INT. JOURNAL OF ELECTRICAL AND ELECTRONIC SYSTEMS RESEARCH, VOL.1, JUNE 2008

Implementation of Motor Current Signature Analysis as a Reliable Monitoring System

A.Gheitasi[1], M.Moghavvemi[2] and R.Omar[3]

***Abstract* — The strategy of Motor current signature has widely been used in industry to diagnose motors faulty conditions. This strategy has some shortcomings that limit it as an engineering auxiliary tool. The main problem of this strategy is its low reliability that in fault diagnosis.**

In this paper feasibility of application of MCSA as an automatic protection system is investigated and a new online diagnosis strategy is proposed, implemented and initially simulated to apply as an automatic system in motors fault diagnosis.

I. INTRODUCTION

Recently the signature analysis method became a popular area of study for condition monitoring, especially vibration monitoring, in order to remove the expensive vibration sensors. But the method is not developed as a carefree automation strategy that can be applied in digital protection. Also it’s seen that in all power systems, the condition monitoring section is completely separated from the protection systems and in most cases the condition monitoring data (SCADA data, vibration data, etc.) just saved and studied by the engineers periodically, so the engineers must take the necessary actions and automatic system protection just limited to controlling and protecting against effective values (RMS) of voltage, current, vibration and other physical conditions with fixed limitations without analyzing the signals components. In some cases some numeric methods and softwares helps the engineers to detect and diagnose the faults but just as a human tools for fault detection.

II. RELATIONSHIP BETWEEN PHYSICAL AND ELECTRICAL QUANTITIES

For any electrical induction machine, a function can be defined. Consider the fed voltage as the input of this function and electrical current as the output. So the output is a direct result of input signal and the transfer function is the effects of physical phenomena on that induction machine as shown in fig1. And mathematically can be shown:

$$I=F(\text{“V”});\ F=f(\text{“M”}, \text{“E”}, \text{“T”}, \text{“O”}) \qquad (1)$$

The only accessible electrical quantities are current and voltage and normally the feeding voltage is independent of induction machine condition, so, this study concentrates on the effects of physical condition on electrical current. It is understood that the effect of any phenomenon on electrical quantities is not independent with other physical phenomena so it’s impossible to study on effects of specific phenomena by ignoring the role of other phenomena.

Generally, in electrical induction machine the physical effects of induction machine reflected to the waveforms of current and analyzing of this factor is a primary and only way to detect electrical and sometimes mechanical overload faults. The protection systems have at least one current module; consequently it’s very economical to use this

---

1.Gheitasi.A, University of Malaya, 50603; Kuala Lumpur, Malaya, Email: Gheitasi@gmail.com

2.M.Moghavvemi, University of Malaya, 50603; Kuala Lumpur, Malaya, Email: Mahmoud@um.edu.my

3.R.Omar, University of Malaya, 50603; Kuala Lumpur, Malaya, Email: rosli_omar@um.edu.my

module as a processor of other faults.

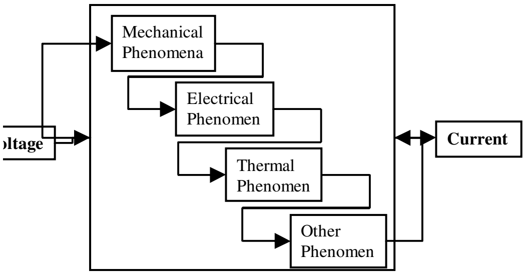


Fig. 1. current signal considered as a result of physical effects on voltage as a transfer function.

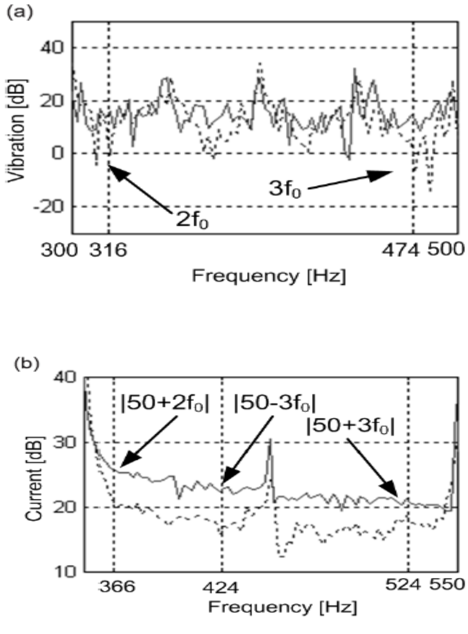


Fig. 2. Relationship of the vibration (a) and current (b) spectra of an unloaded 2-pole induction machine, healthy bearing and defective bearing with 5mm width hole*[5]*.

Vibration harmonics detection from current frequencies contains for induction machines developed and successfully tested in experimental application in various reports [1-4]. However, there are some problems in applying this method in harmonic analyzing. The main Problem in this kind of analyzers is that, these analyzers with using accurate relationship just can be defined for specific kind of motors. Furthermore, the frequency relationships is strongly related by the flux and airgap of motor, and for whatever reason the airgap thickness or other flux parameters change during the operation, the calculation and defined relationships may become invalid. The reliability in current based vibration analyzers is very low and is not a certifiable strategy for applying in protection devices.

This paper proposes a new method of designing a vibration protective system based on current and voltage detection by statistical and mathematical calculation based on patterns knowledge base of faulty situation.

III. FAULT PATTERN DIAGNOSE

Every fault or generally any phenomena, has a specific time pattern and followed on a specific way from start to induction machine break down. If the exact pattern of faults is captured by practical examination or simulation, by checking the input and outputs of that system, it is possible to recognize the fault nature and also the risk and the safety period that the system can continue running with those faults.

The patterns of faulty situation mostly appear as vibration exceeding from specific limitations on some specific frequency. The deviation of these frequencies can identify the extent and risk of the faults. By using frequency respond the risk of faults also is recognizable.

IV. INDUCTION MACHINE SIMULATION IN ABSENCE OF PHYSICAL FACTORS

The state variables of function that relate the current to the voltage sub harmonics in induction machines are "V" "$\int_0^t Vdv$", "I".

$$\left[I(f1) \quad I(f2) \quad \dots \quad I(fn) \right] = \quad (2)$$

$$\begin{vmatrix} V(f1) & V(f2) & \dots & V(fn) \\ \int_0^t V(f1)dV(f1) & \int_0^t V(f2)dV(f2) & \dots & \int_0^t V(fn)dV(fn) \end{vmatrix}$$

$= (2)$

A is state parameter of induction machine. Using a simulation in situation of none-vibration, and in all possible situations, for any state, desirable value of current can be recorded and all this values are saved in database of that induction machine with electrical and mechanical property.

In this paper a three-phase 400v HZ squirrel cage induction motor is used for simulation.

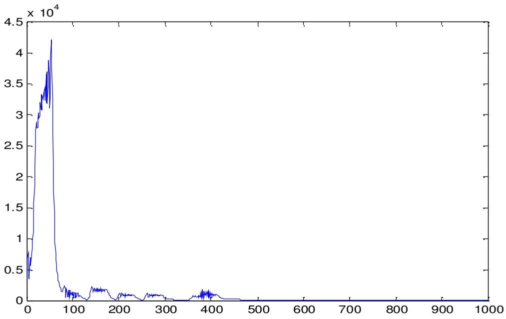


Fig. 3. The different effects of mechanical faults on current

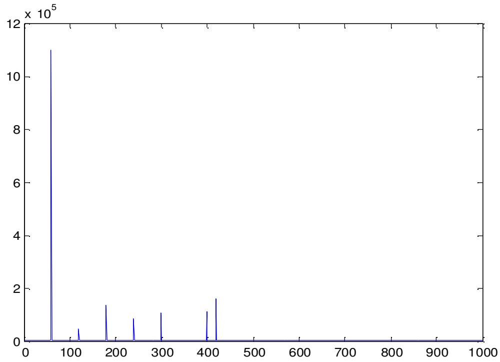


Fig. 4. Simulation graphs

V. SIMULATION WITH PRESENCE OF VIBRATION EFFECTS:

The effects of vibration in current signal are clearly tested and published in some resources [4-6]. The mechanical faults can be diagnosed by detecting unexpected change in specific harmonics of current waveform, and the change's rate indicates fault's severity in induction machines. The system saving time that the induction machine must be removed from faulty situation. In damage prevention, two basic factors can illustrate the fault seriousness: current value of harmonic unexpected magnitude and also rate of primary factor.

The primary detection factor is defined as deviation of real value of any harmonic with the expected value in non-harmonic situation in any state so

The real data of current harmonics are collected by the simulation results as a database of expected current harmonics in that voltage harmonics and integration of this harmonics as a induction machine state.

VI. FAULT DIAGNOSES STRATEGY

Any unexpected events can be categorized as either harmless, controllable risky and dangerous situations. The function of system is to raise alarm in 2nd situations and stop the operation in 3rd; also protection system must guaranty the normal operation of device in harmless situations.

With respect to the induction machine property and faults nature on that specific system, the frequency band is divided in unique limitations; as an example for an induction motor that is operated with fundamental frequency of 50Hz, the frequency band is divide in to unequal zones with maximum length of 20 Hz the center of any zone defined as a correct factor of fundamental frequency.

(1Hz-20Hz), (20-40), (40-60), (60Hz-80Hz), (80Hz-95Hz), (95HZ-110) and etc.

$$\mathrm{F}(M) = \bigcup_{i=1}^{n} F(M_i) \qquad (3)$$

n: number of covered faults

$$\mathrm{F}(M_i) = \bigcap_{i=1}^{m} F(Mi, j) \qquad (4)$$

m: number of diagnosed condition.

$$\mathrm{F}(Mi, j): \begin{cases} \text{(I): } La < f_n < Ls \\ \text{and/or} \\ \text{(II): } L'a < \int_{t0}^{t} \frac{d^n}{d^n t}(f_n - L_n)dt < L's \end{cases} \qquad (5)$$

Non-zero value of 'F' illustrates at least one risky fault and using grows slop of the exceeded harmonics, the system saving time(dead line) can be calculated; in this simulation root mean squared of average of any exceeding frequency rate defined as a time factor criteria.

So $$D=\sqrt{\sum_{i=1}^{n}\left(\int_{t0}^{t}\frac{d^{n}}{d^{n}t}(f_{n}-L_{n})dt\right)^{2}} \qquad (6)$$

saving time, $$t=\frac{\sqrt{\sum_{i=1}^{n}(f_{n}-L_{n})^{2}}}{\sqrt{\sum_{i=1}^{n}\left(\int_{t0}^{t}\frac{d^{n}}{d^{n}t}(f_{n}-L_{n})dt\right)^{2}}} \qquad (7)$$

n: number of involved situations

The saving time in this system is a variable and can be changed during alerting system but in most cases the increasing rate of faults are constant if the system is insulated from other effects as shown in fig. 3.

For integration process in this system a simple method is applied to decrease the processing operation. For example:

$$\frac{m\sum_{i=1}^{m/2}(\mathrm{X(m-i)-X(i))*(m-i)}}{\sum_{i=1}^{m}X(i)} < L's \qquad (8)$$

m: number of samples per trigger.

VII. FLOWCHART ON ONLINE FAULT DIAGNOSIS

The algorithm for the Online Fault Diagnosis (OFD) is shown in fig. 7 (see Appendix).

We have drowned up this algorithm based from proposal made by various researches as discussed before.

In this simulator the MATLAB data processing functions are applied for basic processing of captured data, so the processing ability and accuracy of the simulator is a function of MATLAB abilities.

First of all the current data is captured follow to the chapter from measurements devices usng a data acquisition procedure [6]. Then the primary factors of signal processing (i.e. RMS and Variance) are calculated and the outliers are rejected from the original signal [7]

In this simulation, in order to avoid the wrong data to disturb the data variation, if a captured data become higher than "RMS+3VAR (data)" (RMS of signal +3 times of variance of the signal), it is detected as an outlier and will be removed from the original signal.

In next step the primary calculation is and the normal operation of digital relays is done. Then the data is forwarded.

For this step some common commands defined for the relay simulator as a normal operation of relays. The insertion of these commands is applied to test the common function of protection system that must avoid dangerous situation by commanding the breakers and Warning systems. These commands are resulted from some calculation on the raw and magnitude waveforms and can be classified into three categories:

1. RMS based command
2. definite harmonics calculations
3. THD(Total Harmonic Distortion) based

Generally in fixed temperature and if the machinery and its accessories are in good condition, irregular temperature rising of electrical machinery is the directional effect of mechanical load increasing and also rising of harmonic contents of feeding signals.

The mechanical load increment is detectable easily by overload protection relays, but without referencing the harmonic contents, the thermal effects cannot be detected using overload relays. Thus, without harmonic detection, the only way to protect the electrical machinery against the faults of temperature rising is to install temperature sensors in important parts of machinery, and periodical inspection

The next section is an optional part to save the raw data within data stack. This section is bypassed in this simulator .WSFFT (Windows

Short FFT) is selected to process the data and calculate the frequency patterns.

Here the applied method for signal processing is WSFFT (window short fast furrier transform) where the windows band is the fixed value of samples per trigger. in this simulation 1000 samples are collected in a signal trigger so the windows duration is the time of 1000 samples 1000/48100(sample rate) seconds.FFT is the method to measures the frequency contains in the waveform. After performing FFT transform, the result is not the function of the time.

WSFFT is the new approach to the witch applies the time factor within data processing. WSFFT performs the FFT transform within a signal snapshoot. So for any duration of the signal specific configuration of frequency patterns in that time is calculated, hence the processed signal is the function of time and frequency.

By applying WSFFT it became possible to measure the variation of frequency contains in forming real state situation in order to diagnosis the dynamic patterns. In the next section, the amplitudes of frequency points are compared with the standard look up tables to detect, if the system is in healthy situation or not.

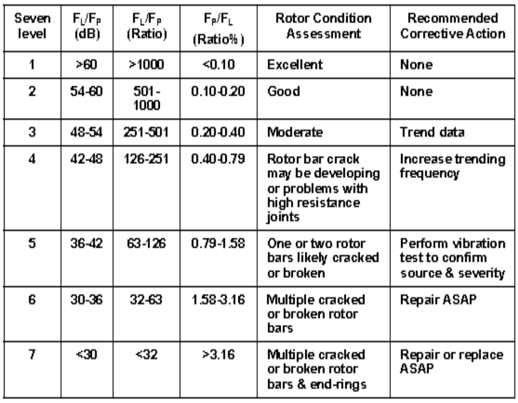
Generally, the protection risks are measured by comparing the significant signal with a standard table that indicate the faults, if level of significant signals is exceeded from the standard value; the system is entered to the alerting zone and then hazardous zone.

These tables are defined by standardization of some measurements for the machine to found when the values of significant signals indicate a considerable risk for the protection target.

Here as an example the risk measurements for rotor problems is as shown below. See Table 1.

TABLE 1

ASSESSMENT OF SEVERITY OF ROTOR BAR DAMAGE [8]. FL REFERS TO THE MAGNITUDE OF THE FUNDAMENTAL FREQUENCY (IN THIS THESIS F0) AND FP RELATES TO THE MAGNITUDE OF THE SYMPTOM FIRST HARMONIC ORDER IN ROTOR BAR DAMAGED



Seven level	F_L/F_P (dB)	F_L/F_P (Ratio)	F_P/F_L (Ratio%)	Rotor Condition Assessment	Recommended Corrective Action
1	>60	>1000	<0.10	Excellent	None
2	54-60	501 - 1000	0.10-0.20	Good	None
3	48-54	251-501	0.20-0.40	Moderate	Trend data
4	42-48	126-251	0.40-0.79	Rotor bar crack may be developing or problems with high resistance joints	Increase trending frequency
5	36-42	63-126	0.79-1.58	One or two rotor bars likely cracked or broken	Perform vibration test to confirm source & severity
6	30-36	32-63	1.58-3.16	Multiple cracked or broken rotor bars	Repair ASAP
7	<30	<32	>3.16	Multiple cracked or broken rotor bars & end-rings	Repair or replace ASAP

In real situation, there is no reliable reference to compare the security of induction machines for various kinds of the faults by using frequency content of the current waveform. So here, the severity level for the mechanical and internal faults, are calculated the same as the rotor bar faults table with comparison of the ratio of significant frequencies to the desired frequency of healthy machine. These references can be more reliable with normalization and standardization of risk management tests

Then the data is passed to the recording section. Here the processed data are saved in a proper format. Here, time labeling is used for data sampling. So after any triggering action, the FFT signal is saved in a definite part of hard, with a definite time naming path.

By using this format, it is to make it easier to load the saved data refer to the date of sampling. Then the frequency zones are configured refer to the faulty patterns and the possibility of presence of symptoms in frequency band and faulty patterns is configured and compared with the present harmonic pattern of the target machine to diagnose the faults. Then by using equation VI the severity of fault is detected. A decision is be made to detect what to do the required commands.

VIII. TESTING

The system is successfully simulated using experimental results of a few induction machines with the alarm limitation of 20% of normal values and the stop limitation of 40% as default limitations. The induction machine precise limitations must be defined using the mechanical properties of that induction machine but normally the fixed limitations also can be used for protection.

IX. DISCUSSION

The purposed system operation during the major mechanical damages is acceptable as a module of protection relay, but in slightly damages and also some kinds of electrical damages that results decrease or being stable in harmonics can't be diagnosed using this system.

For example in broken bar faults, if slightly damaged, the resultant sidebands grows can't be diagnosed hence in one or two broken bars, the faults are easily diagnosed and investigated by following the process.

As shown in fig. 6, the effects of slightly mechanical faults on rotor current is very difficult to diagnose and require a very small tolerance and a low percentage of harmonic grows in system setting, this job decrees the system reliability and may make big mistakes in diagnose and raise unnecessary alarms, furthermore normally slightly mechanical events aren't emergency system failure and it's expected that the slightly events are removed without any treatment, consequently ignoring the slightly mechanical events must be reasonable so undetectable failures can be detected by offline supplementary investigations.

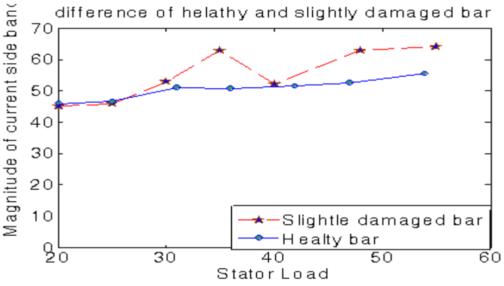


Fig. 5. difference in resultant effect of vibration faults regard to faults seriousness for a motor with damaged bar[9]

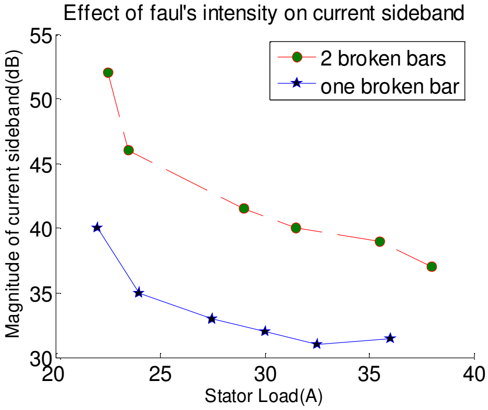


Fig. 6. difference in resultant effect of vibration faults regard to faults seriousness [9]

X. CONCLUSION

A method for sensorless on-line vibration protection of a wide area of electrical induction machines was proposed and initially evaluated by simulation. This paper has shown that electrical induction machine vibration failures can be diagnosed in a sensorless fashion by utilizing the online digital processing in voltage and currents frequency contains referring to the simulation results of induction machine in absences of vibration.

REFERENCES

[1] [1] Riley, C.M, et al., "A method for sensorless on-line vibration monitoring of induction machines" Industry Applications, *IEEE Transactions on Power system,* Volume 34, Issue 6, Nov.-Dec. 1998 Page(s): 1240 – 1245

[2] [2] D. G. Dorrell, W. T. Thomson, and S. Roach, “Analysis of airgap flux, Current and vibration signals as a function of the combination of static and dynamic airgap eccentricity in 3-phase induction motors”, in *Conf.Rec IEEE-IAS Ann. Meeting*, 1995, vol. 1, pp. 563–570.

[3] [3] R. Munoz and C. Nahmias, “Mechanical vibration of three-phase Induction motors fed by nonsinusoidal currents”, in *Proc. 3rd Int. Power Electronics Congr.,* 1994, pp. 166–172.

[4] [4] C. M. Riley, B. K. Lin, T. G. Habetler, and G. B. Kliman, “Stator Current-based sensorless vibration monitoring of induction motors”, in *Proc. APEC’97,* Feb. 1997, vol. 1, pp. 142–14

[5] Izzet Y O nel et al, “Detection of outer raceway bearing defects in small induction motors using stator current analysis”, Sadhana Vol. 30, Part 6, December 2005, pp. 713–722. Printed in India

[6] Guo, Y.; Lee, H.C.; Wang, X.; Ooi, B.-T, “A multiprocessor digital signal processing system for real-time power converter applications”, *IEEE Transactions on Power Systems,* Volume 7, Issue 2, May 1992 Page(s):805 – 811

[7] Thibeault, C., “On a New Outlier Rejection Technique”, *VLSI Test Symposium, 2007. 25th IEEE Publication* Date: 6-10 May 2007 On page(s): 97-103

[8] Aditya Korde, “On-line condition monitoring of motors using electrical signature analysis”, technical report, Diagnostic Technologies India Pvt. Ltd.

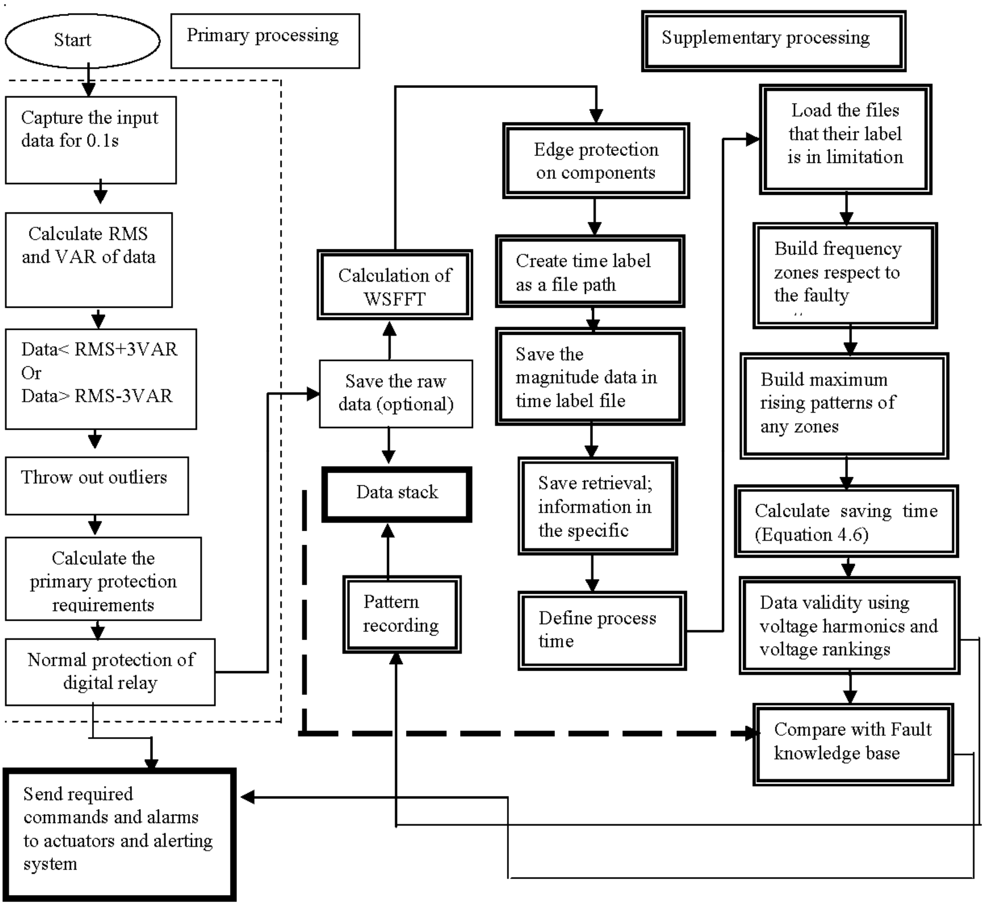
[9] Alan Miletic, Mirko Cettolo, “Frequency Converter Influence on Induction Motor Rotor Faults Detection Using Motor Current Signature Analysis” - Experimental Research, *SDEMPED 2003 -Symposium on Diagnostics for Electric Machines, Power Electronics and Drives Atlanta, CA, USA, 24-26 August 2W3*

Alireza Gheitasi received the B.Sc. In Electrical Engineering (power) from Chamran University of Ahvaz, Iran, in 2003.He have been involved some industrial companies and research projects. He is currently working toward his Master's degree in Power Engineering in University of Malaya, Malaysia.

Mahmoud Moghavvemi is holding the chair of Electrical Engineering, in the faculty of Engineering, University of Malaya. Besides many years of teaching and research experience in Electrical Engineering, he has several years of industrial experience in USA and Malaysia. He is the chief editor of the International Journal of Engineering Science and Technology and, member of board of reviewer of several International Journals in USA, Canada and Australia.

Rosli Omar Obtained his Bachelor of Engineering (Electrical) from University Malaya. .He obtained MSc in Knowledge Based Systems from the Department of Artificial Intelligence, University of Edinburgh and PhD from the Department of Computing, Imperial College; University of London. He is now an Associate Professor in the Electrical Engineering Department, University of Malaya

APPENDIX


Start
Primary processing
Supplementary processing
Capture the input data for 0.1s
Calculate RMS and VAR of data
Data< RMS+3VAR Or Data> RMS-3VAR
Throw out outliers
Calculate the primary protection requirements
Normal protection of digital relay
Send required commands and alarms to actuators and alerting system
Calculation of WSFFT
Save the raw data (optional)
Data stack
Pattern recording
Edge protection on components
Create time label as a file path
Save the magnitude data in time label file
Save retrieval; information in the specific
Define process time
Load the files that their label is in limitation
Build frequency zones respect to the faulty
Build maximum rising patterns of any zones
Calculate saving time (Equation 4.6)
Data validity using voltage harmonics and voltage rankings
Compare with Fault knowledge base