Capacitor voltage boosting using boost converter for Inverter fed Synchronous Motor Drive

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Abstract: In this work, the performance of a synchronous motor drive is enhanced by using a capacitor. Low voltage ride through capability of the synchronous motor drive is achieved by means of the capacitive voltage boosting. A capacitor is connected at the dc bus of the inverter circuitry of the drive. Voltage boost is performed by controlling the duty cycle of the power semiconductor switch connected in series with the capacitor. Torque producing capability of the drive is enhanced through the capacitive voltage boost. Further, the control system is proposed for the improvement of the transient response of the drive. The proposed scheme is validated through the MATLAB simulation.

***IndexTerms* - Synchronous Motor, capacitor, MATLAB / SIMULINK, Power semiconductor switch.**

I. INTRODUCTION

The electric motor drive is widely used in industry [1]. The drive is capable of performing speed change operation, forward motoring, reverse motoring and regenerative braking. Use of modern power semiconductor switch makes the motor drive very efficient. Different motoring modes can easily be obtained by merely controlling the power semiconductor switch [2].
Broadly speaking, the motor drive can be a DC drive or an AC drive. DC motor used in DC drive has some limitations related to commutation and maintenance. Due to the above-mentioned issues, DC drive is not much preferred in the industries [3]. Induction motor drive is a good choice in a harsh and challenging environment of any manufacturing industry. With the development in permanent magnet material synchronous motor drive is gaining popularity [4]. Three-phase permanent magnet synchronous motor is maintenance free like an induction motor due to the use of a permanent magnet for excitation. Moreover, the synchronous motor draws less reactive power from the supply as compared to the induction motor [5].
Power quality of the supply to the motor is not always of good standards. Power quality suffers from various voltage related issues such as under voltage and over voltage [6]. Momentary dip in voltage can affect the time response of the motor. Quality of the manufactured product can be seriously affected even due to a slight dip in voltage. So, the drive used in the manufacturing industry requiring high precision should have low voltage ride through capability [7]. Dip in supply voltage hampers the maximum torque producing capability of the motor. Maximum torque makes the motor accelerate and deaccelerate faster. Torque producing capability determines the transient response of the motor drive [8].
Different issues related to permanent magnet synchronous motor drive have been reported in various literature. In this work, low voltage ride through capability of the drive is incorporated by using a capacitor at the dc bus of the inverter. This capacitor is controlled by a power semiconductor switch such as IGBT, power MOSFET, etc. Whenever there is a temporary dip in supply voltage, the control system senses this abnormal condition and it connects the capacitor by turning on the semiconductor switch which is connected in series with the capacitor [9].
Fig 1 shows the basic structure to address the issue of momentary low voltage. Further, a control system is proposed for the improvement of motor transient response. This control scheme makes the motor drive to have less overshoot during speed change operations.This paper is organized into four sections. Section I gives the introduction to this work. This section tells the need for conducting this work. Section II tells about the basics of the proposed scheme to address the issue related to low voltage. Results of this research work are discussed in section III. Finally, the work is concluded in the last section.

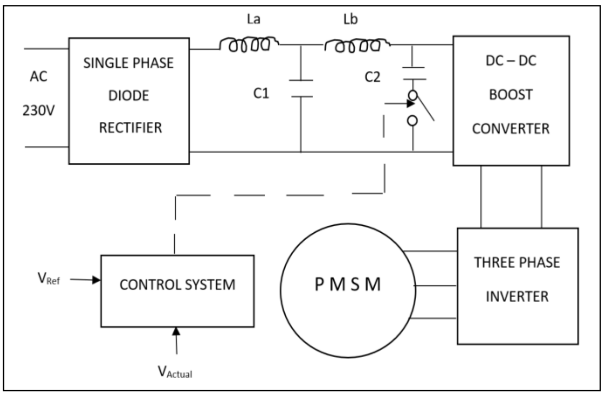


Fig. 1: Basic block diagram of the proposed scheme

II. Basic Principle of the proposed scheme

Power, P developed by the synchronous motor is given by (1). $V_t$is the terminal voltage of the motor. $E_f$is excitation emf. Here E_f is constant because the excitation is produced by the permanent magnets. X_S is the synchronous reactance of the machine. $\delta$is the motor power angle. It is the angle between V_t and E_f. Here, the simplified model is considered by ignoring the stator winding resistance. Torque, τ developed by the motor is given by (2). $\omega$is the motor speed in radian per second. Frequency f is related to the motor speed N_s in revolution per minute according to (3). p is the number of poles in the machine.

$$P = \frac{V_t E_f Sin\ \delta}{X_S} \quad (1)$$

$$\tau = \frac{P}{\omega} \quad (2)$$

$$f = \frac{p\ N_s}{120} \quad (3)$$

Since the torque developed by the motor is dependent on the motor terminal voltage, so any deviation of terminal voltage from the rated value will affect its torque producing capability. The decrease in maximum torque producing capability of the motor drive will make the transient response sluggish. Drive response can be enhanced by the scheme proposed here in this work. The main idea of the proposed scheme is to connect a supercapacitor at the dc bus in the event of low voltage. The capacitor will provide the necessary voltage support for fast acceleration and deceleration of the motor drive. Capacitive support for the voltage boost is controlled by the duty cycle of the power semiconductor device connected in series with it [10-12].

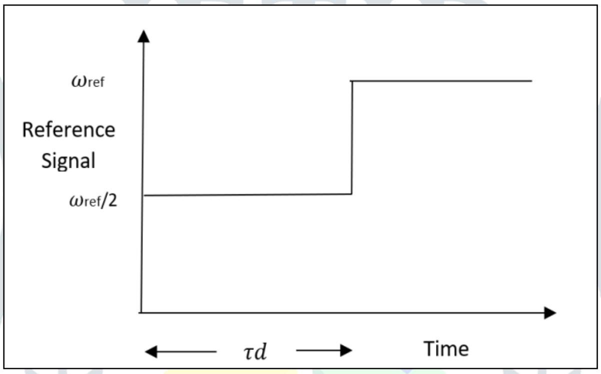


Fig 2: the Basic approach of a proposed control scheme

Further, a control system is proposed to achieve less overshoot in the transient response of the motor drive. Reference command to the control system is modified to accomplish speed change operation. In this proposed work, reduced reference is applied for a time period equal to the time constant of the system then after the full reference is applied to attain the required speed change of the motor [13]. In this way, the value of maximum overshoot can be reduced. The basic approach of the proposed control scheme is given in figure 2.

III. RESULTS & DISCUSSION

The Simulink model of the proposed system is given in fig no 3. The validity of the proposed scheme is tested on MATLAB/ Simulink platform. The input of the drive is 230V AC. This AC voltage is rectified by a diode rectifier. Ripple content in the output voltage waveform of the rectifier is reduced by using a filter. The output of the rectifier is fed to the boost converter. This boost converter is used to raise the level of dc voltage. The boosted dc voltage is applied to the inverter circuitry. Permanent Magnet Synchronous motor is connected at the output port of the inverter circuitry. Heart of the proposed scheme is the capacitor connected at the input dc bus of the boost converter. A power semiconductor switch is used its series to control the charging and discharging of this capacitor. Various parameters used in MATLAB simulation are given in table 1.

TABLE 1: PARAMETERS USED IN SIMULATION

Filter Capacitance, C1	950 µF
Boost Capacitor, C2	75 nF
Inductor (Boost converter), L1	0.5 mH
Output Capacitance (Boost converter), C0	750 µF
Filter inductor (Output port of inverter), L2	55 mH
Filter capacitor (Output port of inverter), C3	7 µF
Motor inertia	0.6329 Kg-sq m
Motor winding inductance (Direct axis)	8.5 mH
Motor winding inductance (Quadrature axis)	8.5 mH

Results of MATLAB simulation are shown in Figs 4-6. Effect of a dip in supply voltage on electromagnetic motor torque is shown in fig 4(c). The corresponding dip in rectifier dc bus voltage and inverter output voltage are shown in fig 4(a) and fig 4(b), respectively. It can be seen from the waveforms that there is a dip in voltage from 0.04Sec to 0.06Sec. Since motor torque is proportional to terminal voltage so there is a reduction in torque from 30 N-m to 18.5 N-m between 0.04 and 0.06Sec. This reduction in motor torque hampers its transient response.

The effectiveness of capacitive voltage boost can be easily seen from the fig 5. The boosted inverter output voltage is shown in fig 5(a). The torque developed by the motor is restored to its original value of 30 N-m. Dip in supply voltage is not reflected in the motor torque. Also, reduction in maximum overshoot in the motor speed- time response using the proposed controller can be clearly seen in fig 6. With the conventional PI controller, speed overshoots to 1620 rpm in the first half oscillation. Overshoot becomes absent in the proposed controller. The only drawback of the system is sluggish response of drive.

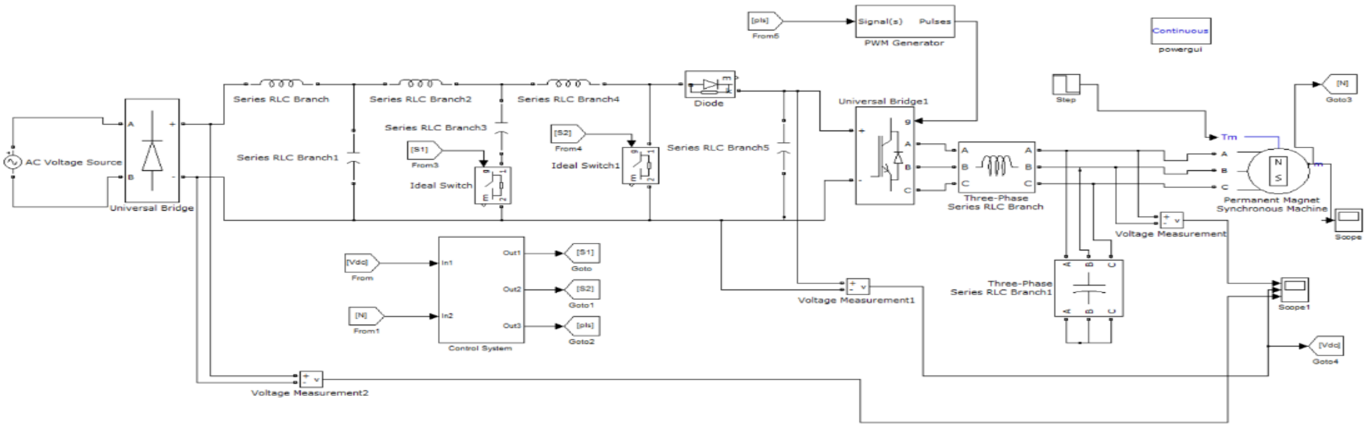
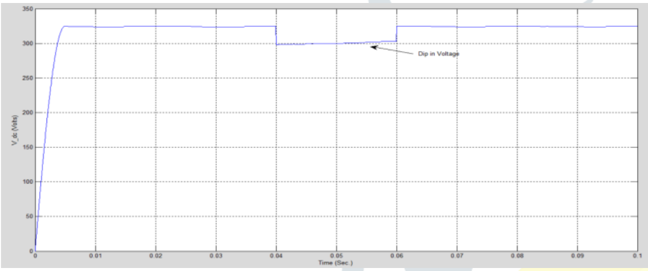
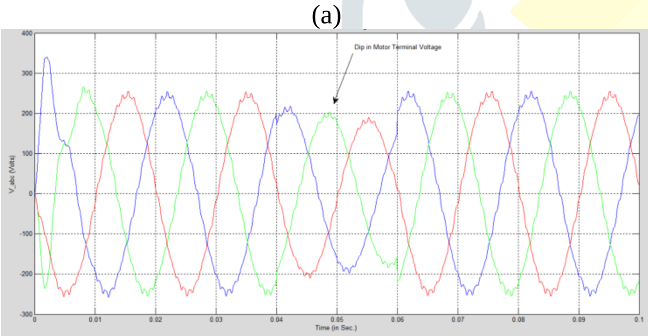


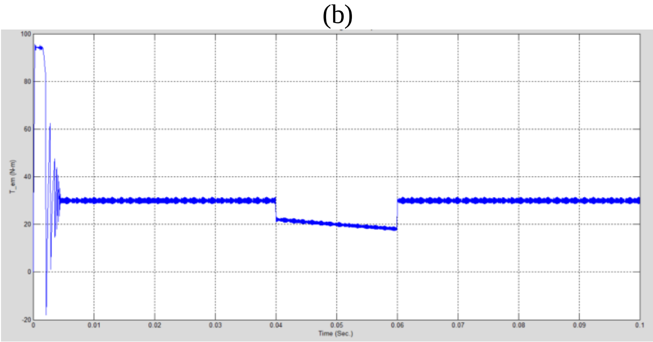
Fig.3:Simulink model of proposed drive



(a)

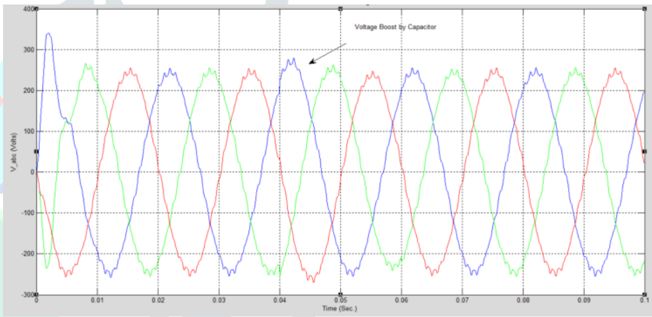


(b)

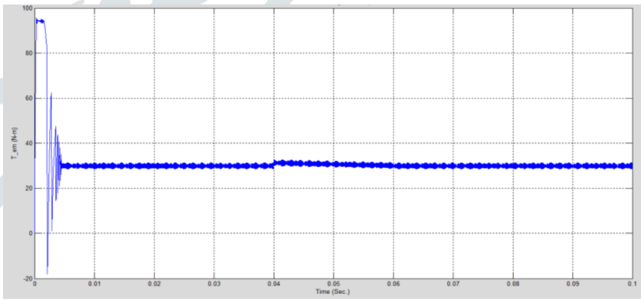


(c)

Fig 4:Waveform during low voltage disturbance (a) Rectifier DC bus voltage; (b) Inverter output voltage; (c) Electromagnetic motor torque



(a)



(b)

Fig 5: Waveform after voltage boost operation by capacitor (a) Output Inverter Voltage; (b) Electromagnetic Motor Torque

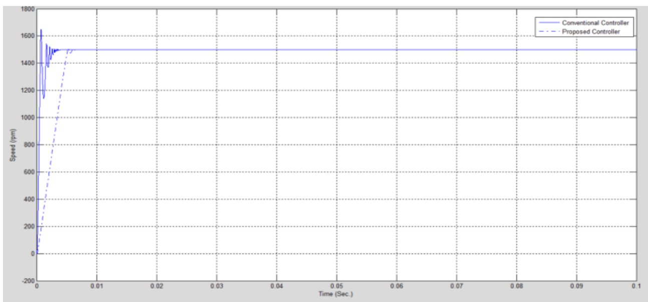


Fig 6: Waveform of motor speed to show the effectiveness of the proposed controller for overshoot reduction.

IV. Conclusion

In this work, low voltage ride through capability of the synchronous motor drive is provided by the capacitive voltage boost. In the event of low voltage, the capacitor is connected at the dc bus to provide the voltage boost.

The simulations results suggest that the proposed scheme is very effective during the temporary under-voltage problem. The Proposed scheme is able to restore the motor torque successfully to its original rated value during low voltage run. In addition, the motor transient response is further improved by almost eliminating the overshoot in the motor speed, but the reduction in overshoot arises at the cost of slight delay in the time response.

Such type of concept can be easily implemented in those applications requiring an excellent dynamic response. The advantage of the proposed system can be used in the manufacturing industry to produce products with high precision and accuracy.

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