A New Fault Detection Tool for Single Phasing of a Three Phase Induction Motor

S.H.Haggag, Ali M. El-Rifaie,and Hala M. Abdel Mageed

***Abstract*-This paper introduces a new tool for fault detection in high voltage electrical networks; the new tool can be used by high speed digital relays to detect fault presence besides selecting the faulted phase(s). The suggested tool uses a new technique that squares both of the instantaneous voltage signal and its complement to produce a unity relation in normal operating conditions. The unity relation will remain undistorted as long as the power system is operating normally; however, the unity relation will change with any sudden change in the voltage signals due to any abnormal conditions. The suggested tool is being applied to detect the single phasing case for a three phase, high voltage induction motor. The simulation was done using Matlab simulink, where the simulation results showed great success of the suggested tool in detecting the single phasing case for all loading conditions. The new technique is then practically applied on a three phase induction motor, where the single phasing case is successfully detected. The practical results showed compliance with the simulink results in distinguishing the single phasing fault.**

Index Terms* *-Induction motors, Single Phasing, Digital relays

I. INTRODUCTION

A three-phase induction motor operating in the steady-state will continue to operate when a disturbance on the system causes the terminal voltages to become single phased. This condition is referred to as “single phasing” and will result in an operating condition that produces excess heating in the motor. Such a condition requires that the motor be provided with protection that will disconnect it from the system before the motor is permanently damaged. Single phasing in three phase induction motors can occur as a result of a fuse blowing or a protective device opening on one phase of the motor. Other possibilities include feeder or step-down transformer fuses blowing. Even though the motor will continue to operate in this condition, the motor will heat up very quickly, and it is essential that the motor be removed from service by the opening of a motor circuit breaker or some other types of protective devices [1,2].

When one phase opens, the current to a motor in the two remaining phases theoretically increases to 1.73 (173%) times the normal current draw of the motor. The increase can be as much as 2 times (200%) because of power factor changes. Where the motor has a high inertia load, the current can approach locked rotor values under single-phased conditions

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Three properly sized time-delay, dual-element fuses, and/or three properly sized overload devices will sense and respond to this overcurrent [3]. Methods for prediction and detection of motor faults are extensively documented in the research literature; many of these methods use stator currents and voltage signals in some form along with signature algorithms to determine or predict fault conditions in an induction motor [4]. Wavelet signal processing, and Fourier analysis are two techniques that can
be used to discriminate the single phasing case from other voltage unbalance cases [5].

In this paper, a new fault detection tool that uses the square value of the instantaneous voltage signal and its complement to produce a unity relation in normal conditions is introduced. The suggested Cos-Sin tool [6] is being applied to detect the case of single phasing (open of one phase) in large induction motors where Matlab simulink is used to simulate a 2.3 KV, 2250 Hp three phase induction motor, the simulation results showed the capability of the suggested tool to detect the case of single phasing, relying on the motor's voltage signal during single phasing. A practical application of the Cos-Sin tool is also shown using Lab View, where the Single phasing case is practically simulated and successfully detected.

II. THE COS-SIN ALGORITHM

The Cos-Sin algorithm is given as follows: the voltage signal at any instant for a given bus-bar is represented by V(t) where:

$$V(t) = V_{max}\cos(wt + Ø) \qquad (1)$$

On the other hand the complement of this signal could be obtained as $V_0(t)$ where:

$$V_0(t) = V_{max}\sin(wt + Ø) \qquad (2)$$

By squaring, adding and normalizing the above two equations, a discrimination signal $S_{CS}(t)$ can then be introduced as follows:

$$S_{CS}(t) = \frac{V^2(t)}{V_{max}^2} + \frac{V_0^2(t)}{V_{max}^2}$$

$$S_{CS}(t) = Cos^2(wt + Ø) + Sin^2(wt + Ø) = 1.0 \qquad (3)$$

The value of S_{CS} (t) is unity as long as there is no effective change in the value of V_{max} and no extra-ordinary condition taking place. This unity relation is distorted as soon as a fault occurs. The peak voltage value is updated every one complete cycle (20 msec for f=50 Hz), where full synchronization is done between the actual voltage signal V(t) and its complement $V_0(t)$ by acquiring the utilized values at the same instant. Fig. 1 shows V(t) with some disturbances due to a fault at peak voltage, while its complement signal $V_0(t)$ appears to depend only on the prefault peak voltage. Fig. 2 shows $S_{CS}(t)$ during normal operation, where the unity relation is kept steady.

III. Simulation Study for Single Phasing in Three Phase Induction Motors

The case of one phase open in an induction motor is simulated using MATLAB simulink [7]. Figure 3 shows the simulink model for a three phase wound rotor induction motor. The parameters of the simulated wound motor are as given in Table I.

An open of one phase case is simulated after 1.5 seconds of the motor operation. Figure 4 shows the deviation in the nominal operating current values at the instant of fault occurrence, the opened phase has a zero current, while the currents of other phases increased to an extent of double the normal operating current. Figure 5 shows the measured voltage signal at the instant of fault occurrence, the opened phase voltage decreased slightly in value while the other phases remained unchanged. The suggested Cos-Sin technique is applied and S_{CS} (t) is obtained following equations 1 to 3. The simulation is done for three different load cases, no load, half load and full load where $S_{CS}(t)$ for all cases are shown in Figure 6. It appears clearly that the amount of maximum and minimum deviation from the unity relation of S_{CS} (t) increases as the load increases from zero to maximum value. Table II, shows the deviation in the unity value of $S_{CS}(t)$ during single phasing of phase A for a time of 0.2 sec. From the shown values, it appears clearly that the new Cos-Sin tool can safely detect the case of single phasing (open of one phase) for high voltage, three phase induction motors

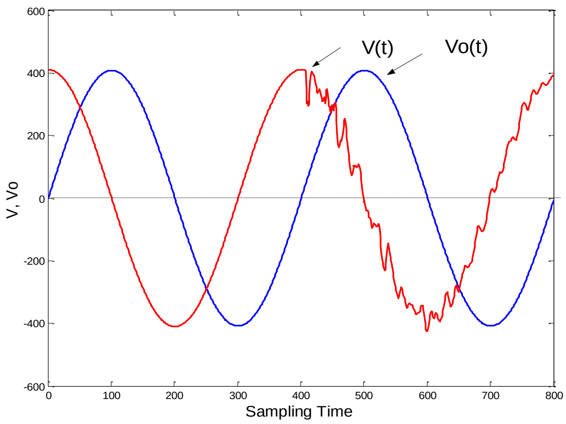

Fig. 1. Normal voltage signal and its complement during abnormal condition

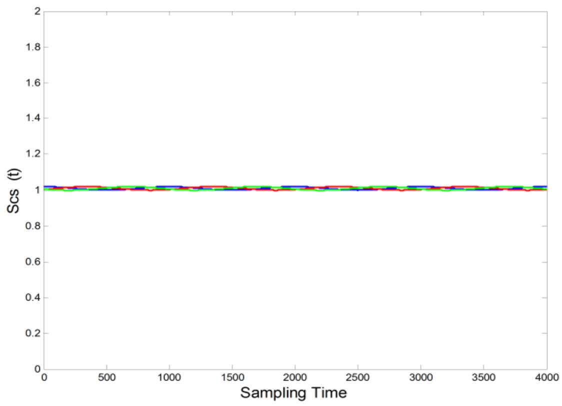

Fig. 2. Discrimination signal during normal operation

TABLE I
PARAMETERS OF SIMULATED MOTOR

Parameter	Value in SI units	Unit
Frequency	60	HZ
Nominal power	2250	HP
Voltage (L-L)	2300	V
Stator resistance	0.029	Ohm
Stator inductance	0.000605	H
Rotor resistance	0.022	ohm
Rotor inductance	0.000605	H
Mutual inductance	0.0346	H
Inertia factor	63.087	$KG.M^2$
Pairs of Poles	4	

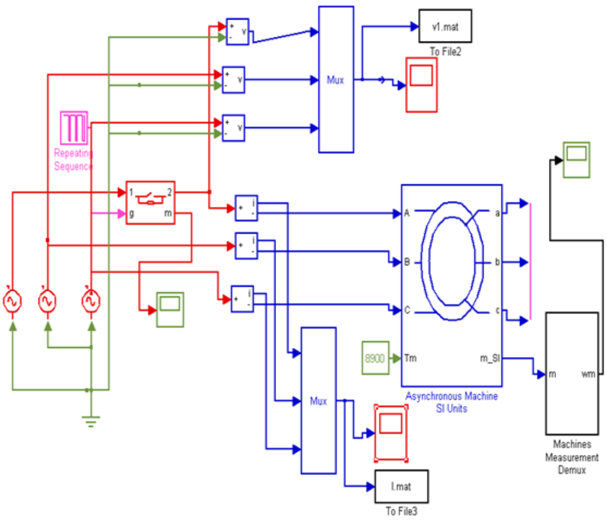

Fig. 3. Matlab simulink model for single phasing of a three phase wound rotor induction machine

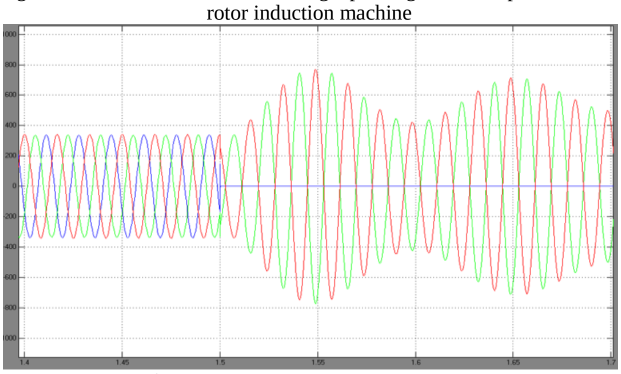

Fig. 4. Deviation of the three phase currents during single phasing at phase-A

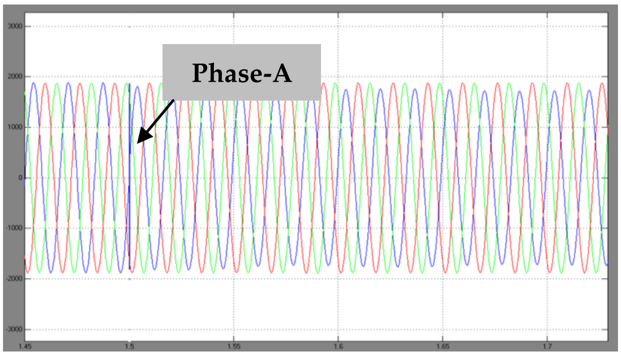

Fig. 5. Three phase voltages during single phasing at phase-A

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IV. FAULT DETECTION CRITERION FOR SINGLE PHASING

To avoid the errors that may occur in the unity relation due to any variation in the peak voltage during normal operation, and since the maximum permissible variation in the peak value of the simulated network's voltage is 5 %, a voltage detection threshold "Ɛ" of a value 0.025 (0.05^2) is used; However, Ɛ will just act as a trigger that initiates the operation of the Cos-Sin tool obtainer to start its mission of detecting fault presence. This is done via calculating the deviation "δ" in S_{CS} (t) in one complete cycle time starting from the instant of fault occurrence, and is given as follows:

$$\delta = \left| 1 - \frac{1}{n}\sum_{i=1}^{n} S_{CS}(i) \right| \quad (4)$$

Where n: is the number of samples of one complete cycle of the system power frequency.

One complete cycle time is used to avoid wrong triggering due to transients.

TABLE II
DEVIATION IN S_{CS} (t) AT DIFFERENT LOAD VALUES OF THE FAULTED PHASE

Load level	δ-faulted phase
No load	0.185
Half load	0.115
Full load	0.101

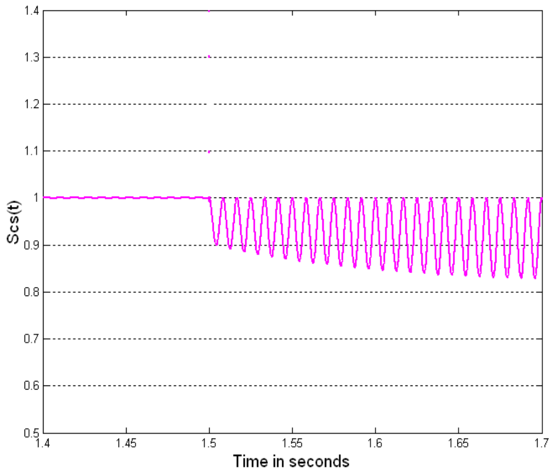

Fig. 6-A. S_{CS}(t) of the opened phase at no load.

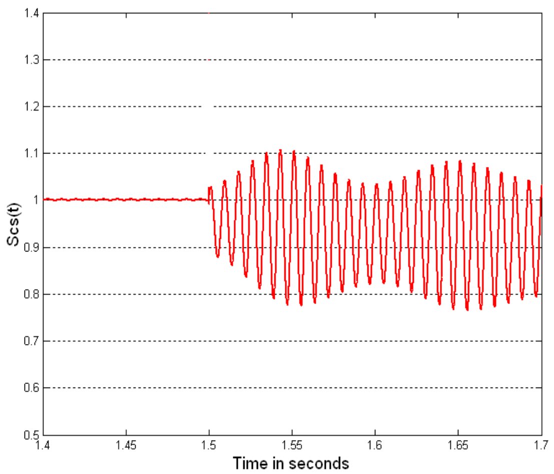

Fig. 6-B. S_{CS}(t) of the opened phase at half load

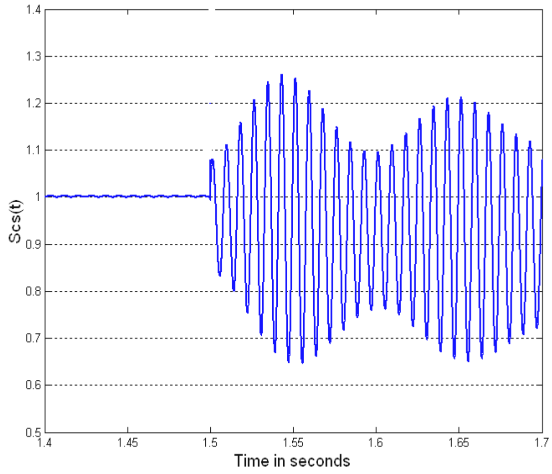

Fig. 6-C. S_{CS} (t) of the opened phase at full load

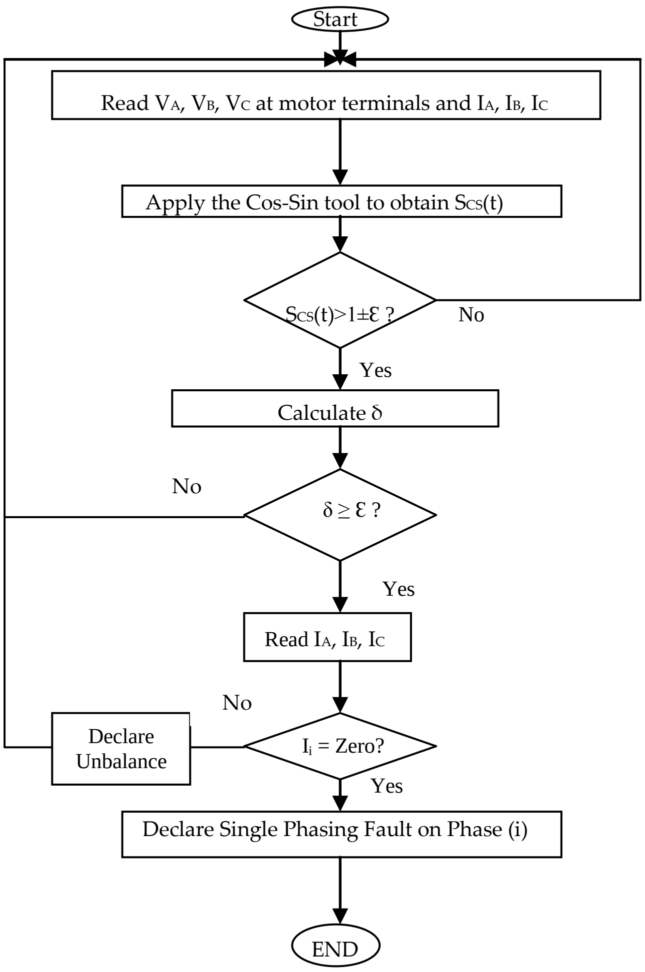

Fig.7. Flow chart of the proposed Cos-Sin tool for single Phasing detection in Three Phase Induction Motors

Figure 7 shows the flow chart of the proposed technique for single phasing fault detection, where both the voltage and current signals are used to differentiate between voltage unbalance and single phasing.

V. PRACTICAL SIMULATION FOR SINGLE PHASING

The suggested tool was practically simulated to check its applicability for implementation in reality. All the network component were modelled where a 400 V power source linked to an auto transformer was used as a supply, a three phase low voltage induction motor that is loaded by a gear

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box was connected to it and a set of both single and 3 phase circuit breakers were connected in series and inserted in between. On the other hand the proposed technique was programmed using the LabVIEW software [8] and all system signals were delivered to the DAQ via voltage and current transformers where they occupied no.6 analogue inputs. Tables III and IV offer the specifications of the data acquisition card and the parameters of the used motor respectively.

Figure 8 presents the connection of the laboratory equipments where the motor phasing condition can be obtained using the single phase circuit breaker shown.

Figure 9 represents the voltage of the opened phase besides its generated complementary signal while figure 10 represents the correspondent currents of the motor during single phasing occurrence respectively. The discrimination signal obtained is illustrated in figure 11.

Table V. provides the deviation in the discrimination signal $S_{CS}(t)$ before and after the single phasing incident.

TABLE III
DATA ACQUISITION DATA

DAQ Specifications			
Series	M	Analogue I/Ps	32 SE/16 DI
PC connection	USB	Analogue O/Ps	4
Sampling	1.25 MS/s	Digital I/Os	48
		Counter-Timers	2

TABLE IV
DATA OF USED MOTOR

Frequency (HZ)	50	Voltage (V)	230/400 Δ/Y
Capacity (KW)	4	Current (A)	14.3-8.2
Cos φ	0.83	RPM	1440
IP	55		

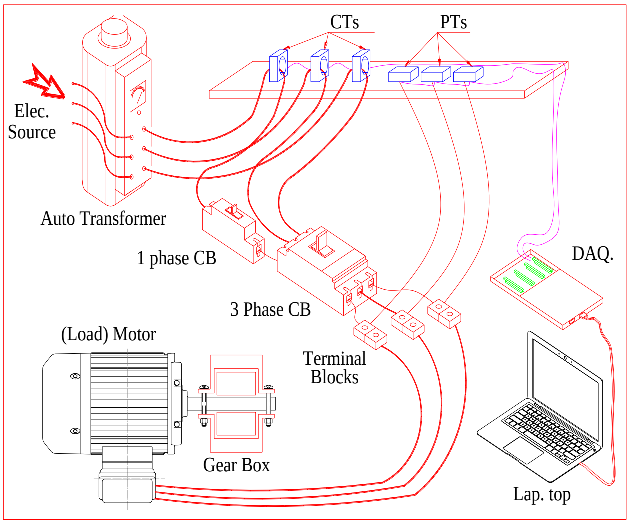

Fig. 8. Laboratory model connection.

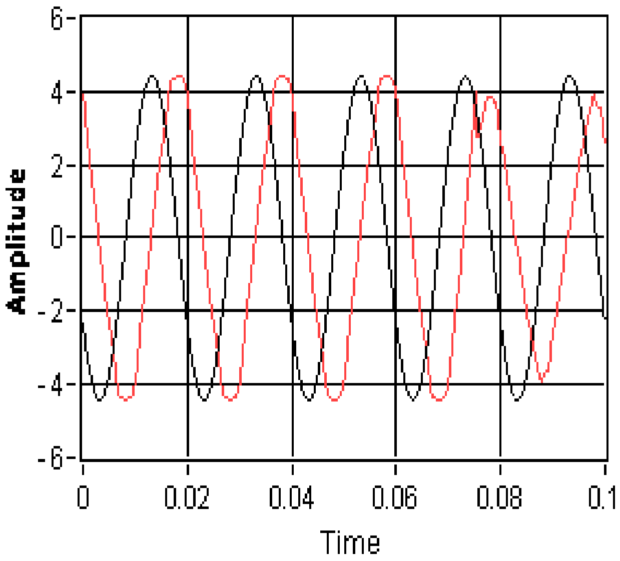

Fig. 9. Opened phase voltage and its generated complementary.

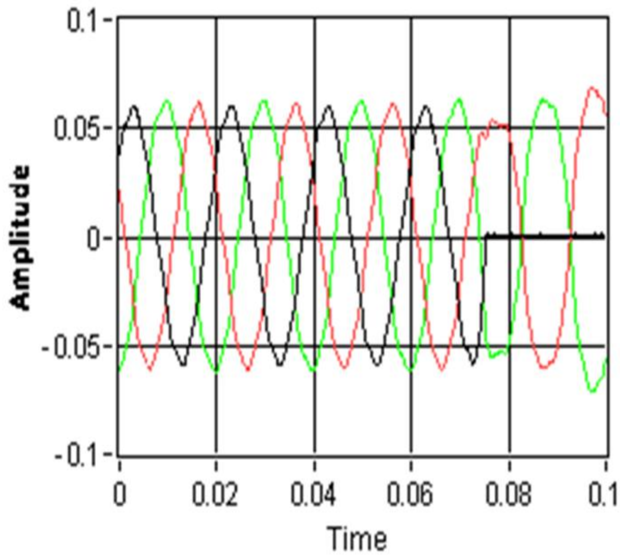

Fig.10. Motor 3 phases currents.

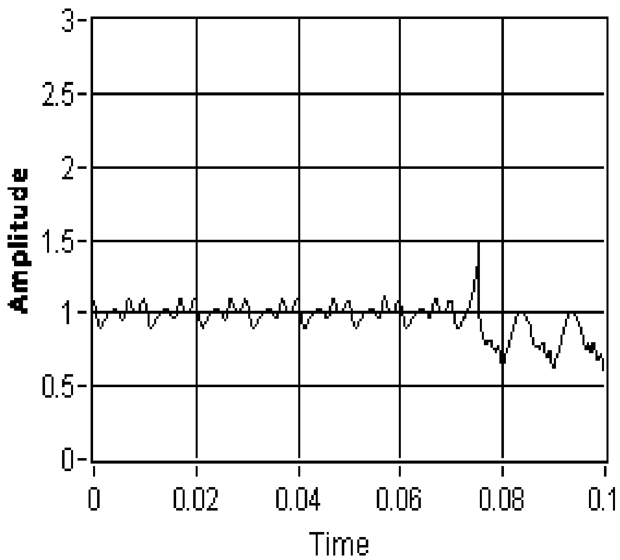

Fig.11. $S_{CS}(t)$ before and after single phasing.

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TABLE V
DEVIATION "δ" DURING SINGLE PHASING INCIDENT AT NO LOAD

Period covered	δ during normal operation	δ After single phasing
Half Cycle	0.05	0.205
Full Cycle	0.04	0.193

The calculated value for δ during normal operation exceeded the threshold value used in simulation owing to the harmonic content in the voltage signal besides the error in detecting the peak value of the original voltage signal every one complete cycle time. That resulted in using another threshold value of Ɛ= 0.06 to avoid any wrong operation. The practical simulation results acquired from the laboratory model almost concurred with the MATLAB simulink simulation outcomes, they both showed the capability of the proposed Cos-Sin tool in capturing the case of single phasing of a motor by using the voltage signal on machine terminals.

VI. Conclusion

The paper introduced a new fault detection tool that can be safely used to detect the case of single phasing in three phase induction motors. The simulation results using Matlab simulink showed complete success of detecting the single phasing case for all load conditions. The laboratory results showed full success of applying the new Cos-Sin tool practically besides showing the capability of detecting the single phasing fault and differentiating between voltage unbalance case and single phasing one. The results of the two implemented simulations showed a large extent of compliance with each other and a great success in detecting the open of one phase case. The suggested tool is characterized by being simple, fast, accurate and executable within digital relaying schemes.

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