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Simulation of Active Front End Converter Based VFD for Induction Motors

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ABSTRACT : Insulated Gate Bipolar Transistor based active front-end converters are widely utilized by industries due to the advantages of bi-directional power flow, unity power factor, low harmonic distortion of the line current, and smaller filter size. In this paper, the MATLAB Simulink model and control of the active front end converter system based VFD for induction motors are presented .

KEYWORDS: Variable frequency drive(VFD),Space vector pulse width modulation(SVPWM),Active front end converter

I. INTRODUCTION

Solid State Variable Frequency Drive is an adjustable speed drive used in electromechanical drive systems to control AC motor speed and torque by varying input frequency and voltage. Over the last four decades power electronics technology have improved performances in the field of VFD's through advances in semiconductor switching devices,drive topologies,simulations and control techniques and control hardware and software. They have already become an integral part of many process plants and their usage is on the rise in industrial, commercial and residential applications. The high dynamic performance, increased flexibility and possible energy savings are among the most important features driving the VFD market.They are also economical, reliable,highly flexible in their use and are rapidly becoming an important segment of the overall industrial and commercial loads seen by most distribution networks.While these new loads do contribute to the overall load growth of the electric utility industry, it does also create potentially severe problems in terms of the "electrical pollution". In addition, these loads are often rather sensitive to voltage dips and short supply interruptions . The effects of these events may include the total disconnection of the particular VFD load thereby causing loss of revenue for the particular user. It will cause a lost of production and may also incur significant restart costs depending on the particular industrial process in which the VFD is used.Hence reliable operation of these VFD's have to be guaranteed in order to avoid malfunctioning or interruption of the process.Also VFD's consume about one third of world's electrical energy and thus its global market penetration is still relatively small.This highlights the need for energy efficiency improvement in new VFD installation.

The standard solution for industrial controlled drives typically have an ac–dc conversion stage followed by dc–ac conversion feeding an induction machine.Traditionally diode rectifiers are used for ac–dc conversion. These rectifiers can only produce a constant DC voltage, which is a function of the system voltage. A thyristor rectifier can be used to produce variable dc output voltage. But, both these rectifiers behave as nonlinear loads. The currents drawn by the rectifiers include a fundamental (or line frequency) component and harmonic components. The voltage drop across the line inductance due to the harmonic currents distorts the mains voltage. Consequently, the other loads connected to the mains are also fed with a distorted voltage.A pulse width modulated (PWM) rectifier draws near sinusoidal currents from the ac mains. Also, the dc output voltage can be regulated, and the input power factor is adjustable. Replacing the diode bridge by an IGBT bridge allows to address regenerative or recuperative operation,reduction of harmonic currents and control of reactive power. For such a converter, the power can also flow in either direction, which is required in many motor drive applications. Since the converter is typically connected in the line-side of a motor drive, this is called a line-side converter or front-end converter (FEC).Active front end converters are becoming an interesting solution for power factor correction and low frequency current harmonic elimination in static power conversion systems. Due to current harmonic restrictions in power distribution systems, active front end rectifiers offer a viable alternative to replace traditional six pulse diode rectifiers in frequency changers. Active front end (AFE) rectifiers have been investigated for the last decade and provide a good solution for the rectifying stage in frequency changers. The main characteristics of AFE rectifiers are the generation of reduced low frequency line current harmonics, due to the use of pulse-width modulation (PWM), a better overall power factor, substantially smaller filter requirements, and inherent regeneration capabilities. Moreover, with the development of new high voltage and current gate controlled semiconductors, such as Insulated Gate Bipolar Transistors (IGBTs) and Integrated Gate Controlled Thyristors(IGCTs),and with the implementation of multilevel structures, PWM-AFEs rectifiers are becoming the standard solution for large-power medium-voltageVFDs and are responsible of the drastic increment in the market share of PWM voltage-source controlled converters.

This paper presents a complete MATLAB Simulink model of an active front end converter based Variable frequency drive for induction motors.

II. PROPOSED SYSTEM

The proposed model consists of a Front End Converter, DC link, Inverter and auxiliary motor loads. The single phase AC supply is given as the input to the Front End Converter. Fig 1 shows the schematic diagram representation of the proposed system. The FEC converts the single phase invariant AC supply to DC which is connected to the grid. This DC is converted to desirable AC voltage by the inverter and fed to the motor loads.

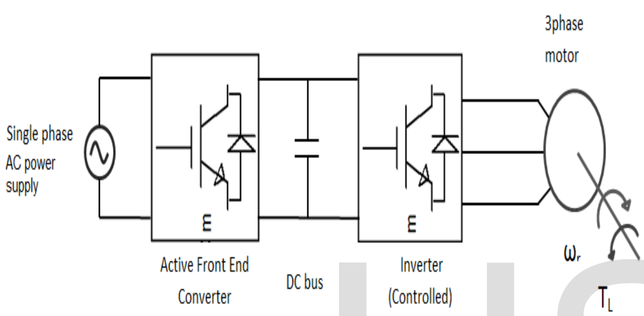

Fig.1 Schematic diagram of the proposed system

FEC Operation is indicated in fig 2.The converter consisting of a single-phase bridge, a high capacitance on the dc side and a single-phase inductor in the line-side. The voltage at the midpoint of a leg or the pole voltage Vi is pulse width modulated (PWM) in nature. The pole voltage consists of a fundamental component (at line frequency) besides harmonic components around the switching frequency of the converter. Being at high frequencies, these harmonic components are well filtered by the line inductor. Hence the current is near sinusoidal. The fundamental component of Vi controls the flow of real and reactive power.

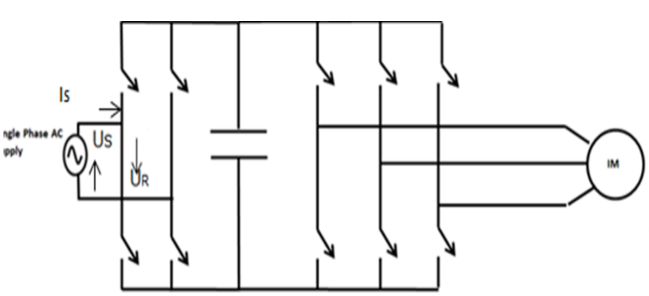

Fig 2: VFD with active front end converter

The active power flows from the leading voltage to the lagging voltage and the reactive power flows from the higher voltage to the lower voltage. Therefore, both active and reactive power can be controlled by controlling the phase and magnitude of the converter voltage fundamental component with respect to the grid voltage.
The following phasors depict the lagging,leading and upf operation.

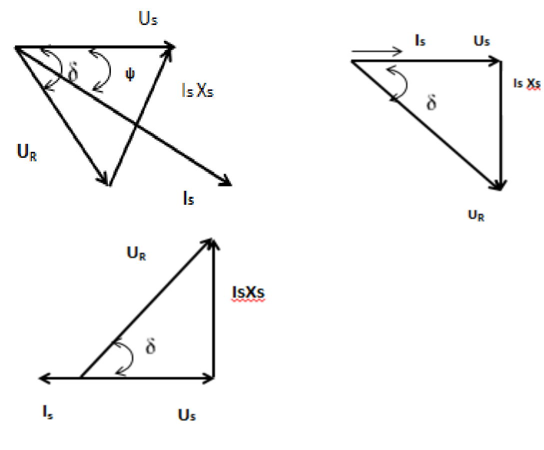

Fig 3 Phasor diagrams of an FEC under different operating modes: 3(a)lagging pf 3(b) unity pf and 3(c) regeneration at unity pf.
Figure 3(a) illustrates the operation of FEC at lagging power factor. The real power flows from the ac to the dc side. Since U_s is greater than U_R, the reactive power flows from the mains to the converter side. Figure 3(b) corresponds to unity power factor operation. As the grid voltage leads the converter pole voltage, real power flows from the ac side to the dc side. Figure 3(c) shows the operation under regenerative mode with the real power flowing from the dc to the ac side and at unity power factor.

Control Algorithm of FEC

The working of Front End Converter is carried out by the control topology as shown in Fig 4.The algorithm comprises of DC bus voltage controller followed by current limiter, unit vector generation, a current controller and a voltage limiter.

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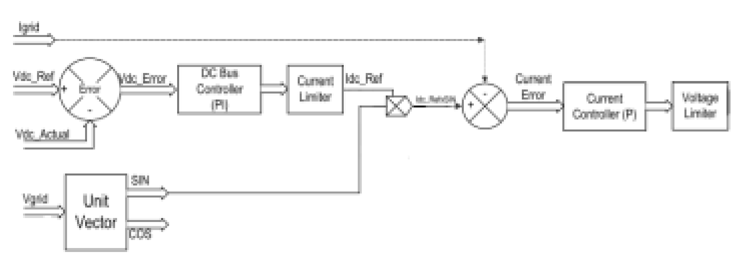

Fig 4 FEC control algorithm

The Vdc error is fed to the DC bus controller which is basically a PI controller whose output is limited to a reference value. Sine component among the unit vectors generated is multiplied to the Idc ref. Now the error in the grid current is controlled using a P controller and limited to a designed voltage value.

Unit Vector Generation

Unit vectors are Sine and Cosine signals which are 90^0 displaced irrespective of variation in grid frequency. , the quantities sinθ and cosθ are the components of a revolving unit vector are required. These quantities should have the same frequency as that of the system voltage The unit vector generation involves low pass filters, and hence considerable dynamics and settling time. Fig5 below shows the simplified block diagram for the unit vector generation.

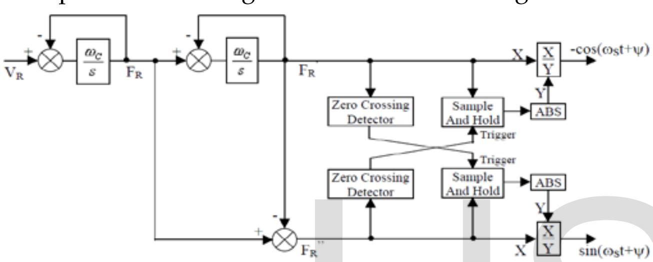

Fig 5 Unit vector generation

Signals FR′ and FR′′ are displaced by 90^0, F_R′ reaches the peak when F_R′′ crosses the zero value. Similarly, F_R″ reaches peak at the zero crossing of F_R′. Therefore, by identifying the zero crossing point of F_R′ and F_R″, their peak can be measured. Thus the sinθ and cosθ, the components of revolving unit vector are generated. When these quantities reaches steady state the control algorithm is to be initiated.

Soft Start of VFD

The soft starting of the variable frequency drive is achieved through the ramping of the input signal till the final 50Hz frequency is reached. This V/f ramping control helps in achieving a linearly increasing set of modulating signals.These signals are compared with a repeating sequence thereby generating pulses for triggering the inverter switches.

III SIMULATION OF PROPOSED SYSTEM

The circuit of an Active Front End Converter based VFD for induction motors is implemented using MATLAB/ SIMULINK.

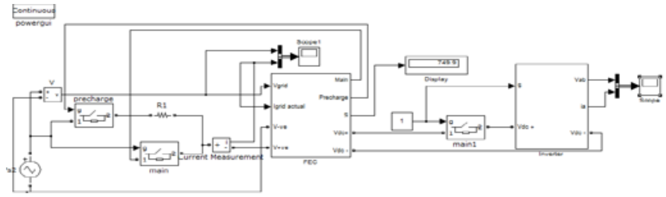

Fig 6 a) The Complete SIMULINK® Model of VFD

Fig 6a) shows the complete Simulink model of VFD which comprises of a Single phase power supply,Front End Converter, DC link, Inverter and three phase auxiliary motor loads.

The sub-models of the various subsystems in the SIMULINK model are shown below

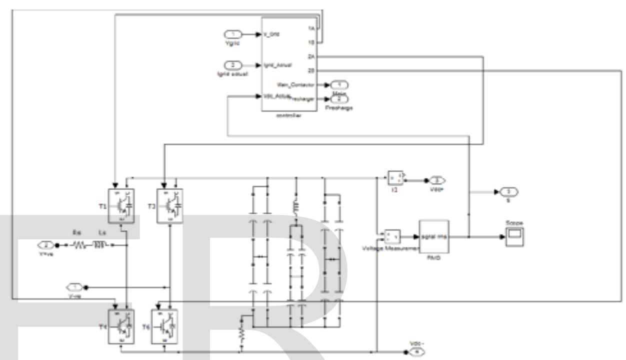

Fig 6b) Front End Converter and DC link

Single phase FEC comprises of four IGBTS connected to he supply as shown.These switches are triggered by gate pulses generated via PWM pulse generation method. FEC converts single phase AC to constant DC.

Fig 6c) depicts the unit vector generation which involves low pass filters, and hence considerable dynamics and settling time. If the controller is initiated before unit vector reaches steady state, the angle θ is erroneous. Consequently, controller generates references that are inappropriate, leading to high starting currents. Hence, to limit the starting currents, the control algorithm is to be initiated only after the unit-vector reaches steady state.

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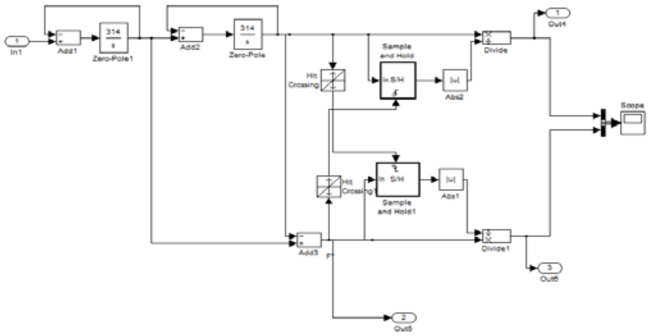

Fig 6c) Unit vector generation

III RESULTS AND DISCUSSIONS

A simulation model of this VFD with no load,R load and motor load is created in MATLAB/SIMULINK so as investigate circuit waveforms.

A. Input Voltage

The waveform of the input single phase voltage and current is shown in Fig 7.

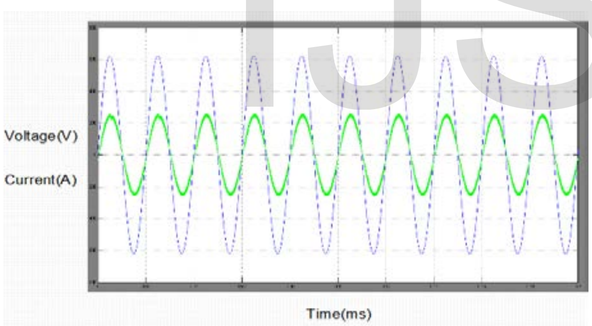

Fig. 7 Input voltage and current

Fig. 7 shows the voltage and current waveform of the input power supply with the load connected in each phase. From the diagram can see a unity power factor operation of the active front end converter.

B.Unit vectors generated

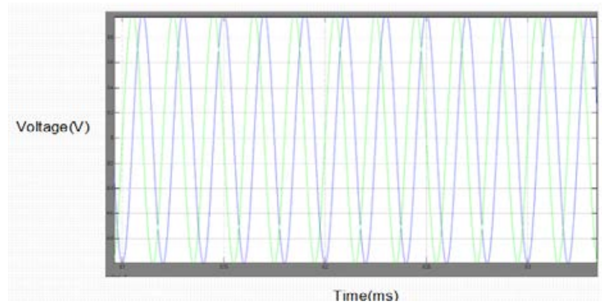

Fig. 8 Sine and Cosine unit vectors

Fig 8 shows the unit vectors. The sinθ and cosθ, the components of revolving unit vector are generated. When these quantities reaches steady state the control algorithm is to be initiated.

FEC operation

1)No load

Fig 9 shows the output of the active front end converter during no load operation. The input AC is converted to perfect DC in few seconds.

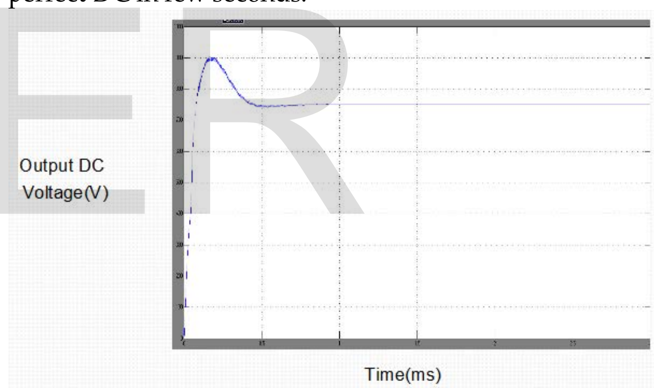

Fig. 9 FEC output at no load

2)R load

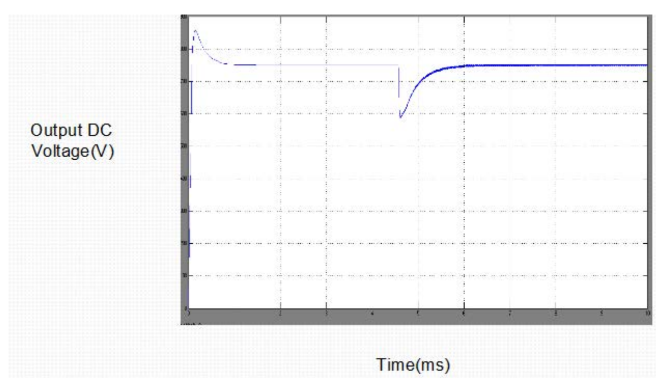

Fig 10 FEC output at R load

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During no load after the initial rise in DC voltage it gets settled to a stable level within few milliseconds. When the resistive load is switched in the circuit,DC suddenly dips and then slowly recover to the stable value as before.

3) *Motor load*

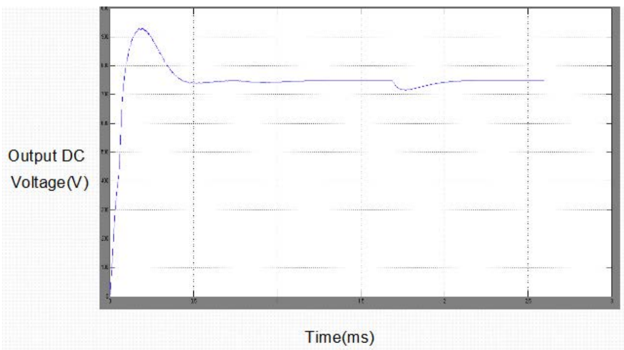

Fig. 11 FEC output at motor load

Fig 11 shows the behaviour of DC when a motor load is connected to the inverter. The small dip corresponds to the instant when input ramping frequency settles down at 50Hz.

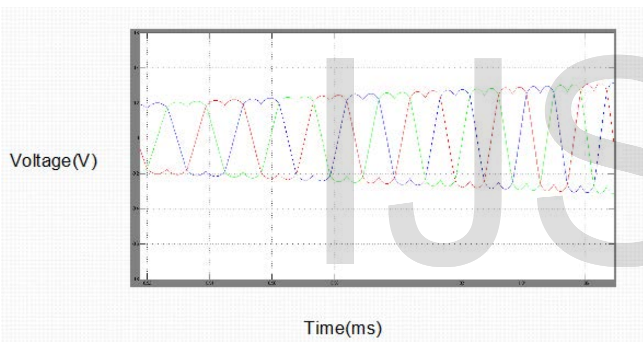

Fig.12 Three phase modulating SVPWM waveforms for the inverter.

Fig 12 shows the three phase modulating SVPWM waveforms for the inverter.The increasing frequency of the modulating signals are clearly seen in fig 13.

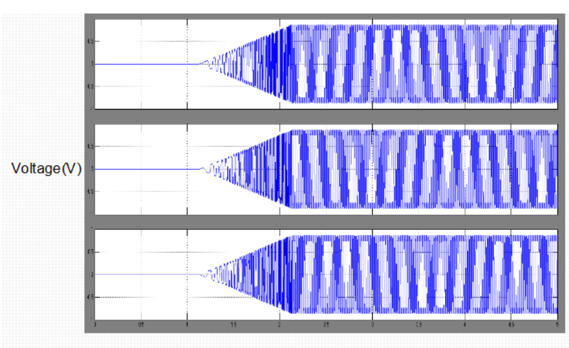

Fig 13 Variable Frequency SVPWM

Fig 14 show the inverter current and voltage. The parameters are initially ramping in nature till they get settled at the peak value at 50Hz.

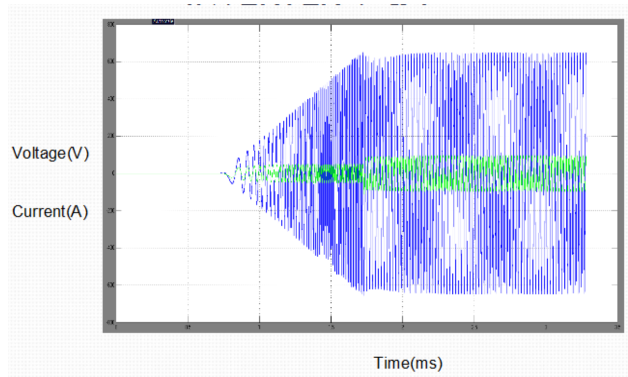

Fig. 14 INVERTER V & I

Fig 16 shows the zoomed view of the fig at 50Hz . It shows the inverter current is lagging with respect to inductor voltage

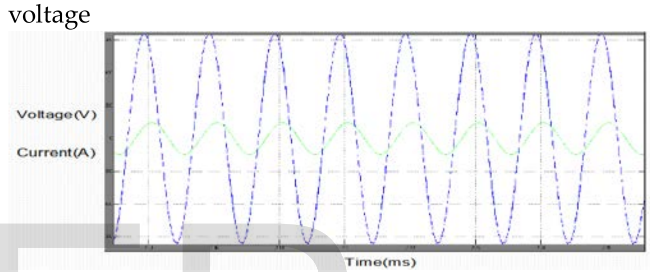

Fig.15 Zoomed view of Inverter V & I showng lagging operation

IV CONCLUSION

Active front end converter and the complete Simulink model of the VFD for induction motor have been analysed with output waveforms. FEC's are becoming an integral part of industrial drive systems due to its incomparable advantages.

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