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Thyristor based Symmetrical Fault Detection Technique in De-Energized Distribution Feeder

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ABSTRACT: *A distribution feeder is de-energized during the period of maintenance or in bad weather conditions such as rains, and heavy winds. After the completion of maintenance or clearance of the bad climatic conditions, the same feeder is re-energized again to supply the load. But before re-energizing the feeder it is good practice to check whether the feeder is free of faults or not, because during the maintenance or bad weather conditions there may be a chance of short circuits in the system. If a three phase asymmetrical fault is present in the system it can be easily identified by analyzing the current waveforms, but a three phase symmetrical fault cannot be identified by analyzing the current wave forms alone. Further, if a voltage pulse is applied to the de-energized side either a stalled motor or a capacitor bank can cause large currents like a short circuit fault. Therefore, a fault detection technique based on the harmonic impedance characteristics is proposed. This method is effective for detection of three phase symmetrical fault and to discriminate a stalled motor or a capacitor bank from the fault. MATLAB computer simulation results are provided in this paper to verify the effectiveness of the proposed method.*

KEYWORDS: Symmetrical fault, harmonic impedance, stalled motor, capacitor bank.

I. INTRODUCTION

After the over head distribution feeder is de-energized for a certain period of time due to reasons like maintenance, storms and repairs the feeder is to be re energized again. As there is a possibility of humans or animals to get in contact with feeder unknowingly, the reclosing or re-energizing the system is major consideration for utilities point of view. Now a day's major contribution is made towards the development of techniques to check whether the de-energized system is free from short circuits or not, so that it can be re-energized again safely without causing any damage to the personnel and or the connected equipments. Compared to the detection of faults in energized feeder, detection of faults in de-energized feeder is more difficult. It requires the generation and application of a low level voltage signal initially so that if any personnel or animals incidentally in contact with the de-energized feeder may get a small shock and get away, then after the signal strength should be increased to detect the faults.

A fault detection technique called thyristor based device technique is proposed in this paper. Here the firing angle of the thyristor is changed to get the desired signal strength. Low-voltage pulse can be created to satisfy the safety requirement, and a high-voltage pulse can be produced to break down an insulated gap of a high-impedance fault when necessary. The proposed device is also having the unique feature of detecting different kinds of faults. Faults may be symmetrical or asymmetrical and it may be between phase and ground or phase and phase.

This paper is to provide a symmetrical fault detection method and considering situations of downstream stalled motors or shunt capacitor banks. Since a symmetrical fault affects all three phases equally, the method based on the difference of three-phase currents as like in asymmetrical faults detection [1] is not applicable here. Further, when a voltage pulse is applied to the de-energized circuit, either a stalled motor or a capacitor bank can cause a large current like a short circuit. Thus, it is necessary to explore a new fault detection

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method that is not only based on the fault current magnitude. In this paper, a fault detection method is developed based on the harmonic impedance characteristics [3]. Combined with the asymmetrical fault detection algorithm developed in [1], this detection scheme can detect all kinds of faults and can distinguish a fault from a stalled motor or a shunt capacitor bank.

II. PROPOSED FAULT DETECTION METHOD

As shown in Figure 1, a voltage from one energized phase and neutral is fed to all three phases of a de-energized side of distribution feeder through a cascaded structure of thyristors, when the thyristors T1, T2, T3 are fired simultaneously on a certain degree before the voltage cross zero and thyristor T4 is not fired. The corresponding current pulse in each phase depends on the line condition. In a normal condition, the injected currents are very small and if there is a symmetrical fault, inrush currents will show up in all phases at the same time. However, this fault current magnitude highly depends on the fault resistance. It is therefore difficult to set up an appropriate current magnitude threshold to detect whether a fault exists, especially considering the possibility of a high-impedance fault. Further considering the situations of stalled motors and shunt capacitor banks connected at downstream, where a high current similar to a short circuit may be produced, a fault detection method not just based on the current magnitude is required. To meet this fault detection requirement, a new method based on the harmonic impedance is introduced in this article. The harmonic impedance can represent the frequency response of power networks. With its unique characteristics, the harmonic impedance can be effectively used to detect a symmetrical fault. The harmonic impedance can also be used to distinguish a stalled motor or a capacitor bank from a fault.

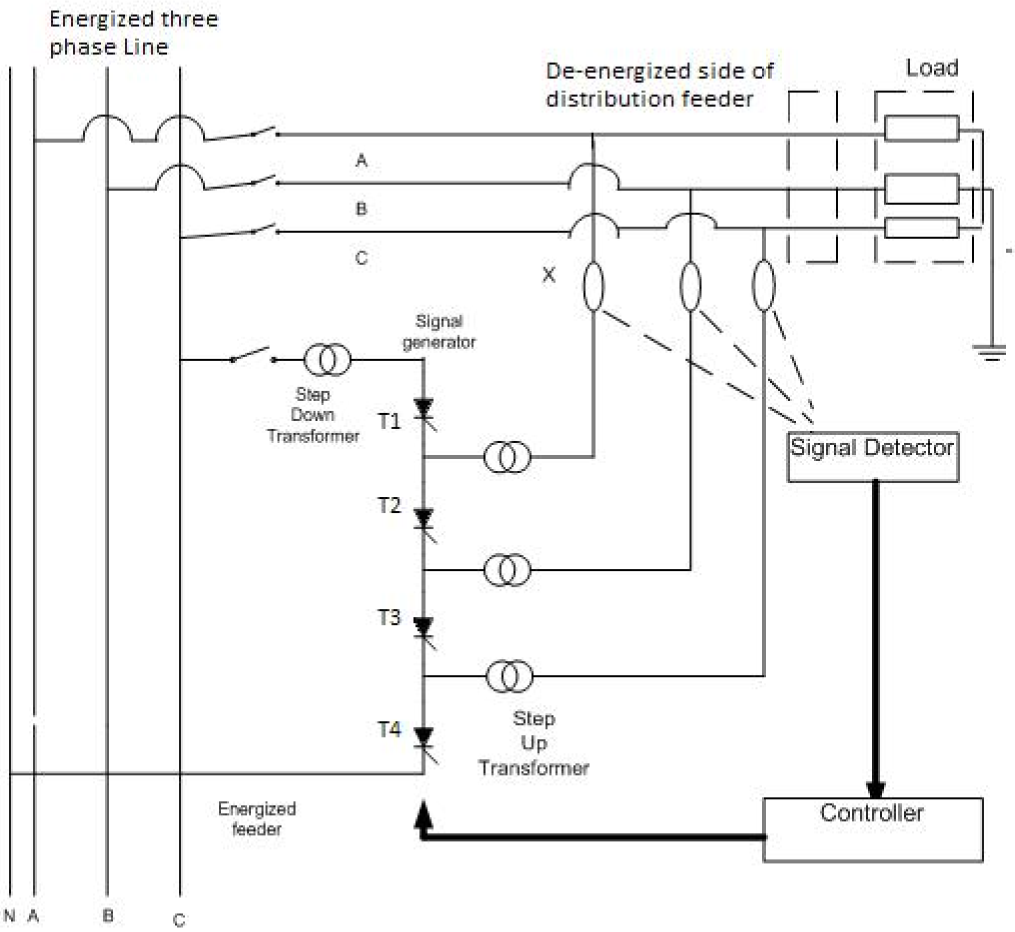

Figure 1: Proposed scheme for symmetrical faults detection.

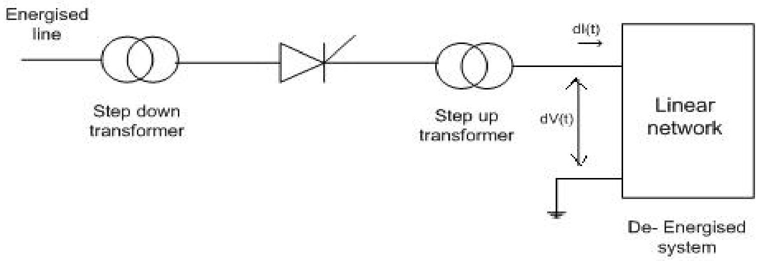

Figure 2: Downstream de-energized lines a linear network

Considering the downstream de-energized line as a linear network (Figure 2), an equation can be established according to the Fourier transform of non periodic signals.

$$dV(jw) = Z(jw) * dI(jw)$$

Where $dV(jw)$, $dI(jw)$ are the Fourier transforms of transient voltage, current and $Z(jw)$ is the harmonic impedance.

The harmonic impedance can therefore be expressed as

$$Z(jw) = \frac{dV(jw)}{dI(jw)}$$

Or

$$Z(f) = \frac{dV(f)}{dI(f)}$$

Where w =2πf, and f is the frequency.

These equations imply that the harmonic impedance can be measured by using the DFT of transient voltage and current signals. To implement this approach, the Fourier transforms of the current and voltage are created using an FFT algorithm. Separating harmonic impedance $Z(f)$ into its resistance and reactance parts gives

$$Z(f) = R(f) + jX(f)$$
$$= \mathrm{Re}\left[\frac{FFT\big(dV(f)\big)}{FFT\big(dI(f)\big)}\right] + j\,\mathrm{Im}\left[\frac{FFT\big(dV(f)\big)}{FFT\big(dI(f)\big)}\right]$$

The basic principle of the proposed idea is to utilize the change of $Z(f)$ in different conditions to detect a symmetrical fault.

III. METHODOLOGY AND MATLAB SIMULATION

a) Harmonic impedance characteristics under No-fault and Symmetric fault conditions:

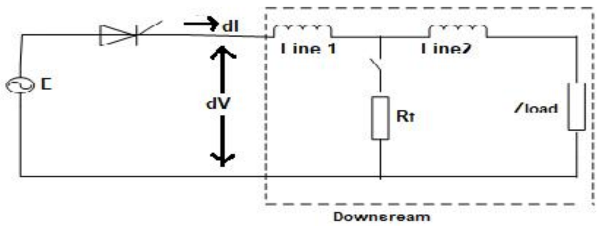

Figure 3: Equivalent circuit of the proposed idea

If there is no fault or the system is healthy, the fault resistance R_f in Figure 3 is not included in the equivalent circuit, and then the harmonic impedance of the de-energized downstream is

$$Z(f) = R(f) + jX(f) = R_{lo} + j2\pi f(L_{lo} + L_{li})$$

From the above equation it can be said that the harmonic reactance $X(f)$ is proportional to the frequency and inductance of load and the line.

However, if a symmetrical fault is present in the system the fault resistance R_f in Figure 3 is included in the equivalent circuit, and the harmonic impedance will become

$$Z' = R'(f) + jX'(f) = X_{li}(f) + R_f // \left[R_{lo} + j\left(X_{lo}(f) + X_{li}(f)\right)\right]$$

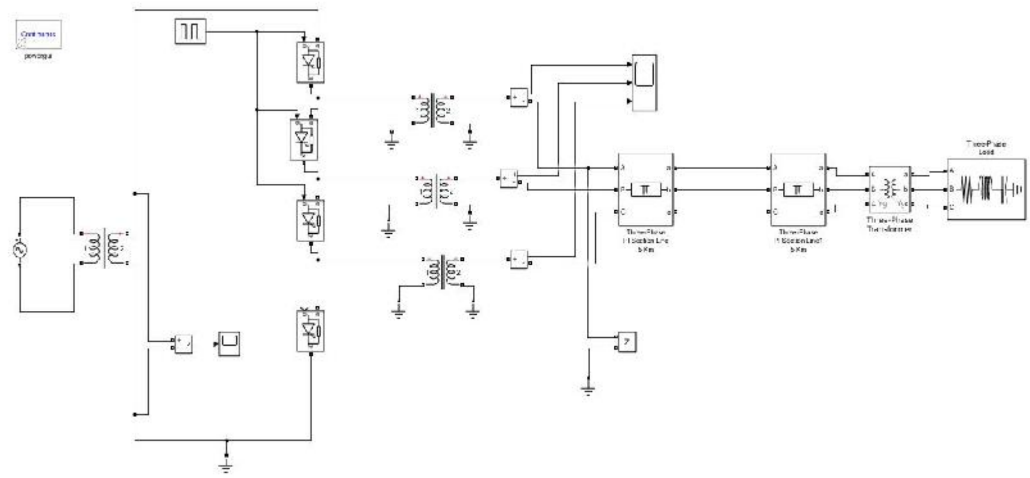

Figure 4: Simulation of the de-energized distribution feeder under No-Fault Condition

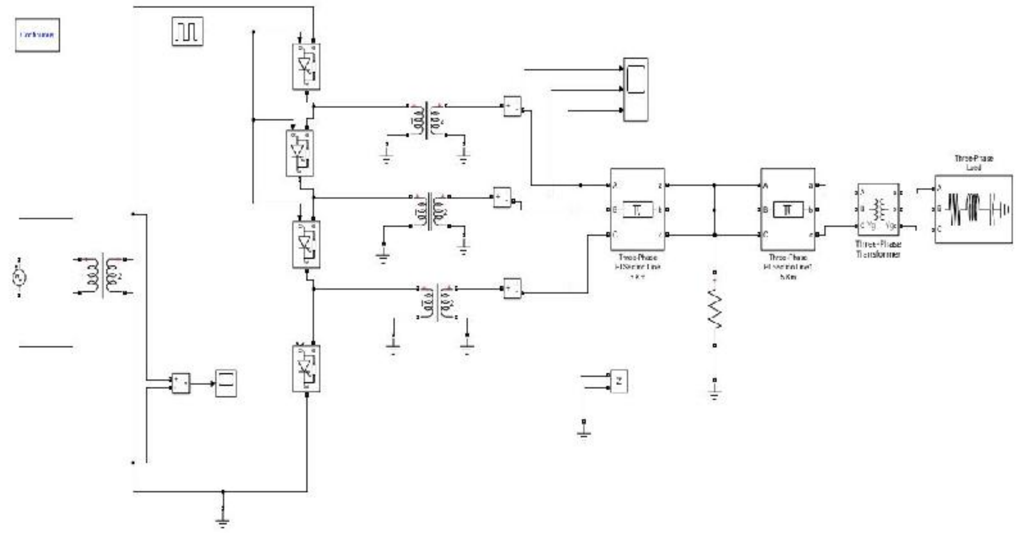

Figure 5: Simulation of the de-energized distribution feeder under Symmetrical Fault Condition with a fault Resistance R_f =10Ω

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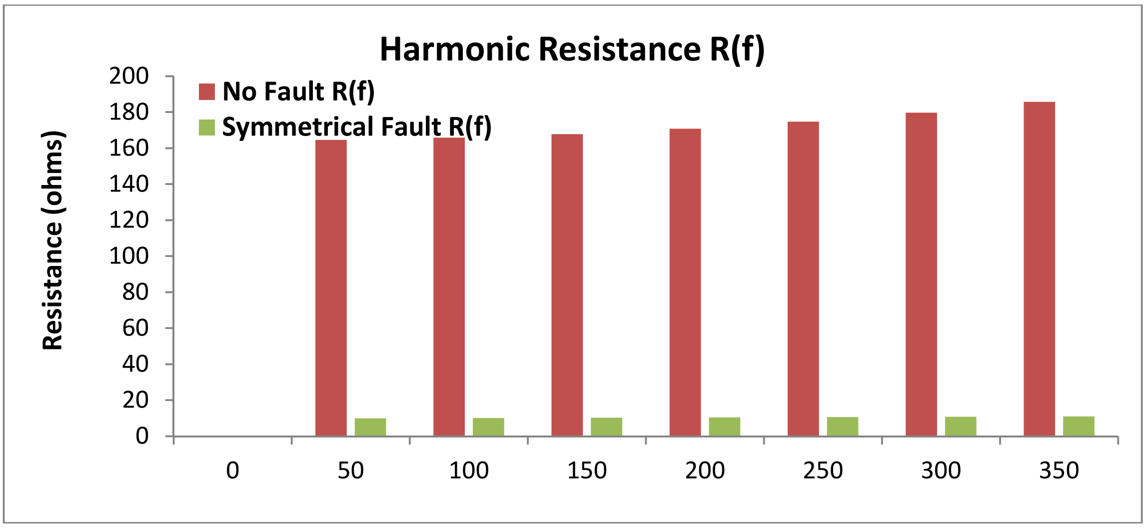

Figure 6: Comparison of Harmonic Resistance R(f) in No-Fault and Symmetrical fault conditions

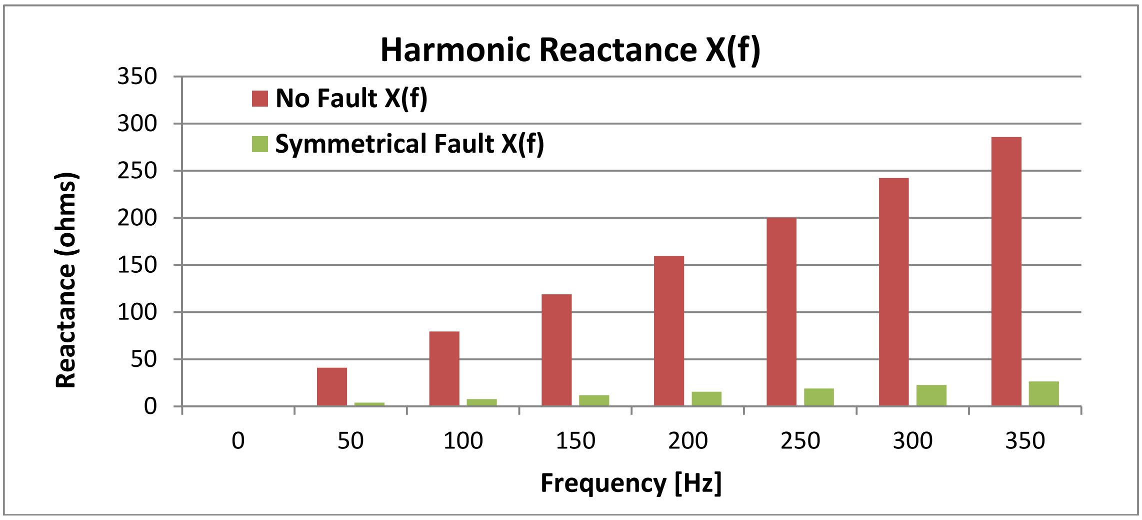

Figure 7: Comparison of Harmonic Reactance X(f) in No-Fault and Symmetrical fault conditions

The simulation circuits with No-fault and Symmetrical fault cases are shown in Figure 4 and 5 and the harmonic resistance R(f)and reactance X(f) in the two are compared in Figs. 6 and 7 respectively. It is seen that under No-fault condition the harmonic reactance is proportional to the frequency, and under symmetrical fault condition also the harmonic reactance is also proportional to the frequency. However the harmonic reactance X(f) under symmetrical fault condition is small than the harmonic reactance X(f) under No-fault condition and almost it has no significant change at low frequencies.

Based on the above analysis, the harmonic impedance can be utilized for symmetrical fault detection. The decision logic is therefore as follows.

1. Measure the current and voltage waveforms after giving the triggering pulse to thyristors T1, T2, T3
2. Are the currents are same?

If NO, there is an asymmetrical fault in the system

If YES, estimate the value of harmonic Reactance X(f)

i. If X(f) is proportional to frequency , there is NO fault

ii. If X(f)is no significant change as the frequency increases, there is a symmetrical fault in the system.

b) Harmonic impedance characteristics under the presence of Stalled motor:

Typically, the power factor of motor under starting is in between 0.2 ~ 0.3, and the inrush current at start is about 600% to 800% of the rated current. Thus, a stalled motor in connected to a distribution feeder can cause a large current when they are de-energized. This high current with a stalled motor is comparable to the symmetrical fault current and indicates that the current magnitude is not a good indicator to distinguish a symmetrical fault from a normal condition of a stalled motor. Using the reactance versus frequency criterion a fault is effectively distinguished from a stalled motor situation, but it cannot distinguish a stalled motor from a no fault condition as they both have a similar X/f ratio. However, detecting the existence of a stalled motor is not really the purpose of this paper. As long as a fault can be effectively detected, the proposed detection scheme can work properly. The MATLAB simulation circuit of the proposed system with a stalled motor is shown in Figure 8 and corresponding harmonic reactance characteristics are shown in Figure 9. The harmonic Reactance X(f) increases with increase in frequency in both conditions of symmetrical fault and with stalled motor. However, the harmonic Reactance with a stalled motor is very higher than that of a symmetrical fault case.

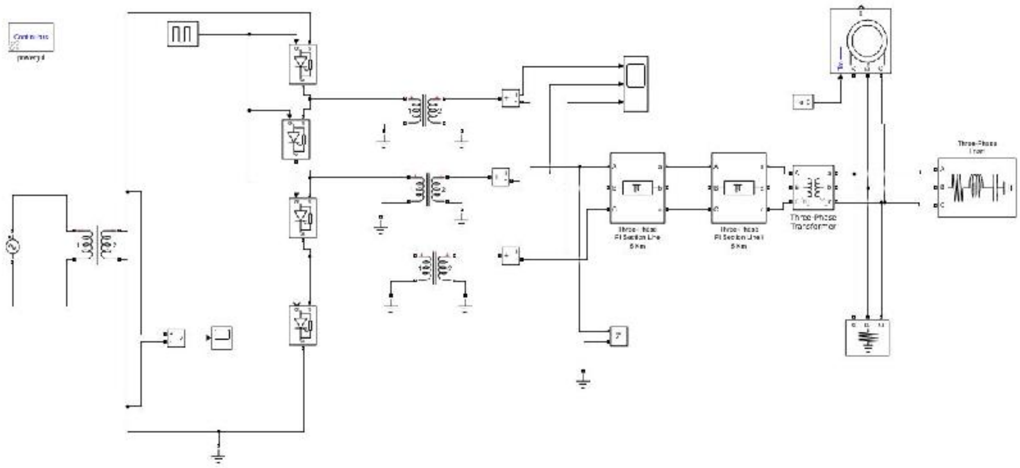

Figure 8: Simulation of de-energized distribution feeder with a Stalled Motor

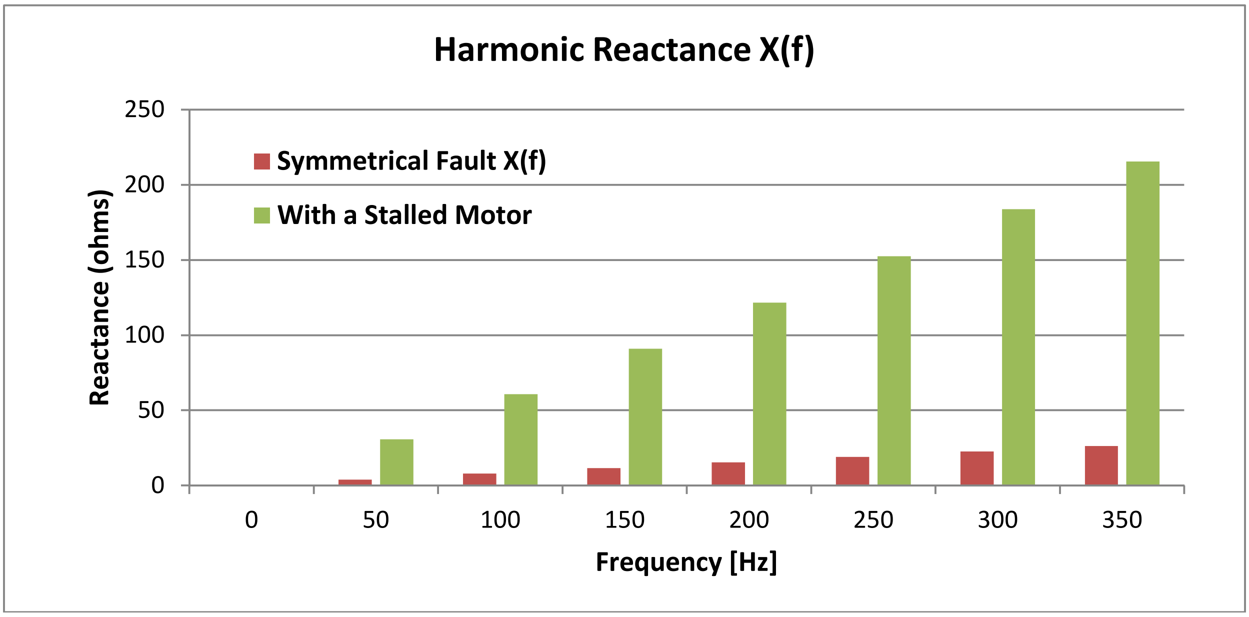

Figure 9: Comparison of Harmonic Reactance X(f) of Symmetrical fault with a Stalled motor

c) Harmonic impedance characteristics under the presence of Capacitor bank:

A capacitor bank is connected in parallel to a distribution system to provide the reactive power compensation, and to improve the voltage profile, thereby improving the quality of the electrical supply and operation of the power system. However, with its capacitive reactive power compensation, a capacitor bank current is similar to that of a symmetrical fault and the magnitude of current is comparable with the magnitude of the fault current. It is therefore difficult to distinguish a fault from a capacitor bank if only comparing the currents waveforms in the time domain. In the frequency domain, the capacitor almost has no contribution in the dc component (0 Hz) and its harmonic impedance ($1/j\omega C$) decreases as the frequency increases. The MATLAB simulation of the de-energized distribution feeder with a capacitor bank connected in parallel is shown in Figure10.

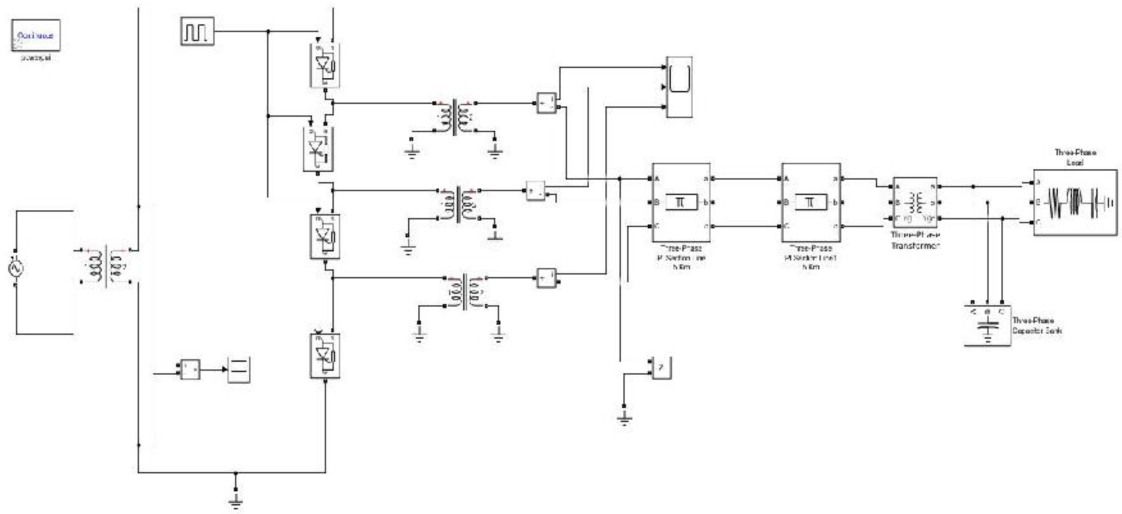

Figure 10: Simulation of de-energized distribution feeder with a Capacitor bank in downstream.

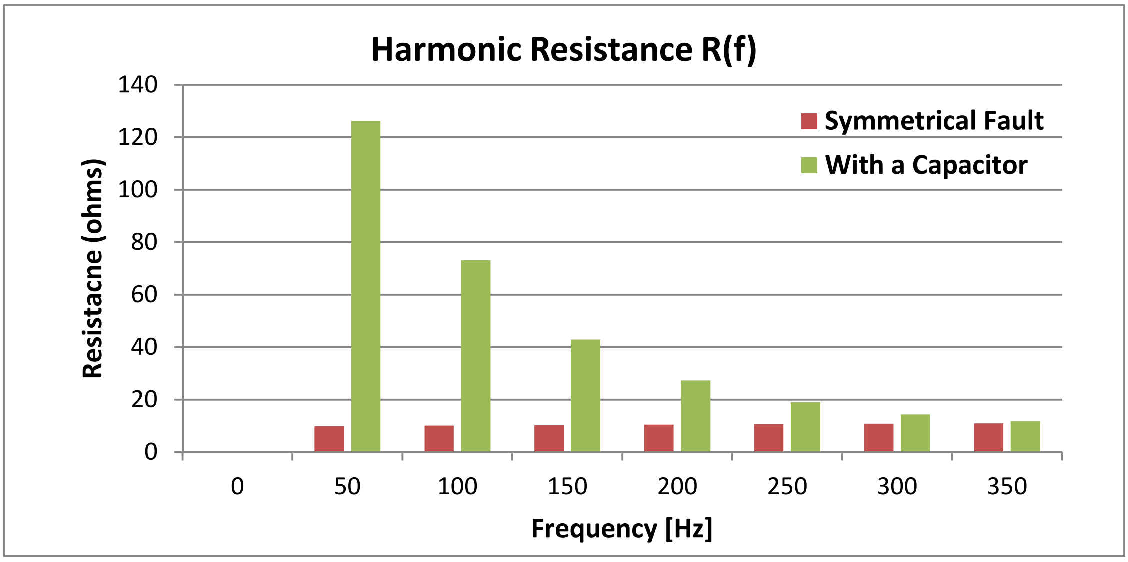

Figure 11: Comparison of Harmonic Resistance R(f) in No-Fault and Symmetrical fault conditions

When a capacitor bank is connected to the de-energized side of the distribution system, the harmonic resistance in a symmetrical fault condition and in a normal condition with the presence of capacitor bank are compared in Figure 11. It can be observed that with the increase of frequency, the harmonic resistance decays rapidly when there is a capacitor bank. However, if a symmetrical fault exists, the change of harmonic

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resistance in is very small. Thus, this difference provides the criterion for distinguishing a fault from a capacitor bank.

d) Harmonic impedance characteristics under the presence of both stalled motor Capacitor bank:

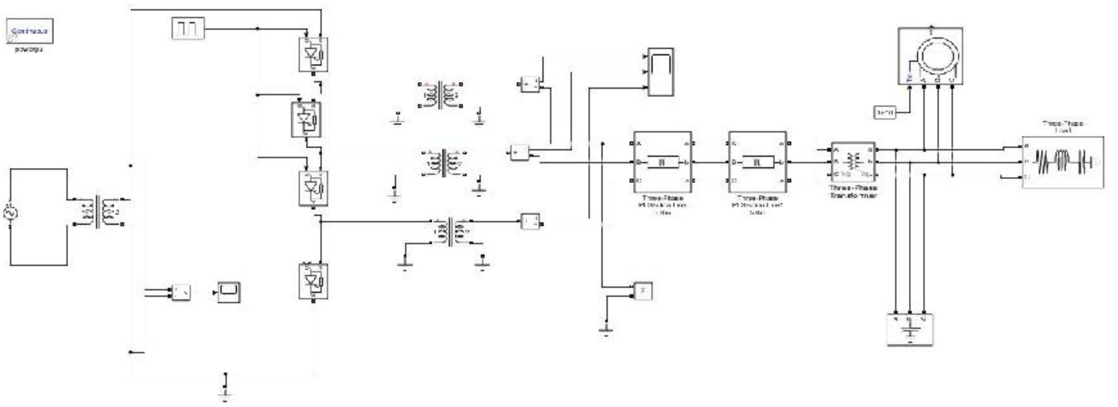

Figure 12: Simulation of de-energized distribution feeder with both a Stalled motor and a Capacitor bank in downstream.

If a stalled motor and a capacitor bank exist in the downstream, the harmonic impedance will not follow the patterns discussed before since parallel resonance may occur with the motor and the capacitor. If the motor and the capacitor are both connected to the de-energized system in parallel, the harmonic impedance will become as shown in Figure 13. Apparently, the parallel resonance occurs at the frequency 180 Hz. The magnitude of the impedance at resonance frequency is limited due to the existence of the resistance. Generally, the resonance frequency depends on the system capacitance and reactance. If the capacitance is small, the resonance will occur at a higher frequency. Figure 14 shows the simulation result when a 2.5 MVar capacitor is replaced by a 0.25MVar capacitor. Within the frequencies between 0~350 Hz, the scenario of parallel resonance is not observed. However, the difference between the faulted and the No-Fault cases is significant in Figures 13 and 14. Thus, a symmetrical fault can still be detected even though there is a parallel resonance introduced by a capacitor and a stalled motor.

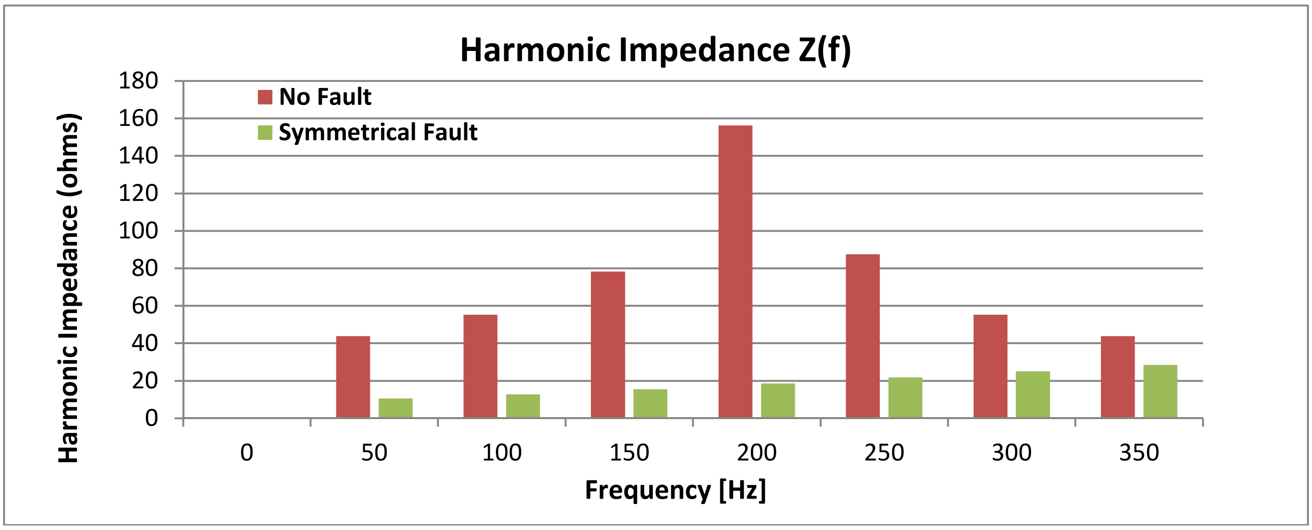

Figure 13: comparison of Harmonic impedance characteristics when a 2.5 MVA capacitor and a 5000hp motor are connected in downstream.

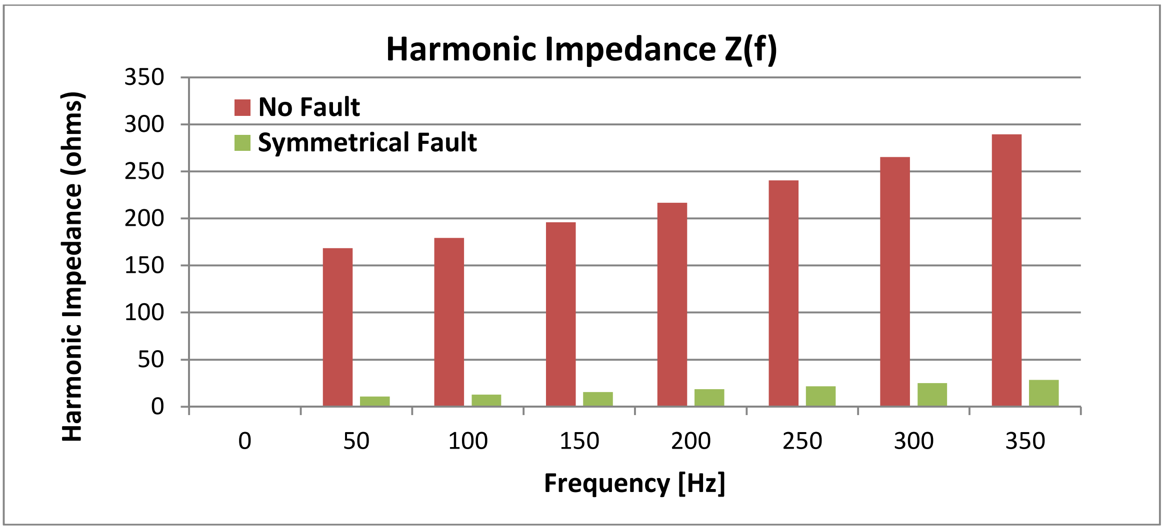

Figure 14: comparison of Harmonic impedance characteristics when a 0.25 MVA capacitor and a 5000hp motor are connected in downstream.

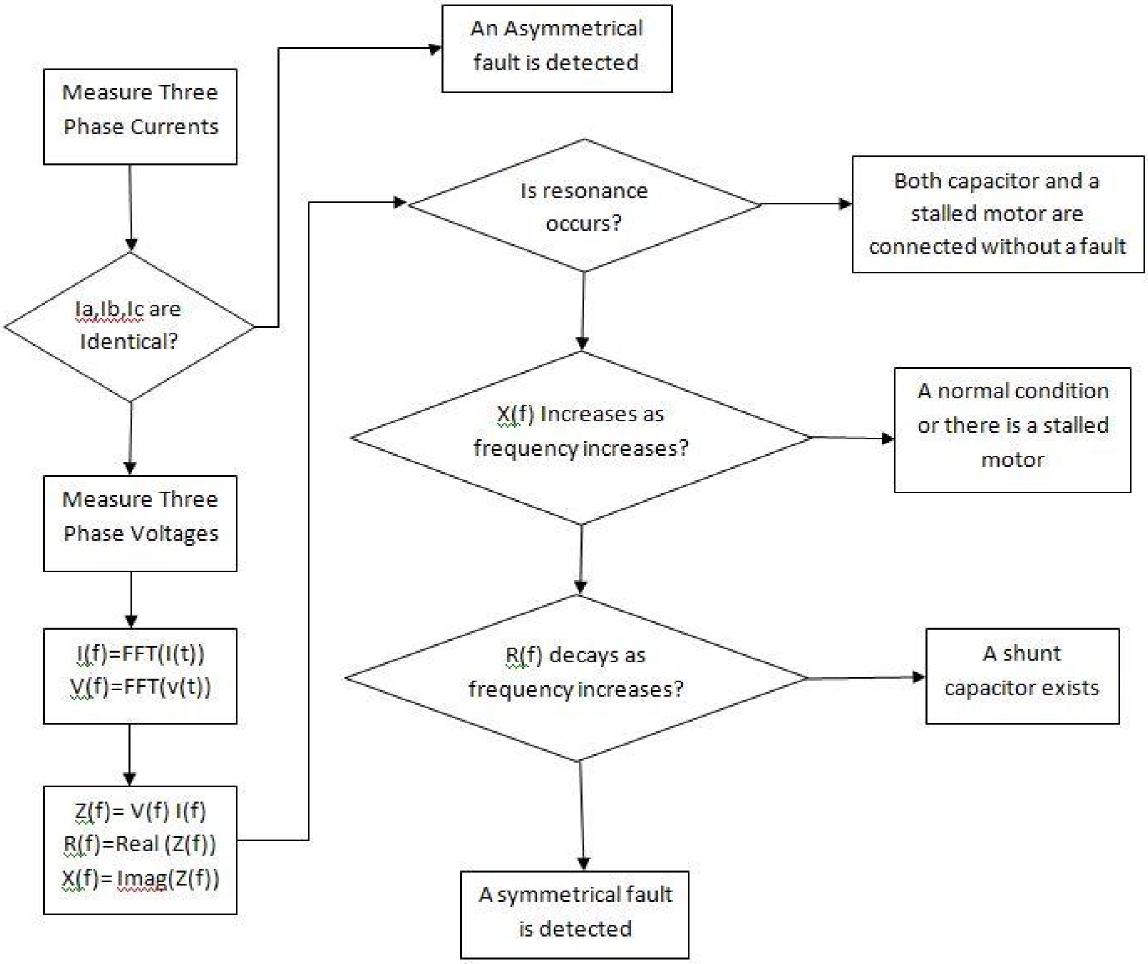

Figure16: Flowchart for overall logic of symmetrical fault detection

Finally, with the aforementioned analysis for harmonics impedance characteristics under different situations, and combined with the asymmetrical fault detection method in [1], the fault detection procedure including the harmonic impedance analysis can be updated as follows.

1) Measure the currents and voltages of three phases after triggering the thyristors T1, T2, and T3 simultaneously.
2) Are currents the same?

If NO, turn to asymmetrical faults analysis (as in [1]).

If YES, calculate, $Z(f), X(f),$ and $R(f)$ by using the Fourier transforms of the current and voltage with an FFT algorithm.

i. If harmonic resonance is observed in $Z(f)$, it indicates that a capacitor and a motor are connected and the line is healthy.

ii. Otherwise, if $X(f)$ has a large increase with the increase of a frequency and is almost proportional to the frequency, it indicates that a normal condition or a stalled motor exists.

iii. Otherwise, if $R(f)$ decays as frequency increases, a capacitor is connected without fault.

iv. If both $R(f)$ and $X(f)$ have no significant change as frequency increases in the observed frequencies (0 ~ 350 Hz), it indicates that a symmetrical fault exists.

The overall logic for symmetrical fault detection based on harmonic impedance is summarized in Fig. 16 represented below.

IV. ACKNOWLEDGEMENTS

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V. CONCLUSION

This paper focuses on the detection of symmetrical three-phase fault detection in a de-energized distribution system, where the presence of a stalled motor or shunt capacitor bank in downstream makes the fault detection more strenuous as they behave like short circuits. Compared to the detection of asymmetrical faults, the detection of symmetrical fault with before mentioned conditions necessitate a detection technique other than simply comparing the three-phase currents. Thus, a new detection technique based on the harmonic impedance characteristics under the downstream circuit is developed and suggested. This method can be effectively used for symmetrical fault detection and for distinguishing a fault from a stalled motor or capacitor bank. Finally, the fault detection procedure, including symmetrical and asymmetrical faults and with consideration of possible stalled motor or capacitor banks at downstream, is presented with a flow chart and the results have been verified in MATLAB computer simulation.

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