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Current Harmonics Analysis of Inverter-Fed Induction Motor Drive System under Fault Conditions

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Abstract—— This paper presents harmonic analysis of motor current signatures under different fault conditions of medium and high power Variable Frequency Drive (VFD) systems. Computer simulation of a VSI fed induction motor based on constant voltage/frequency (V/f) operation is implemented using Powersim (PSIM) simulation software. Frequency response characteristics of motor currents are compared to analyze fault conditions in motor drive system.

***Index Terms*— Induction Motor, Fast Fourier Transform, Motor Current Signature Analysis, PWM Inverter, Frequency Response.**

I. Introduction

NDUCTION motor for many years has been regarded as the workhorse in industrial applications. In the last few decades, the induction motor has evolved from being a constant speed motor to a variable speed, variable torque machine. Its evolution was challenged by the easiness of controlling a DC motor at low power applications. When applications required large amounts of power and torque, the induction motor became more efficient to use. With the invention of variable voltage, variable frequency drives (VVVF), the use of an induction motor has increased.

Variable frequency Voltage Source Inverters (VSI's) are widely used to control the speed of 3-phase squirrel cage Induction Motors (IM) over a vide range by varying the stator frequency. In particular the VSI's are widely preferred in industries for individual medium to high power variable speed drive systems, driving a group of motors connected in parallel at economic costs.

Most modern variable frequency drives operate by converting a three-phase voltage source to DC using rectifier. After the power flows through the rectifiers it is stored on a dc bus. The dc bus contains capacitors to accept power from the rectifier, stores it, and later deliver that power through the inverter section. The inverter contains transistors that deliver power to the motor. The "Insulated Gate Bipolar Transistor" (IGBT) is a common choice in modern VFDs. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. The IGBT uses "pulse width modulation" (PWM) technique to simulate a sine wave current at the desired frequency to the motor.

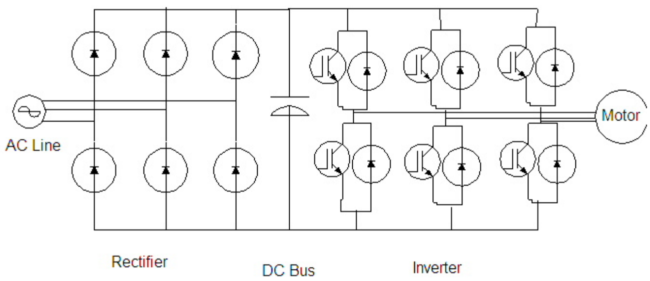

Fig.1. Block diagram of IM drive system

Present investigations are mainly concerned with constant 'V/f' control operation, provided by the 6-step VSI which excites the three phase stator winding of IM. A simulation model of such induction motor drive system is developed and its dynamic response is verified by observing torque, current and speed responses to establish acceptability of the model. Then a series of simulations are carried out for three different post fault conditions which are: open circuiting of one of the six IGBTs gate signal, blowing off one IGBT in the inverter module, line to ground fault at one of the motor phase terminals. Under these fault conditions time domain and frequency domain analyses are performed to discriminate fault types.

II. Simulation Model

Computer simulation is the discipline of designing a model of an actual or theoretical physical system, executing the model on a digital computer, and analyzing the execution output. Simulation model of the motor drive system developed in Powersim (PSIM) [1] has been used for this study as shown in the Fig. 2. A three phase supply source along with source impedances to make it non-ideal has been included in the model. First stage is an uncontrolled rectifier followed by dc link capacitor and reactor. Induction motor has been controlled by an inverter made of IGBT switches

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[3-6].Control signals for switches are generated by a sinusoidal pulse width modulator (SPWM) controller. To keep 'V/f' ratio constant, motor terminal voltage magnitude and frequency are adjusted by setting controller parameters. In this model induction motor is subjected to drive a constant torque load. Motor current, voltage, speed, developed electromagnetic torque along with supply main currents are sensed and analysed.

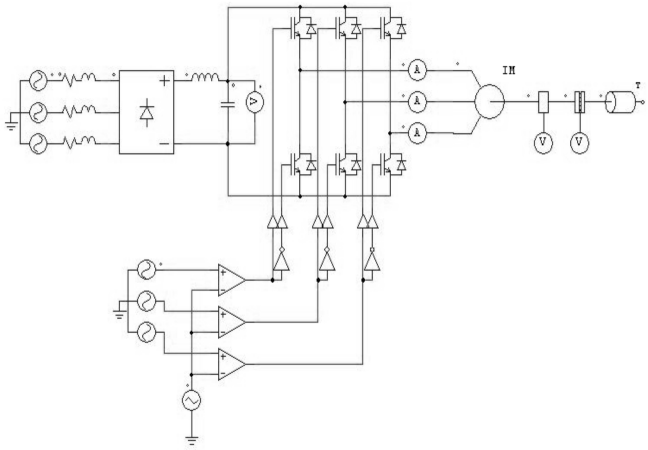

Fig. 2. Simulation model circuit diagram

III. Validation of Simulation Model

After construction of the simulation model the performance and reliability of the model have been verified by analyzing the following profiles [2]:

1. Dynamic responses of motor drive system
2. Steady state motor current
3. Developed electromagnetic torque
4. Supply current

After simulating the model, profiles as shown in Fig.3. are obtained. In Fig. 3 the dynamic responses of motor drive system (1) are shown and in Fig. 4 remaining verifications (2-4) are shown.

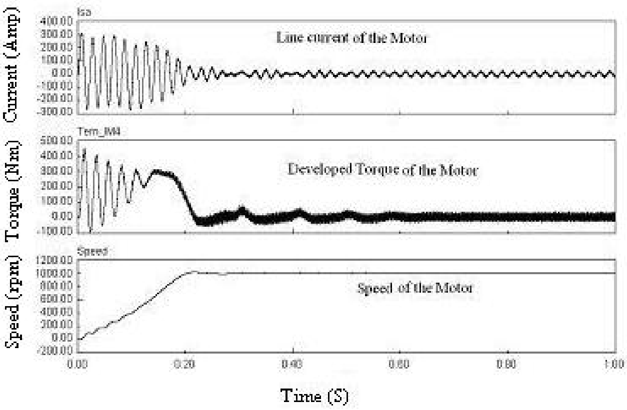

Fig.3. Dynamic responses of motor drive system

From the above profiles it can be concluded that the model is unambiguous. For further checking Fourier analysis of motor current and supply current can be analyzed [7-9]. In the Fig. 5 FFTs of motor current and supply current of the model is shown.

Harmonics that is multiple of 2 cancels out each other. The same is true for 3rdorder harmonics (3rd, 6th, 9th etc.). Because the power supply is 3 phase, the third order harmonics cancel each other out in each phase. This leaves only the 5th, 7th, 11th, 13th etc. The magnitude of the harmonics produced by a VFD is greatest for the lower order harmonics (5th, 7th and 11th) and drops quickly as we move into the higher order harmonics (13th and greater).Hence the simulation model is acceptable and can be considered as a healthy motor-drive system.

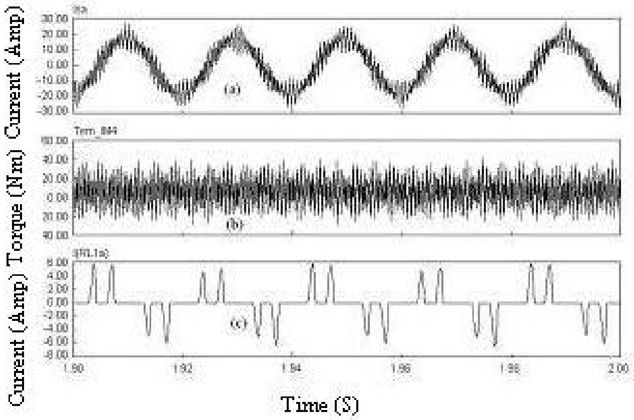

Fig.4. Steady state motor current (a), developed electromagnetic torque (b), supply current(c) profiles of healthy motor-drive system.

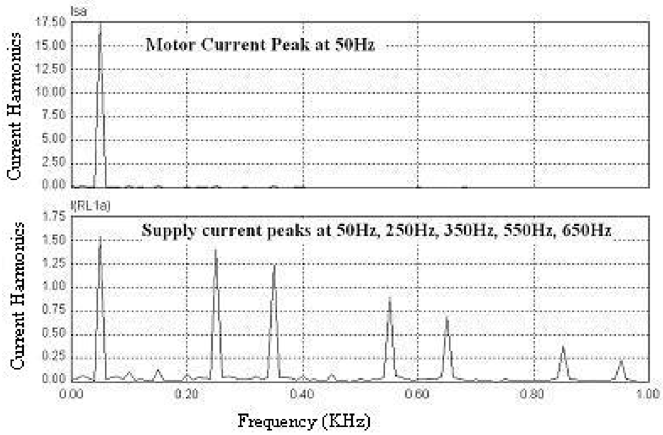

Fig.5. FFTs of motor current and supply current of model

IV. Conditions Under Study

In the present work, simulation studies have been performed on a 3-phase induction motor. Here the fault conditions in the simulation model are created in the three following ways.

1. Fault at one of the six IGBTs gate terminals.
2. Blowing off one IGBT in the inverter module
3. Line to ground fault at one of the motor phase terminals

V. Simulation Results and Analysis

A. Fault at one of the six IGBTs gate terminals (case -1)

In this case the analogy applied in the simulation is to make one of the six IGBTs gate terminals to be grounded. In fact, here, upper IGBT of phase A is grounded for the purpose of simulation under the specified condition. The motor current profiles of the three phases are then recorded. They are shown in the Fig. 6 and 7.

The discrete Fourier transform can be computed efficiently using a Fast Fourier Transform (FFT) algorithm. Fig. 8 is the frequency domain transformed signal after FFT of Phase A current signal obtained from the model, simulated under specified condition in case 1. Fig. 9 shows the FFT of current signal of Phase B and C i.e. the healthy phases.

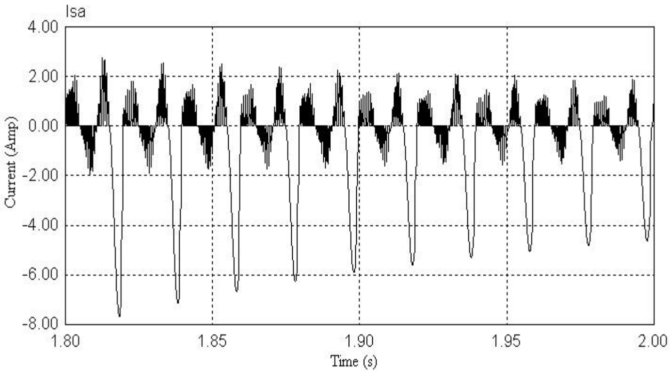

Fig.6. A-phase motor current profile with open circuited gate control signal of upper IGBT in phase A

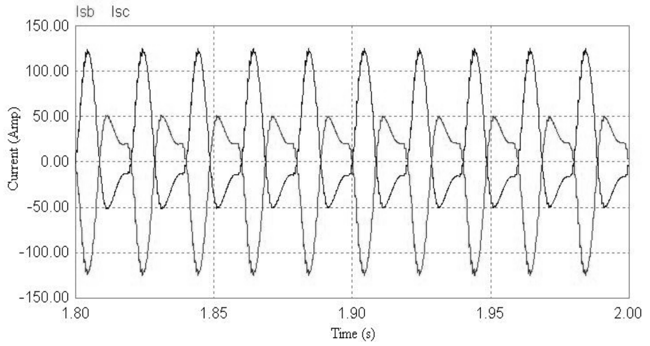

Fig.7. B&C-phase motor current profiles with open circuited gate control signal of upper IGBT in phase A

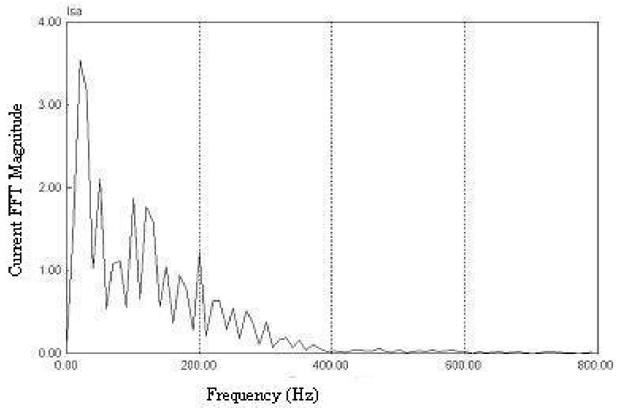

Fig.8. A-phase motor current profile's FFT with open circuited gate control signal of upper IGBT in phase A

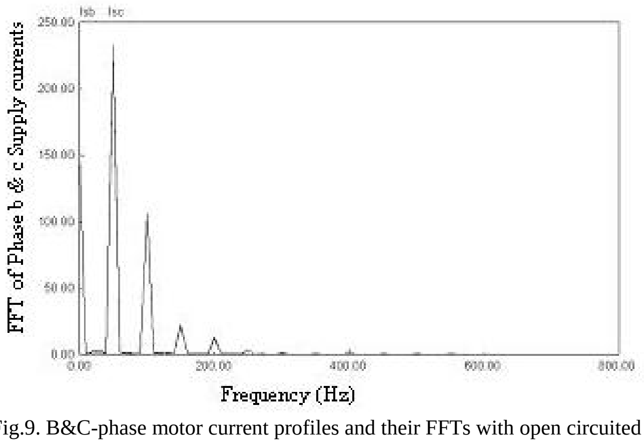

Fig.9. B&C-phase motor current profiles and their FFTs with open circuited gate control signal of upper IGBT in phase A

From Fig. 8 it is clear that the FFT signature of the phase A is not matching with the healthy motor FFT signature.

In the specified condition the typical supply current profiles are also recorded. This is shown in the Fig. 10. After recording profiles of the supply current FFT algorithm is applied to the Fig. 10. FFT signatures are shown in the Fig. 11.

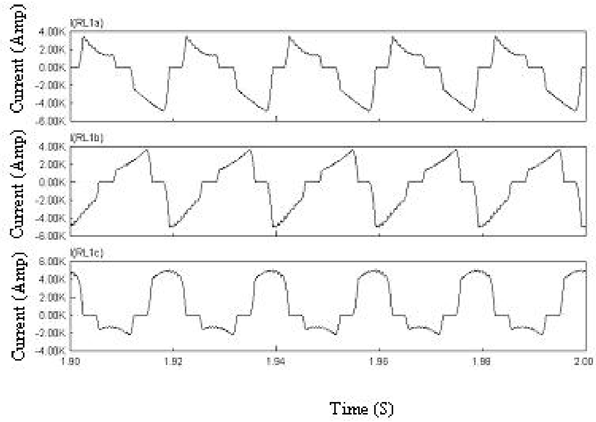

Fig.10. Momentary Supply current profile of Phase A, B&C during the faulty environment specified.

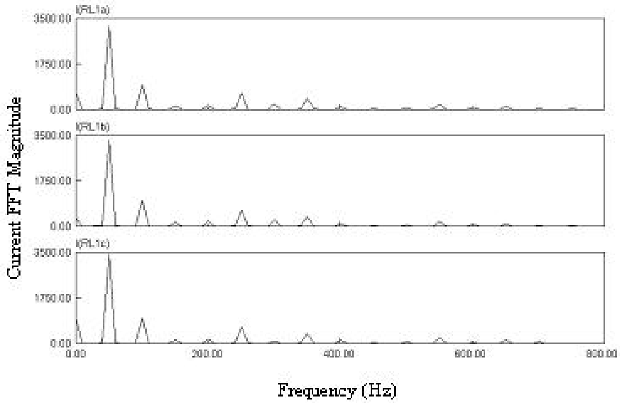

Fig.11.FFT of supply current profile of Phase A, B&C during the faulty environment specified

B. *Blowing off one IGBT in the inverter module (case -2)*

To simulate this condition in the model the upper IGBT in the phase A has been replaced by a high resistance. Introduction of the high resistance with one of the six IGBTs is equivalent to the open circuiting of one of the six IGBTs. The motor current signature is recorded and FFT algorithm is applied to it to analyze and compare with the healthy motor drive system. The motor current signatures and their corresponding FFT profiles are shown in the Fig. 12 and Fig. 13 respectively.

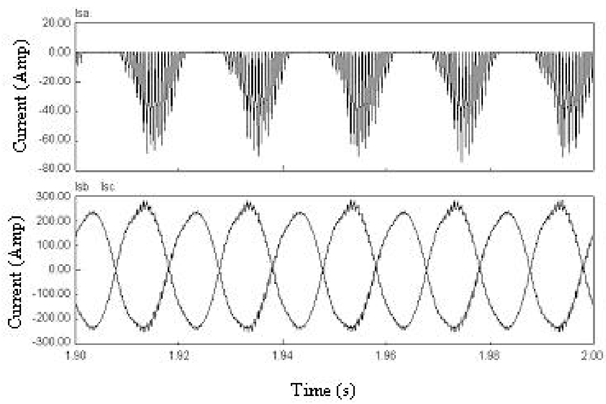

Fig.12. Motor current profile of Phase A, B&C during the faulty condition specified.

The resistance incorporated with the upper IGBT in the model is in range of meg-ohm. Other parameters of model are unchanged during the simulation.

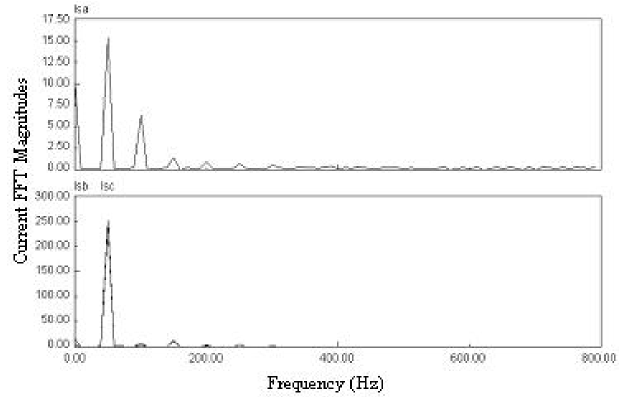

Fig.13. FFT of motor current profile of Phase A, B&C during the faulty condition specified.

The supply current profile and their FFT are recorded in Fig. 14 and fig. 15 respectively.

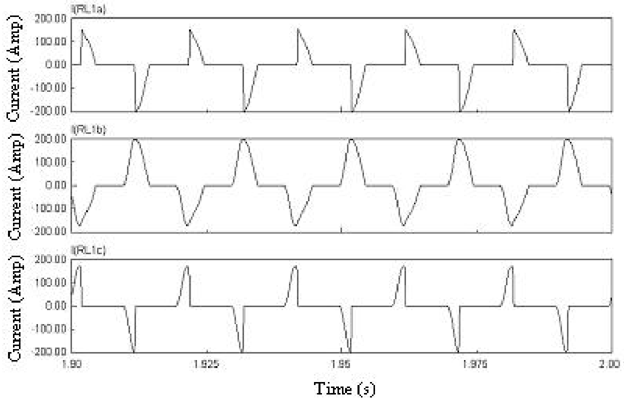

Fig.14. Supply current profile of Phase A, B&C

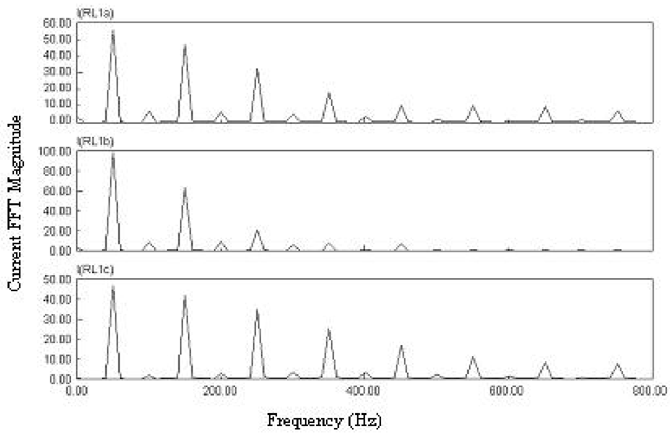

Figure 15: FFT of Supply current profile of Phase A, B&C

C. Line to ground fault at one of the motor phase terminals (case -3)

In this type of simulation a switch is introduced in the phase C. Initially the switch is open i.e. phase C is a healthy one. With the help of the PSIM software after the transient period switch is being closed i.e. line to ground fault at Phase C is created. After creating the specified environment matching with case 3 the motor current profiles are recorded which are shown in the Fig. 16. FFT algorithm is applied to the Fig. 16 for the purpose of frequency domain analysis. Frequency domain profiles of three motor current signatures are shown in the Fig. 17.

Similar to the above two cases supply current to motor is simulated as shown in Fig.18. and their FFT profiles are recorded by applying FFT algorithm and their frequency domain profiles are shown in Fig. 19.

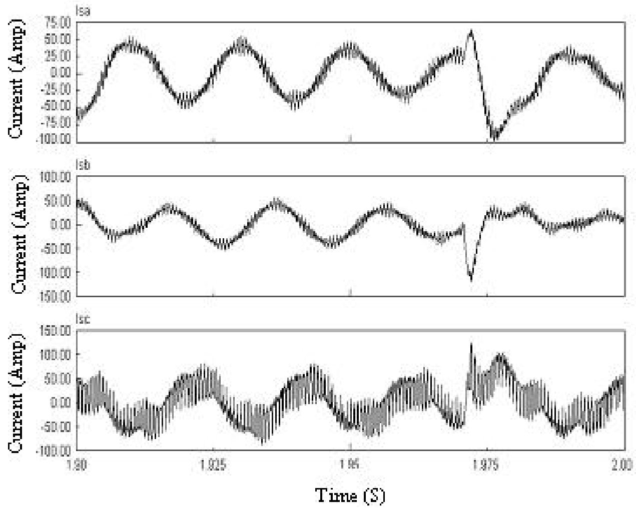

Figure 16: Motor current profile of Phase A, B&C

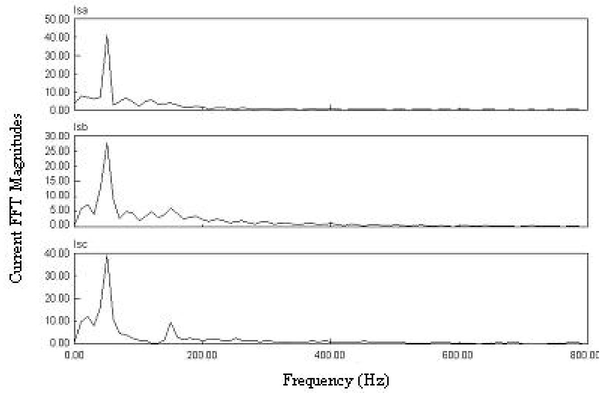

Fig.17. FFT of motor current profile of Phase A, B&C

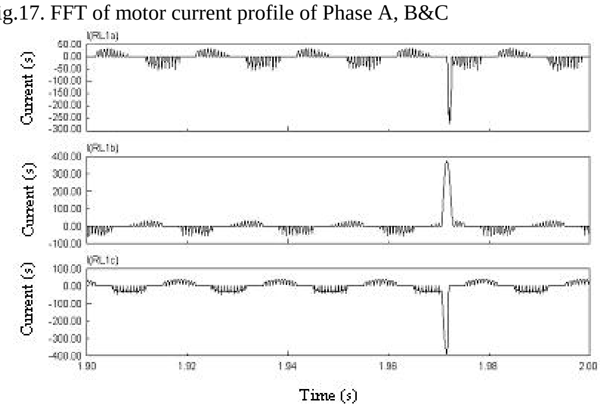

Fig.18. Supply motor current profile of Phase A, B&C

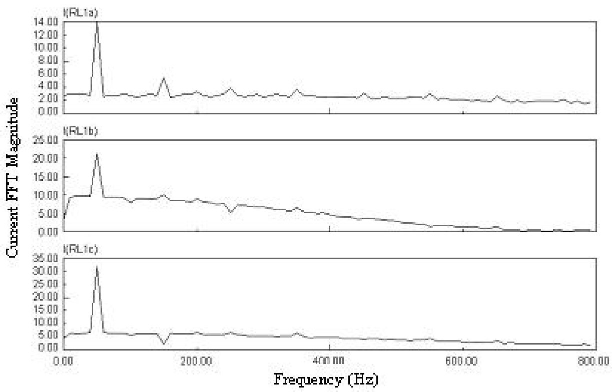

Fig.19. FFT of supply current profile of Phase A, B&C

VI. CONCLUSION

In this study frequency domain analysis technique has been used as a tool to discriminate different fault states. The frequency responses for different fault conditions are studied and compared to establish the utility of FFT algorithm to identify the nature of fault. Frequency responses under three different fault conditions are distinctly different which are precisely presented in this paper. Hence, as a preliminary study few simple fault conditions are analyzed and aiming to use the same approach for simulating and identifying some more complicated fault situations of modern VFD systems.

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