Field weakening strategy in vector control of induction motor during voltage saturation region

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ABSTRACT - The main aim of the project is to obtain field oriented vector control of induction motor during the inverter saturation. From this vector control method, it is possible to utilize the maximum output voltage available from the inverter completely without exceeding the voltage and current rating of controllers. When the inverter voltage gets saturated, the quadrature axis current controller modifies the flux reference instead of directly obtaining the quadrature axis voltage reference, because when the inverter voltage saturates, there is one degree of freedom available, i.e., either the direct axis voltage or quadrature axis voltage can be controlled independently. Space vector switching strategy is used to control the inverter gate. Hence low switching frequency operation of inverter is possible, which makes it attractive scheme for the traction system. MATLAB based implementation is carried out for this project. Tools used are FPGA controller, Induction motor, Interfacing board, 2-level inverter

Keywords - Field weakening, FPGA Controller, Over modulation, Vector control , Voltage Saturation

List of Symbols

�	Leakage Co-efficient
L_m	Magnetizing inductance
i_{mr}^*	Flux current reference in rotor flux oriented squirrel cage induction motor drive
ω_s	Stator frequency of motor in rad/sec
ω_m	Mechanical frequency of motor in rad/sec
ω_m^*	Reference mechanical frequency of motor
$i_{sR}^{act}, i_{sY}^{act}, i_{sB}^{act}$	Sensed instantaneous stator currents of RYB phases respectively
$i_{sR}^{fun}, i_{sY}^{fun}, i_{sB}^{fun}$	Estimated instantaneous fundamental stator current of RYB phases respectively
r, s	Represents rotor and stator respectively
$V_{sR}^{ref}, V_{sY}^{ref}, V_{sB}^{ref}$	Instantaneous stator voltage references of RYB phases respectively
V_{sd}^*, V_{sq}^*	d-axis and q-axis stator voltage reference respectively
V_s^{max}	Maximum length of stator voltage space vector = $\sqrt{V_{sd}^2 + V_{sq}^2}$
i_s^{max}	Maximum length of stator current space vector = $\sqrt{i_{sd}^2 + i_{sq}^2}$
i_{sd}^*, i_{sq}^*	Stator current reference for d-axis and q-axis

I. INTRODUCTION

The variable speed drives are widely used in industrial application. Most of industries use AC motors for their processing. The standard in those drives are induction motor and synchronous motors. The induction motor control has two types of speed control that is scalar control and the other is the vector control. V/F control is an example of scalar control and Indirect Field Oriented Control and Direct Field Oriented Control comes under vector control techniques. In this project direct vector control method of Vector Control is used.

Field Weakening stage of operation in induction motor is a recently introduced method where the control of induction can happen during the saturation of the inverter voltage. This field weakening stage occurs at the place where the voltage saturation occurs in the inverter that is when the inverter operates at the six-step mode of operation.

II. BASIC BLOCK DIAGRAM

The Basic block diagram is as shown Fig.1 .It contains mainly two parts-The induction motor fed from 2-level inverters and FPGA controller. The line currents of induction motor and D.C. input of the inverter are sensed from the current and voltage sensors respectively. The interfacing board converts the sensed physical quantities into a range of A/D converters. Thus obtained input from the interfacing board, A/D converters the physical quantities into digital quantity and gives the output to the Field programmable gate array(FPGA) controller.

In FPGA there are mainly four units-SVPWM switching, Speed estimation block, Vector control with flux weakening and Harmonic current estimation. This proposed method uses sensorless speed estimation method. The speed of rotor can be estimated from speed of stator and speed of air gap as explained in[1]. The line currents of induction motor contains harmonic, so it cannot be used with the low frequency switching (IGBT switch) which are used in

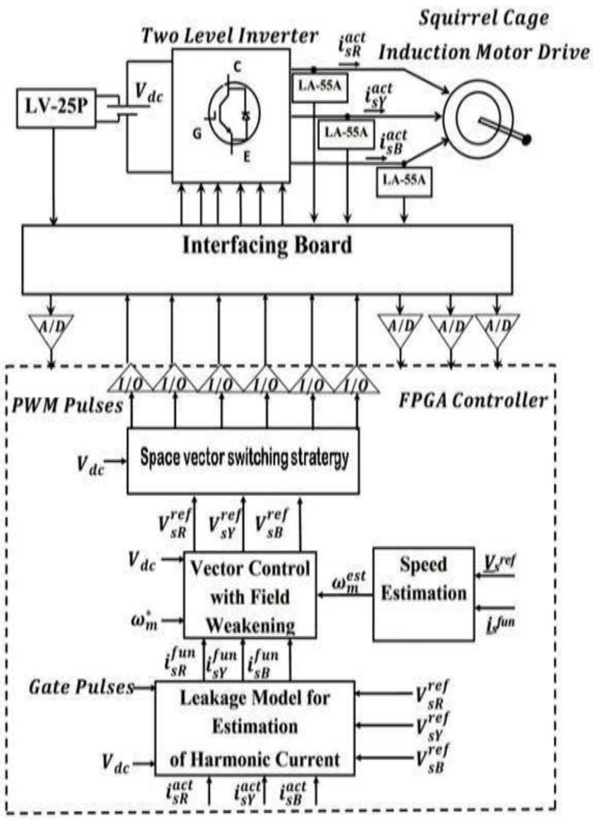

Fig.1.Basic Vector Control diagram

inverter. Filters cannot be used to remove the harmonic current as it hampers the current controller. So the harmonic currents also need to be estimated as explained in [2].Thus obtained fundamental line currents are fed to the vector control unit. The main focus of project lies on vector control with flux weakening. The flux weakening, an integral part of vector controller, enables the use of maximum output of inverter and also avoids the current controller from the saturation. Input pins of FPGA gives the gating pulses to the gate drivers of switches through the interfacing board. Interfacing board increases the gate pulse voltage to 15V D.C.

III. MODIFICATION IN VECTOR CONTROL

The conventional basic block diagram for field oriented control system is as shown in Fig.2 .This block diagram is sufficient to run the motor below the base speed in rotor flux oriented reference frame.

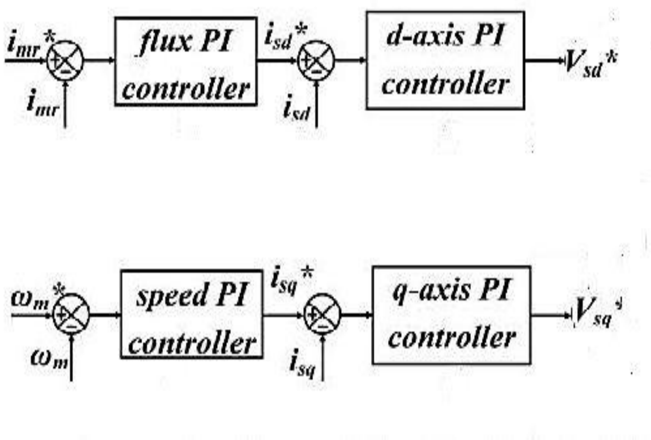

Fig. 2. Current controller in Vector diagram

The conventional basic block diagram for field oriented control system is as shown in Fig.2 .This block diagram is sufficient to run the motor below the base speed in rotor flux oriented reference frame.

Modification of conventional vector control to operate above the base speed is as shown in Fig.3. . Flux current reference i^*_{mr} and torque current reference i^*_{sq} are needed to be modified in order to operate in field weakening above the base speed. The block FF i^*_{mr} block provides the flux current reference and the block FF i^*_{sq} provides the torque current reference to operate the motor above the base speed.

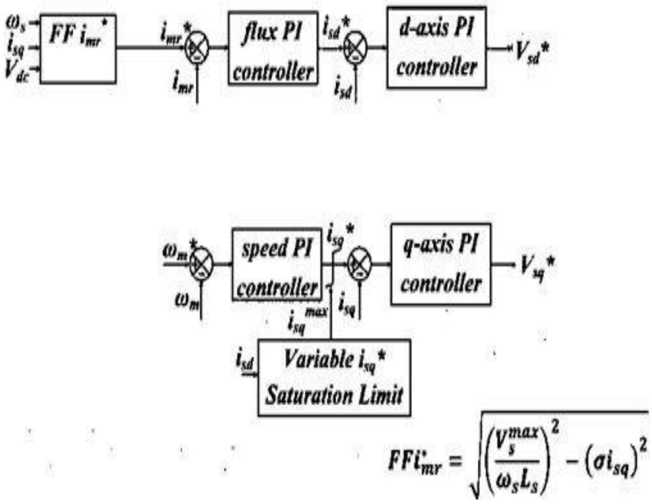

Fig. 3.Modification in current controllers of vector diagram

1 Modification in flux reference

As the speed increases, the flux gets reduced. In order to keep the flux to the optimum value flux current reference is calculated from the below equation.

$$FF\ i^*_{mr} = \sqrt{\left(\frac{V_s^{max}}{\omega_s L_s}\right)^2 - \left(i_{sq}\sigma\right)^2}$$

(1)

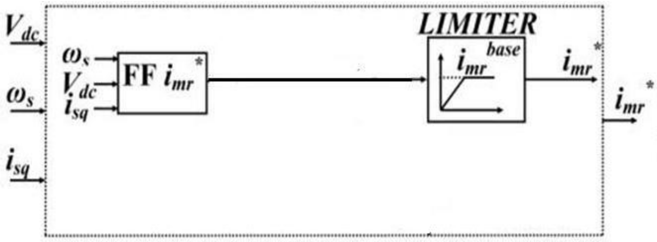

Fig.4. Modification in flux current

In order to utilize the maximum output from inverter, stator voltage is kept at the maximum value which can be obtained from state stator voltage equation [3].Below the base speed, the flux reference is very large. Therefore the flux reference value is fixed within a limit as shown in the Fig. 4.. Below the base speed, flux value is kept at the rated value.

2 Modification in torque reference

In order to have maximum torque for a given speed reference the torque reference $i_{sq}$is kept at its maximum value without making the current controller to saturate. Therefore the torque current reference is calculated from equation (2).

$$i_{sq}^{max} = \sqrt{(i_s^{max})^2 - i_{sd}{}^2}. \quad (2)$$

Field weakening region is split into two regions- flux weakening region 1and flux weakening region 2. Flux weakening region 1lies below the constant slip region and rest of region stay in flux weakening region 2.In flux weakening region 1 the flux current reference is calculated from $i_{sq}^{max} = {i_{sd}}/{\sigma}$ is greater than the value of i_{sq}^{max} calculated from $\sqrt{(i_s^{max})^2 - (i_{sd})^2}$ which in turn helpful to find flux weakening region 1 or 2. The flux reference is altered from i_{sq}^* to i_{sq}^{max} helpful to run the motor at maximum possible torque [3].

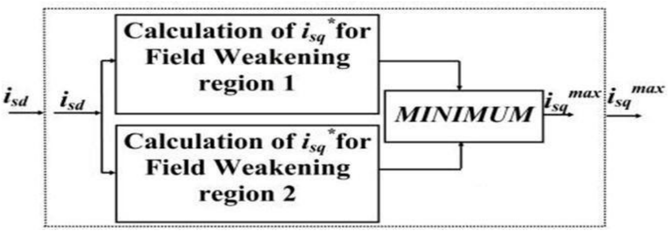

Fig.5.Modification in Torque reference

Modification in quadrature and direct axis voltages-Quadrature axis voltage V_{sq}^*) and direct axis voltage V_{sd}^*) are obtained from the quadrature and direct axis current controllers respectively. Above the six step mode of inverter, it is not able to control the Induction motor as it is impractical. If the voltage saturate, either the V_{sd}^* or V_{sq}^* should be varied to bring the inverter voltage within the six step mode. Therefore a limiter is used to compare the voltage of V_{sq}^* and $\sqrt{(V_s^{max})^2 - (V_{sd})^2}$.

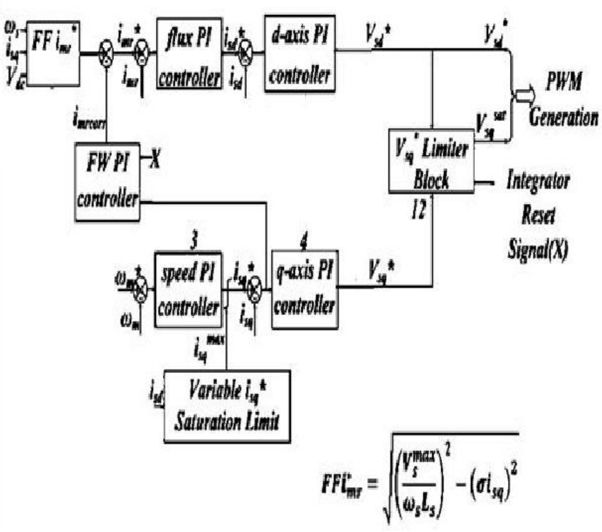

Fig.6. Modification in current controller

If V_{sq}^* obtained is greater or equal than the $\sqrt{(V_s^{max})^2 - (V_{sd})^2}$, then onwards the quadrature axis voltage is varied from the flux current i_{mr}^*) or from the i_{sd}^*. Since variation in i_{sd}^* leads to variation in i_{mr}^* it is preferable to control the V_{sq}^*voltage from the i_{mr}^*still the inverter output voltage becomes lesser than the six step mode. The signal X integrator is used to check whether the quadrature axis voltage is within the limit and if the quadrature axis voltage is exceeded the signal X sends the signal to FW PI controller as shown in Fig.6.

The signal X is generated form the above Fig 7.. The current controller $i_{sq}$is always active, it remains in the saturated only when the six step mode of operation.

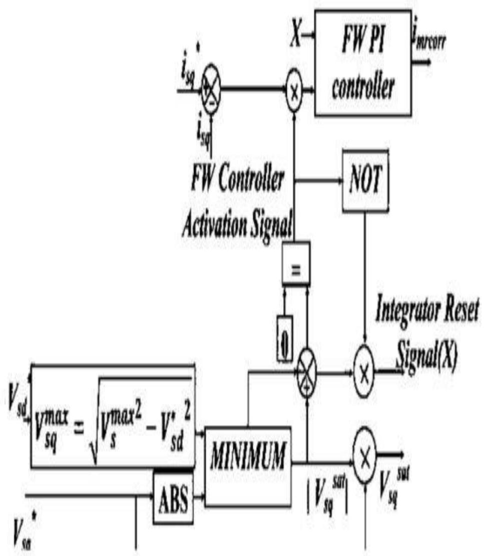

Fig.7. Generation of signal X

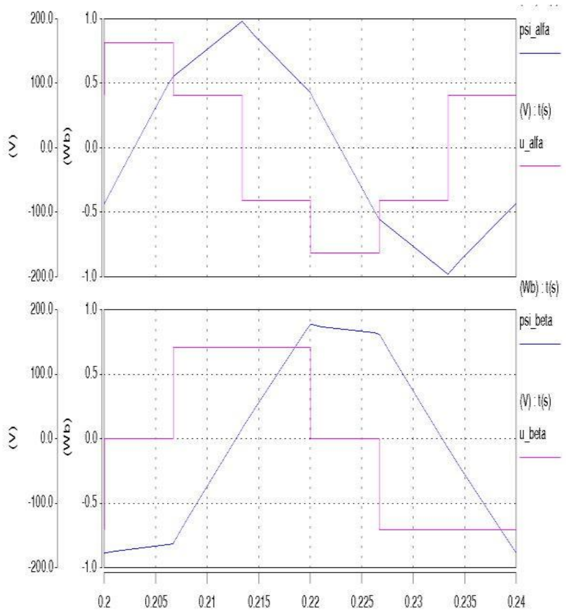

Fig.8.Simulation of inverter under the six step mode operation

IV. CONCLUSION

This paper proposes, the modification in flux weakening strategy when the inverter voltage enters to the six step mode of operation. From the modified method of flux weakening it is possible to current controller even at inverter saturation method. In this paper, space vector strategy which can be extended in over modulation region for low switching and fundamental line current of induction motor from harmonic current estimation is done.

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BIOGRAPHIES

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