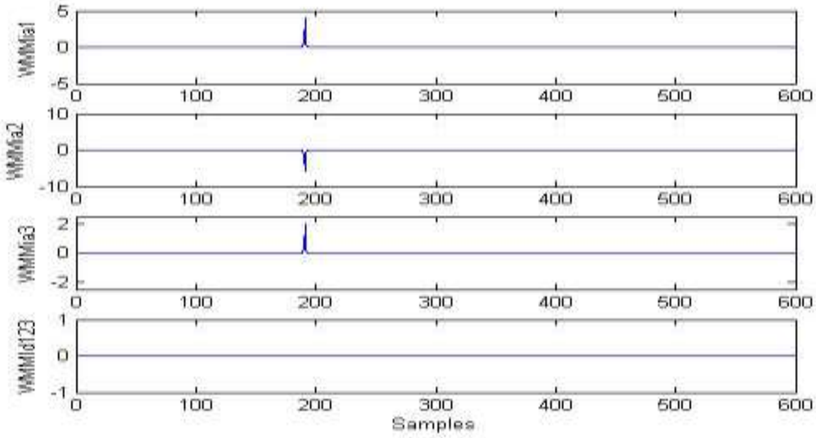

**Figure 5.** WMM of the three currents (phase a) and differential currents for ABC to ground fault with resistance equal to 100 ohm.

### C- External Fault with C.T's Saturation

"Fig. 6" shows the WMM of all currents (i1,i2,i3) for phase a at the moment of phase A to ground fault occur at location d2 with 100 ohm fault resistance , it can be seen the WMM of differential current near to zero that first step cannot be improved . Also in "Fig. 6" shows that both currents in faulty circuits and differential current have a WMM at about 2ms (20 sample) after a fault starting moment. It is the starting moment of CT saturation. But other circuits have no WMM at 2ms after a fault starting moment. So second step cannot be satisfied. Therefore the busbar protection scheme will not operate in this case.

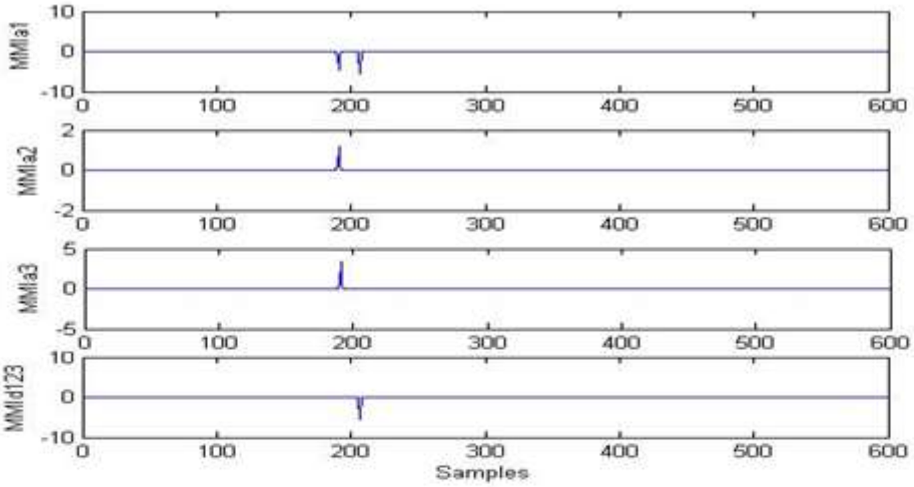

**Figure 6.** **WMM of the three currents (phase a) and differential currents for phase A to ground Fault with C.T saturation at 2ms after fault starting moment with fault resistance equal 100 ohm.**

### D- Effect of Fault Path Resistance

In "Fig. 1", a phase a to ground internal fault occurred at d1 in the busbar. We have done some internal fault simulations with different fault resistance. The simulation results have testified that the busbar protection is not affected by fault path resistance. Table 1 shows three simulation results with fault resistance 10, 100 and 200 ohm. In the table it can see that the differential current for all current for phase (a) WMM greater than Th1 and $|WA^{7th}|$ for three cases greater than Th3 .

**Table 1: WMM for three currents for phase (a) and WA of internal faults**

| Resistance Fault | WMM ia1 | WMM ia2 | WMM ia3 | WMM ida1,2,3 | $\|WA^{7th}\|$ |
|---|---|---|---|---|---|
| **10** | -46.81 | -16.3698 | -23.3123 | -86.4973 | 46.8153 |
| **100** | -4.1035 | -1.434 | -2.384 | -7.5759 | 4.1035 |
| **200** | -2.0843 | -0.7284 | -1.0354 | -3.8481 | 2.0843 |

### E- Faulty Phase Selection

The absolute values of WMM of the first scale of detail of three phases differential currents are obtained over the same moving data window for the detection of faulty phases. "Fig. 7", "Fig. 8", and "Fig. 9", depict the variations in WMM of differential current for three phases with fault incidence angle for LG, LLG and LLLG faults at d1. It can be observed that the WMM of differential current of faulty phases is always greater than the Threshold Th4 value, and that of healthy phases is less than the Th4 value. Thus the faulty phases can be detected effectively.

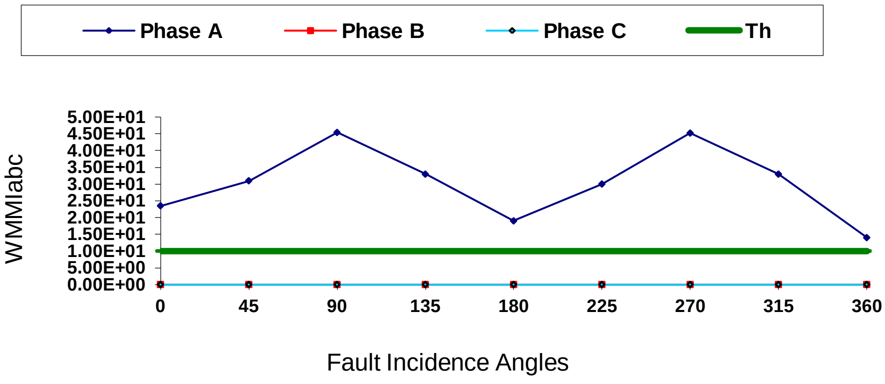

**Figure 7.** **Variation in WMMId(a,b,c) for A-G busbar fault at d1**

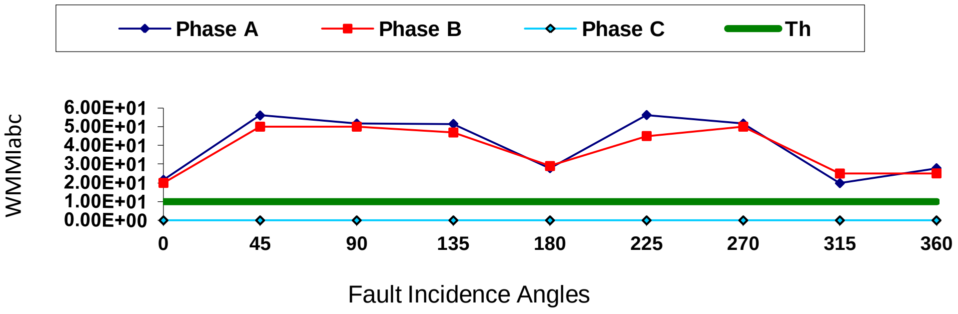

**Figure 8.** **Variation in WMMId(a,b,c) for AB-G busbar fault at d1**

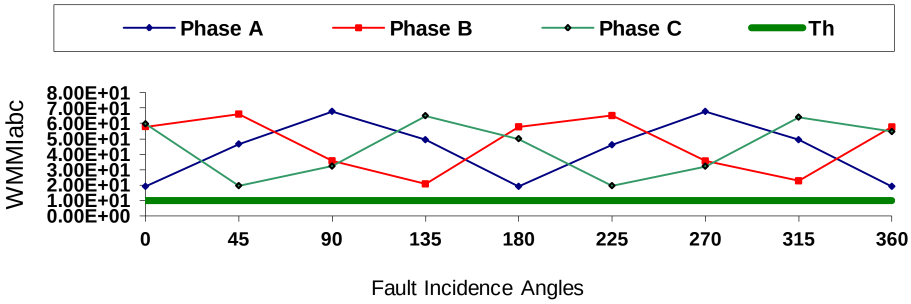

**Figure 9.** **Variation in WMMId(a,b,c) for 3-phase to ground busbar fault at d1**

## 6. CONCLUSION

An algorithm for busbar differential protection was proposed using modulus maxima wavelet transform and GA to detect busbar faults and faulty phases. This busbar protection scheme utilizes modules maxima wavelet transform to decompose currents signals into different frequency bands (high frequency band and low frequency band). High frequency currents enable the busbar protection to operate fast. The optimal values of thresholds are obtain using GA. The performance of the proposed algorithm was tested using different types of external and internal faults with variations in fault resistance. Also, C.T saturation in external fault is considered .The results showed the capability of the proposed algorithm in detecting internal faults and discriminating them from external faults as well as identified the type of fault after one cycle of the fundamental frequency. The proposed scheme is proved to be fast, reliable and stable under various conditions.

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