Fault Current Discrimination during Induction Motor Starting

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***Abstract*—Induction motors draw a very high current during starting. Over-current relays designated to protect the motors have to accurately discriminate between the starting current and high current occuring during terminal faults. Several techniques have been used for this purpose ranging from simple time delay in relay actuation to AI techniques like neural networks. The main parameters used for discrimination are the amplitude and phase angle of the fundamental component of the current. This paper presents a simulation study of the induction motor starting phenomenon investigating the behaviour of the fundamental component of the current with and without fault. The processing of the current signal involves removing the decaying DC component and estimating the ampitude and phase of the fundamental component of current. The behaviour of the current has been studied using algorithms suitable for implementation on a digital processor platform.**

***Index Terms*—Induction motors, Relays, Signal processing algorithms.**

I. INTRODUCTION

Induction motors constitute a majority of the industrial load in operation today. Due to their robustness, they will continue to be a workhorse of the industry for a long time to come. Induction motor protection has been a major area of study for the industry as well as academia. The over-current relay is the most important sentinel in such a scenario due to the simplicity in application. However the conventional over-current relay is incapable of any form of discrimination of the different types of high currents occuring in such a system. Several starting methods are in use which will reduce the starting current considerably [1]. Still the most preferred method is the DOL (Direct On Line) starting due to its simplicity. Most of the relays in the market use an intentional time delay or reduced sensitivity of the instantaneous element to prevent tripping during start-up. The fault currents due to short circuits can be a cause of concern in hazardous environments. Hence an intentional time delay can lead to catastrophic accidents. With the advent of numerical relays, it is possible to process the current signal with advanced mathematical techniques for discriminating between various conditions. A method based on the variation in amplitude of the fundamental component of current has been presented in [2]. The variation in phase angle between starting of an induction motor and terminal fault was used in a digital protection scheme devised in [3]. Motor starting identification has been done using impedance sensing [4]. The main task in processing the current waveforms is the separation of the different frequency components. Complete frequency characterisation of induction motors have been presented in [5]. The most popular algorithms are the Fourier full cycle and Fourier half cycle algorithms [6]. Wavelet transforms are emerging as strong alternatives to Fourier algorithms and have been dealt with in [7]. This paper attempts to study the induction motor starting phenomenon using MATLAB/SIMULINK. The behaviour of the fundamental component of the current has been studied using digital processing algorithms, as a criterion for fault current discrimination.

978-1-5090-0128-6/16/$31.00 © 2016 IEEE

II. INDUCTION MOTOR STARTING

A. Starting and Fault Currents

The starting current of induction motor may persist for several seconds to minutes and may be as high as 5.5-5.6 times the full load current [8] in the case of DOL starting. When the motor capacity is less or when the power network is 'stiff', the preferred method of starting is the DOL starting. The starting current is characterised by the presence of a DC component as well as the fundamental frequency component in the absence of any space harmonics. The DC component of the starting current depends on the X/R ratio of the induction motor which is usually in the range of 10-20 [9]. The fundamental component has a varying power factor which is usually in the range of 0.15-0.2 [9]. The persistance of the starting current depends on the load conditions and the acceleration of the motor. Higher acceleration causes lesser duration for the starting current. The starting current has been studied by modelling a motor circuit in MATLAB/SIMULINK. A 3.3 kV, 4 pole motor driving a fan load has been modelled. The fan load varies directly with the square of the angular velocity. Hence the motor accelerates at a high rate in the beginning due to less load. The parameters have been chosen based on an actual motor used in the industry. The block diagram of the circuit model is given in Fig 1. The starting current waveform along with phase voltage for initial few cycles is given in Fig 2. The presence of space harmonics is not considered in the simulation. Hence the motor current consists only of the decaying DC component and the fundamental frequency component as mentioned earlier. The current during a terminal fault is not very different from the starting current in the initial stages where it will be having a decaying DC component. On the contrary, the amplitude of the fundamental component will not be decaying significantly with time as in the case of

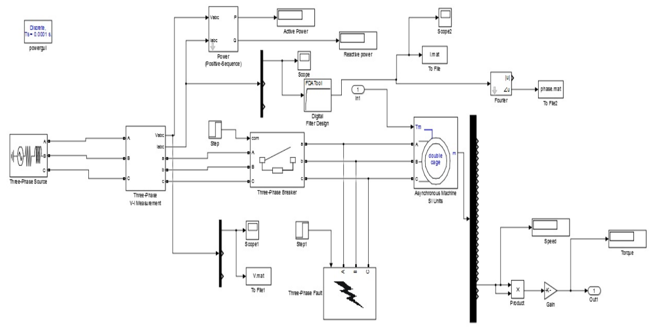

Fig. 1. Modelled System in MATLAB

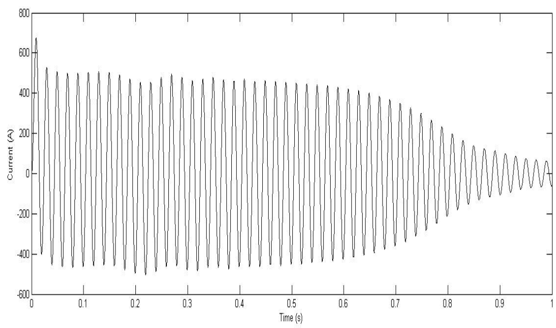

Fig. 2. Starting Current Waveform

motor starting. The fault current in case of a terminal fault with a resistance of 3Ω is given in Fig 3. This is to ensure that the fault current and starting current are comparable in magnitude which would present an ambiguous scenario for the overcurrent relay.

B. Fundamental Component of Current

The main difference between the fault and starting currents is in the behaviour of the fundamental component. The fault current sees a constant fundamental component unless it is occuring close to a synchronous generator. The amplitude and phase angle of the fundamental component varies with respect

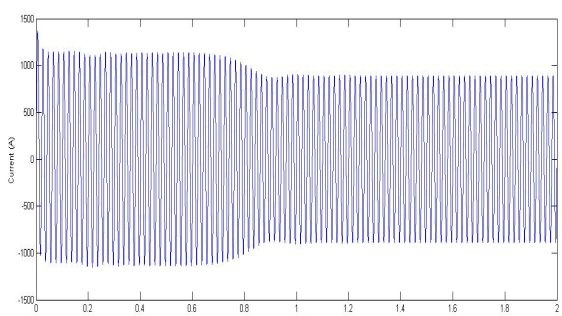

Fig. 3. Fault Current Waveform

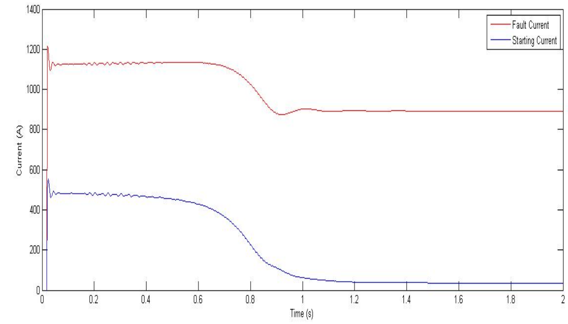

Fig. 4. Variation in Amplitude of Fundamental Component of Current

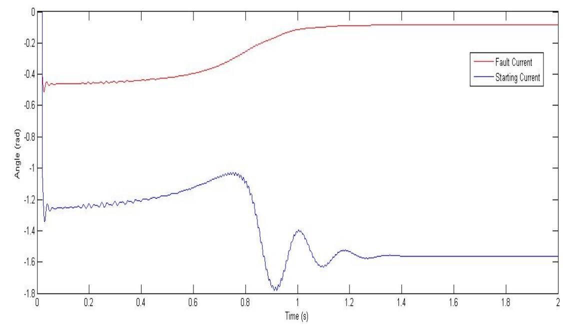

Fig. 5. Variation in Phase angle of Fundamental Component of Current

to time considerably in the case of the starting current.

III. ESTIMATION ALGORITHMS

As seen in the previous section, the fundamental component of the current holds the key for successful discrimination between fault and starting conditions. There are several algorithms for the estimation of amplitude and phase angle using the sampled values of current on a digital processing platform. The Half-Cycle Fourier and Full-Cycle Fourier Algorithms are the conventional solutions but require a higher number of samples and consume more processing time. From the perspective of digital protection, the computational load imposed by the algorithms is also of prime importance. Hence other algorithms requiring lesser number of samples will be investigated here. The variation in amplitude and phase angle of the starting current and fault current has been determined using Fourier full cycle algorithm and is given for reference in Fig 4 and Fig 5 respectively.

A. Effect of decaying DC component

The decaying DC component which is the inevitable effect of the machine and cable inductances is the major source of error in the estimation algorithms. The removal of the DC component facilitates the use of any of the above mentioned algorithms. Wavelet transforms are mostly used currently for the removal of the DC component. The discrete wavelet transform can act as an alternative to the Fourier algorithms with far lesser number of samples. The Daubechies-4 algorithm

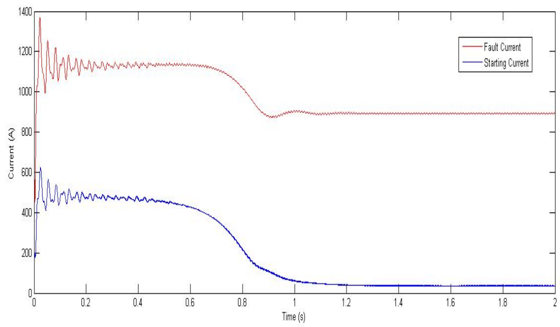

Fig. 6. Amplitude during starting and fault determined by Mann Morrison Algorithm

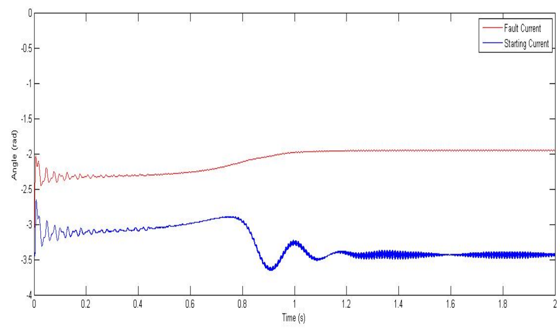

Fig. 7. Phase Angle during starting and fault determined by Mann Morrison Algorithm

has been found to be suitable for digital relaying applications in power systems [12]. IIR filters with sufficient order can provide another alternative. As part of this study, a tenth order IIR filter was used for removal of the DC component. Morphological Transforms are also used for the removal of the decaying DC component [10].

B. Mann-Morrison Algorithm

The Mann-Morrison algorithm uses two samples to calculate the amplitude and phase angle of a purely sinusoidal waveform. The algorithm calculates the derivative and hence is prone to instabilities in case of disturbances in the waveform [10]. The amplitude is given by

$$I[k] = \sqrt{(i[k])^2 + ((i[k+1] - i[k])/\Delta t \omega_0)^2} \qquad (1)$$

The phase angle is given by

$$\phi[k] = tan^{-1}(\frac{i[k]\omega_0 \Delta t}{i[k+1] - i[k]}) \qquad (2)$$

The recorded current waveform has been processed by using Mann Morrison algorithm. The variation in amplitude of the fundamental current during starting and fault conditions is given in Fig 6 and variation in phase is given in Fig 7.

C. Rockfeller Udren Algorithm

The Rockfeller Udren Algorithm is also used for estimating amplitude and phase angle in phasor measurement applications. This algorithm makes use of three sample points as well

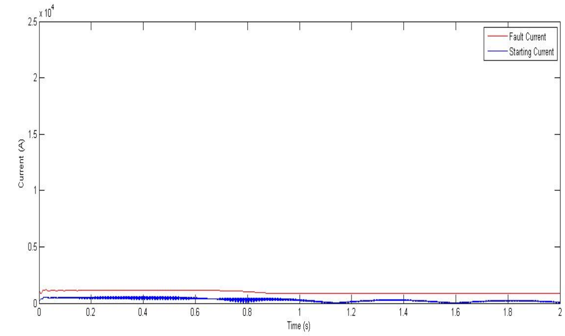

Fig. 8. Amplitude during starting and fault determined by R-U Algorithm

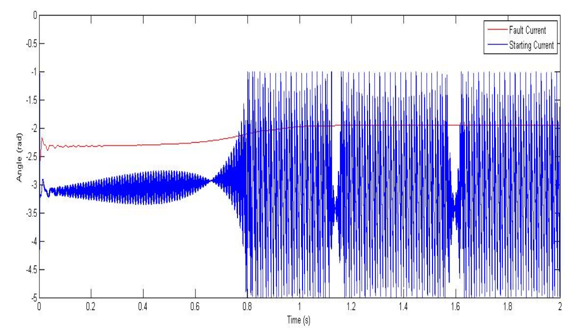

Fig. 9. Phase angle during starting and fault determined by R-U Algorithm

as the first and second derivatives and hence is more prone to disturbances in the input signal while at the same time giving higher accuracy. The first and second derivatives are obtained using central difference approximations [10]. One key benefit of this algorithm is that the constant DC offset if present will not effect the accuracy of the algorithm [11]. The amplitude is given by

$$I[k] = \frac{1}{\omega_0}\sqrt{i'[k]^2 + \frac{i''[k]}{\omega_0}^2} \qquad (3)$$

The phase angle is given by

$$\phi[k] = -tan^{-1}(\frac{i''[k]}{\omega_0 i'[k]}) \qquad (4)$$

The variation in amplitude and phase angle for starting and fault currents are shown in Fig 8 and Fig 9 respectively. The amplitude plot shows a shoot-up in the value at the beginning while the phase plot of the starting current shows oscillations at zero crossings. This will be due to the presence of the second derivative in the equations. Both the algorithms mentioned uses two to three samples of data and are sensitive to the apparent sampling rate [10]. Other short window algorithms such as Miki - Makino and Gilbert - Shavolin [11], are also suitable for similar applications.

D. Discrimination of Fault Current

The amplitude and phase of the fundamental component of current has been obtained by using both the algorithms.

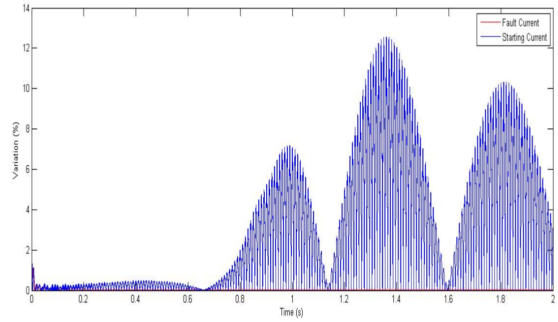

Fig. 10. Variation in amplitude

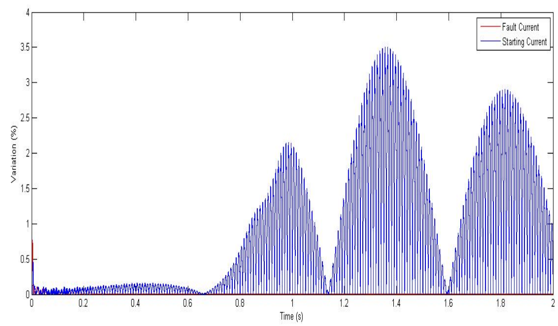

Fig. 11. Variation in phase angle

Mann Morrison algorithm gave more stable values compared to Rockfeller Udren algorithm. The values determined using Mann Morrison algorithm were used to calculate the variation in amplitude and phase using the present value and the previous value. This will not consume too much memory or processing power. The variation in amplitude of the fault and starting currents is given in Fig 10 and that of phase is given in Fig 11. Due to the initial perturbance, the first few samples are not included in the plot. The percentage variation in amplitude after different cycles is given in Table I and that in phase angle is given in Table II. From the above tables, it is clear that

TABLE I
PERCENTAGE VARIATION IN AMPLITUDE

No. of cycles	Percentage variation in amplitude for fault current	Percentage variation in amplitude for starting current
5	0.07	0.25
10	0.04	0.31
50	0.01	7.17
100	0.008	3.10

using the variation in amplitude or phase angle as the criterion, effective discrimination is possible between fault currents and starting currents of comparable magnitudes after atmost 10 cycles of current waveform.

IV. CONCLUSION

The starting current phenomenon in induction motors has been studied using a MATLAB/SIMULINK model using a fan

TABLE II
PERCENTAGE VARIATION IN PHASE ANGLE

No. of cycles	Percentage variation in phase for fault current	Percentage variation in amplitude for starting current
5	0.03	0.03
10	0.004	0.09
50	0.007	2.10
100	0.004	1.00

load. The starting current has been contrasted with fault current at the machine terminals. The amplitude and phase angle of the fundamental component of current has been found to be the key factors in successful discrimination of fault current from starting current. The behaviour of the current was studied using Mann Morrison algorithm and Rockfeller Udren algorithm. Upon comparing the behaviour of the current in the two cases, it has been observed that it is possible to discriminate between the two conditions after atmost 10 cycles of ac current.

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