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FPGA Based Vector Control of Induction Motor

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***Abstract**: To get the desired response of the sensor less Vector controlled Induction Motor (SVC-IM) by the experimental setup, the controller implementation for the generation of the PWM signals is the key role. It is possible with the rapid growth of electronic industry such as high speed digital signal processors (DSPs) with micro controllers available in the present market. In the past DSP technologies were used to realize the several SVC-IM schemes, i.e. KF, PI, GA and PSO respectively. However, it creates issues related to the time delay and execution of the PWM signals, etc., as a results system becomes complex. Therefore a new approach is implemented to overcome the issues related to the execution time, namely Field Programmable Gate Array (FPGA) processors are suggested in the present market. Moreover the programming is done using very high speed hardware descriptive language (VHDL)*

Keywords: FPGA, SVC, Induction Motor, MATLAB.

I. INTRODUCTION

To get the desired response of the SVC-IM by the experimental setup, the controller implementation for the generation of the PWM signals is a crucial role. It is possible with the rapid growth of the electronic industry, such as high-speed digital signal processors (DSPs) with microcontrollers available in the present market. In the past, DSP technologies were used to realize the several SVC-IM schemes, i.e., EKF, FLC, ANN, GA, and PSO, respectively. However, it creates issues related to the time delay and execution of the PWM signals; as a result, the system becomes complex. Therefore a new approach is implemented to overcome the issues related to the execution time, namely Field Programmable Gate Array (FPGA) processors are suggested in the present market. Moreover, the programming is done using very high-speed hardware descriptive language (VHDL). The FPGA is ideally suited for making high-performance processors with a capability for implementing highly parallel arithmetic architectures. The speed, size, and the number of inputs and outputs of a modern FPGA far exceed that of a microprocessor or DSP processor. At the last experimental setup for the SVC-IM with various control schemes such as the conventional Extended Kalman filter (EKF), PI-controller and evolutionary schemes like GA and PSO was developed to verify with the simulation results. The performance characteristics of the conventional methods are thoroughly compared with known evolutionary control schemes like GA and PSO.

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II. HARDWARE IMPLEMENTATION

A. Block diagram of FPGA Based Controller for SVC-IM (complete hardware configuration)

The complete circuit diagram of the project and the experimental setup is shown in Fig. 1. The three-phase 440V 50Hz AC supply is fed to the three-phase diode bridge rectifier with a filter capacitor. DC is sensed by the current sensor (HE025T01). The dc output of the diode bridge rectifier is given to the three-phase PWM Voltage Source Inverter (VSI), which drives the three-phase squirrel cage induction motor. The three-phase A.C. Currents are sensed by three current sensors (HE025T01); these currents are inputs to the FPGA module.

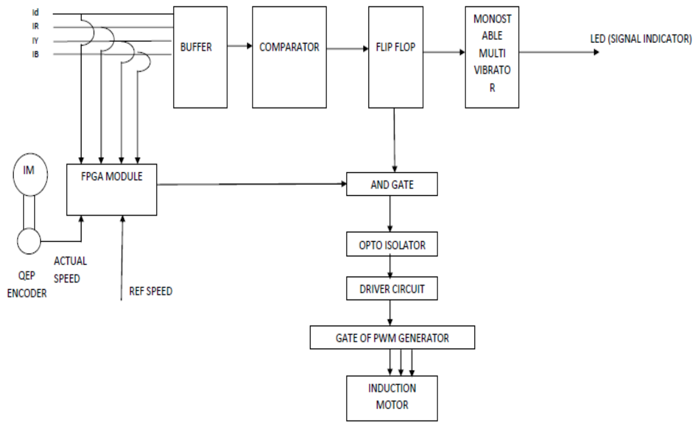

Fig. 1. The block diagram of the proposed FPGA based controller for SVCIM

B. Power Circuit Unit

The power circuit unit is shown in Fig. 2. It constitutes of a three-phase supply, diode bridge rectifier, DC sensor, AC sensor, and PWM VSI.

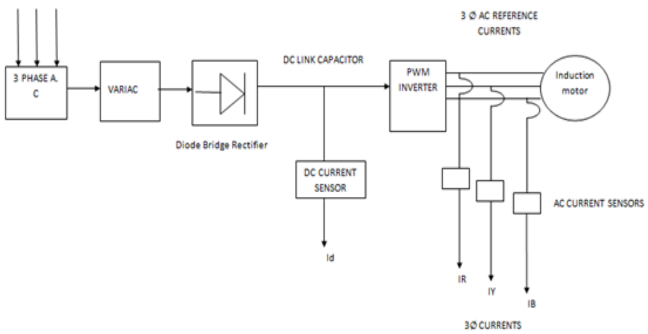

Fig. 2. The Power circuit unit

C. Speed Estimation Unit

It consists of a QEP optical sensor, FPGA external hardware interrupt pin. In Indirect vector control scheme, the speed sensing is mandatory. The speed is measured by the simple arrangement of a QEP optical sensor. The sensor generates 512 pulses per rpm. By measuring the time of the pulse, we can measure the speed of the rotor in rpm or rad/s. The speed sensor output is given to the FPGA external hardware interrupt pin P3.2 (INT0) for measurement. The FPGA is programmed in such a way that it continuously measures the period of the pulses for measuring the speed.

D. Signal Conditioner Unit

The essential components include Buffer, comparator, flip flop, and monostable multivibrator. For protection, a signal conditioner is used. It consists of Buffer (TL084), Comparator (LM339), Flip Flop (4027), Monostable multivibrator (4098). The output currents of the current sensors are applied to buffer for smoothening, and the output of the buffer is applied to the comparator, which compares input DC and references current. If the input DC is well within the limits of the circuit, the comparator sends a signal to flip flop, and its output becomes high. The output of flip flop is sent as one of the input to AND gate (4081), the other input to AND gate is from the FPGA module, i.e., triggering pulses. When both inputs are high, the AND gate generates a high output, which transfers the triggering pulses to a driver circuit (IR2110) through opto isolators (6N137). (Used to isolate High voltage and Low voltage dc voltages) to the gate of Inverter. If it exceeds the limits, the comparator sends a signal to the monostable multivibrator, which in turn checks that no signal reaches the gate for firing pulse generation. Then the monostable multivibrator sends a signal to led to go red, indicating a warning. Then the input Three-phase supply controlled by a variac is reduced, which reduces input to the diode bridge rectifier and dc-link current and hence the output of an inverter. Power Circuit for accessories: It consists of dc power supplies for the buffer, comparator, opto isolator, flip flops, and multivibrator. The power supply unit also consists of 15-0-15V supply for buffer (consisting of IC 7915,bridge rectifier,15-0-15V transformer)and 0-15V supply for comparator circuits (consisting of IC 7815, bridge rectifier and 0-15V transformer), 0-5V supply for opto isolator circuit, AND Gate, Flip flops and Monostable Multivibrator circuits(consisting of IC 7915, bridge rectifier,15-0-15V transformer) .

E. FPGA Module

The FPGA module forms the heart of the controller which plays a vital role in the generation of gating signals for the PWM inverter. The outputs of the current sensors, speed encoders are connected to the inter phase board, and these signals reach the FPGA module through 34pin FRC (Flexible ribbon cable) cable to the FPGA input port. The FPGA unit senses these input signals and converts them to digital signals through A/D Convertors. The following sequence of events generates the switching signals.

1. by using the Up/down keys of the FPGA Module, the reference speed is set.
2. Reading actual speed from motor QEP Encoder and reference speed as set speed error is generated.
3. This speed error is applied to PI Controller, where Kp and Ki's values are loaded. The output of the PI Controller generates a torque component current (iq).
4. The flux of rated value is given to the motor, which generates flux component of current (id).
5. Generation of slip frequency ωsl from iq and id current components.
6. Generation of ωelectrical from ωmechanical (from mechanical angle obtained from QEP encoder, multiplying by pair of poles)
7. Finding actual speed by adding ω mechanical and ωsl.
8. Generation of Ө by integrating ωm.
9. Formation of lookup tables for SinӨ and CosӨ values for unit vector generation.
10. Conversion from the d-q reference frame to **α-β** reference frame by park transformation and from **α-β** reference frame to a-b-c three-phase frame by Clarks Transformation.
11. Generation of switching signals for the PWM inverter gate.

F. Inter phase board

The FPGA pulses generated from the module are applied to the interphase board through 24 pin FRC Cable. The output of the interphase board is applied to the AND gate, which generates a signal of high when flip flop output goes high. The output of the AND gate is given to the optoisolator, which isolates the high voltage ground (15V) from low voltage ground (5V) through the driver circuit to the PWM Inverter gate.

G. VHDL Coding Unit

In this study, the Xilinx FPGA application board is taken as a basis for a real-time application. For analysis, an indirect field-oriented controlled induction machine driven by a Voltage Source Inverter (VSI) is analyzed by using the Matlab /Simulink model. The Xilinx FPGA chip generates the control signals for the VSI in the related model. But, the FPGA chip needs Very-high-speed Hardware Description Language (VHDL) codes to generate the control signals for the related controller. Usually, the Matlab Simulink Package does not provide an interface for the VHDL needed for the controller to be embedded in the FPGA chip. However, the Xilinx System Generator Tool provides such an interface, that is, a control algorithm developed by Xilinx System Generator Tool convenient to be used with traditional Simulink block sets can be translated to the VHDL codes needed for the controller for embedding in the FPGA chip.

The basics for VHDL Coding are as follows:

1. Library declaration
2. Input and Out variables declaration.
3. Local variable declaration.
4. Entity and architecture
5. Simulation and verification of logic.
6. Assigning PINs for output variables.
7. Generating program file i.e., .bit files.
8. Dumping the program to FPGA Module through emulator cable. The input power supply of 5V is given through the adaptor whose input is 230 V A.C.

H. Motor Unit

A three-phase induction motor with a belt arrangement and mounting for QEP is used for analysis: The ratings of the motor considered are as follows:

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Table- I: The ratings of the motor

Sino	Parameter	Rating
1	Power	1H.P.
2	Voltage	415V
3	Speed	1430 Rpm
4	Frequency	50Hz
5	No of Poles	4
6	Current	1.8A

III. EXPERIMENTAL AND SIMULATION ANALYSIS

The analysis for speed, current, and torque for various loads for sensor less vector controlled induction motor implementing FPGA Module is as follows:

Case 1: Full load current of 1.8Aand speed of 1000rpm (Kalman filter controller)

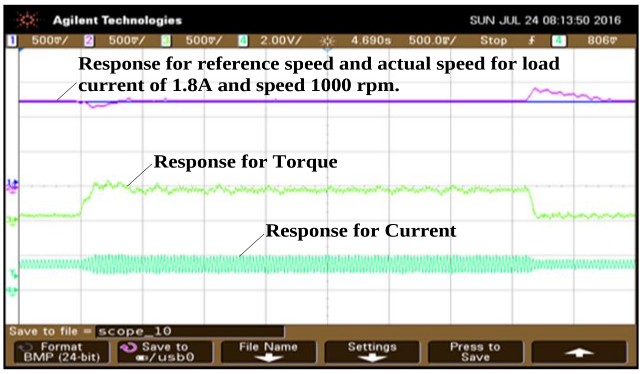

Fig. 3. Experimental results of actual speed, reference speed, torque, and current.

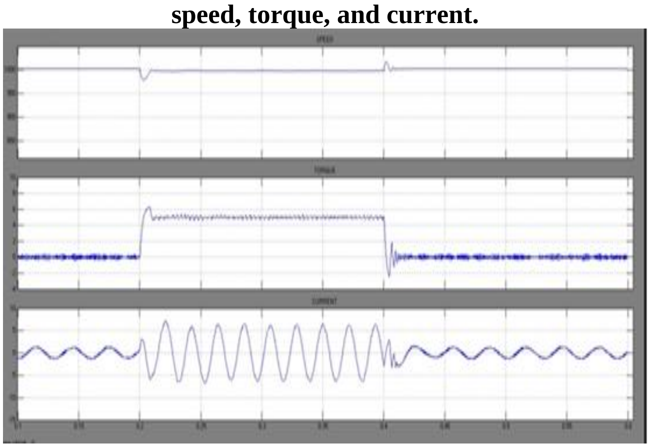

Fig. 4. Simulation results of actual speed, reference speed, torque, and current for Kalman Filter controller

The above analysis is done considering a Kalman filter controller for a full load current of 1.8A and at a speed of 1000 rpm. The waveforms for actual speed, reference speed, current, and torque are shown in figure .12. When full load current is applied at 0.2 seconds, the speed drops to 950 rpm, and torque rises to 5.8 N-m and load current increases to 2.75A.

Case 2: Full load current of 1.8 A and speed of 1000 rpm (Conventional PI controller)

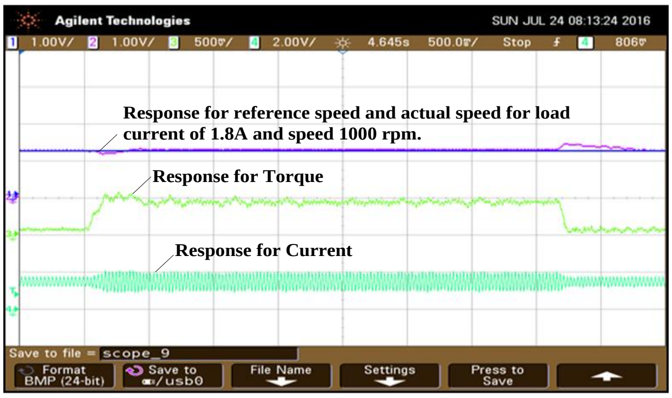

Fig. 5. Experimental results of actual speed, reference speed, torque, and current.

The analysis is done considering a Conventional PI controller for a full load current of 1.8A and at a speed of 1000 rpm. The waveforms for actual speed, reference speed, current, and torque are shown. When full load current is applied for 2 sec, the speed drops to 980 rpm, and torque rises to 5.65 Nm, and load current increases to 2.64A.

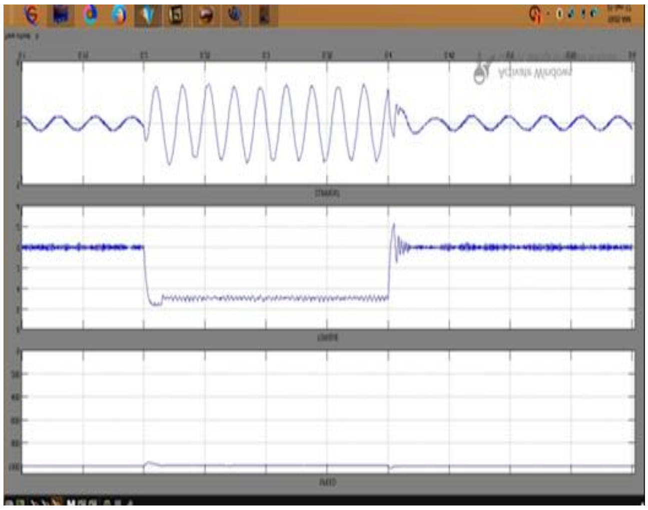

Fig. 6. Simulation results of actual speed, reference speed, torque, and current for the conventional PI controller.

Case 3: Full load current of 1.8 A and speed of 1000 rpm (GA Tuned PI controller)

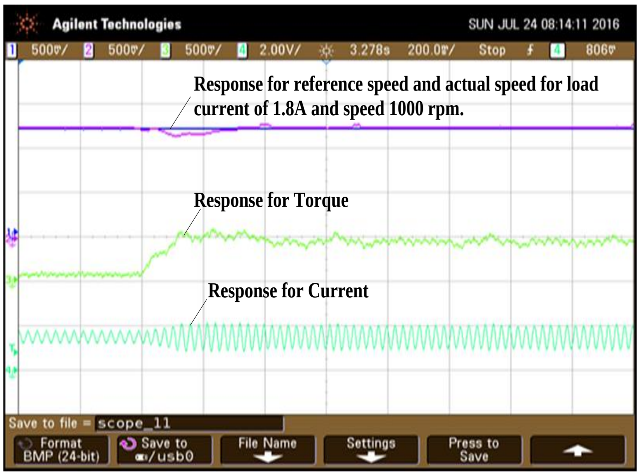

Fig. 7. Experimental results of actual speed, reference speed, torque, and current.

The above analysis is done considering a GA Tuned PI controller for a full load current of 1.8A at a speed of 1000 rpm. The waveforms for actual speed, reference speed, current, and torque are shown. When full load current is applied at 2 sec, the speed drops to 990 rpm, and torque rises to 5.2 Nm and loads current increases to 2.5A.

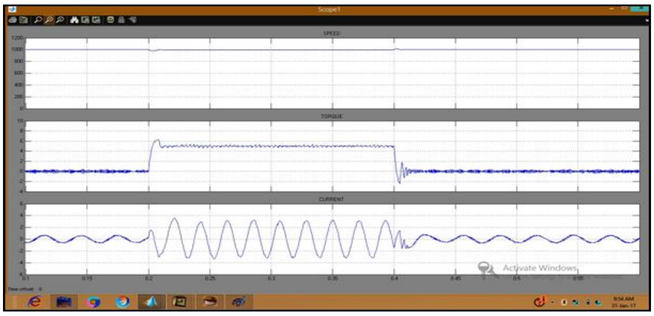

Fig. 8. Simulation results of actual speed, reference speed, torque and current

Case 4: Full load current of 1.8 A and speed of 1000 rpm (PSO Tuned PI controller).

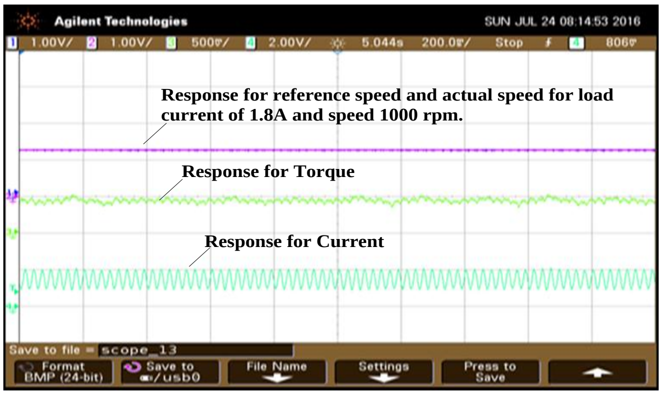

Fig. 9. Experimental results of actual speed, reference speed, torque, and current.

The above analysis is done considering a PSO Tuned PI controller for a full load current of 1.8A at a speed of 1000 rpm. The waveforms for actual speed, reference speed, current, and torque are as shown. When full load current is applied for 2 sec, the speed drops to 995 rpm, and torque rises to 5.2 Nm and load current increases to 2.2amps.

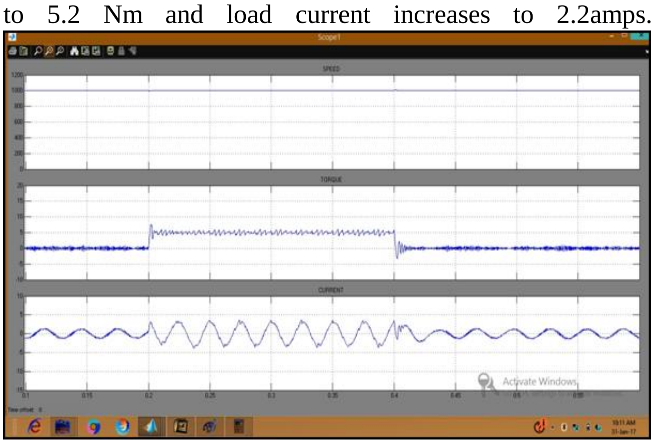

Fig. 10. Simulation results of actual speed, reference speed, torque, and current.

IV. COMPARISON OF SIMULATION AND HARDWARE RESULTS OF FPGA BASED CONTROLLER

Case-1: The analysis is done at a full load current of 1.8A and torque of 6Nm at a speed of 1000rpm, as shown in Table- II. From the analysis at full load and speed of 1000rpm, the change in speed for Kalman filter controller is 5%, the conventional PI controller is 2%, GA tuned PI Controller is 1%, and PSO tuned PI controller is 0.2%. Similarly, the change in torque for the Kalman filter controller is 16%, the conventional PI controller is 8%, GA tuned PI Controller is 1%, and PSO tuned PI controller is 0.4%. The change in current for Kalman filter controller is 52.7%, the conventional PI controller is 46.6%, for GA tuned PI Controller is 38.8%, and PSO tuned PI controller is 22.2%.

Table- II: Analysis of the results for Case-1

Parameter	Kalman	PI(conventional)	GA tuned PI	PSO tuned PI
Speed(Rpm) (simulation)	950	980	990	996
Speed (Experimental)	955	976	984	995
Torque(N-m) (simulation)	5.8	5.65	5.4	5.2
Torque (Experimental)	5.7	5.6	5.4	5.2
Current(Amps) (simulation)	2.75	2.64	2.5	2.2
Current (Experimental)	2.74	2.65	2.5	2.1

Case-2: The analysis is done at 3/4 full load current, i.e., 1.35 A and torque of 6N-m at a speed of 1000rpm, as shown in Table-III. From the above analysis at full load and speed of 1000rpm the change in speed for kalman filter controller is 4%, conventional PI controller is 2%, GA tuned PI Controller is 1% and PSO tuned PI controller is 0.2%.The change in torque for Kalman filter controller is 16%, conventional PI controller is 15%, GA tuned PI Controller is 4% and PSO tuned PI controller is 1%. The change in current for Kalman filter controller is 77.7%, conventional PI controller is 62.8%, GA tuned PI Controller is 60% and PSO tuned PI controller is 55.5%.

Table- III: Analysis of the results for Case-2

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Parameter	Kalman	PI(conventional)	GA tuned PI	PSO tuned PI
Speed(Rpm) (simulation)	960	980	990	995
Speed (Experimental)	965	975	980	980
Torque(N-m) (simulation)	5.8	5.75	5.2	5.05
Torque (Experimental)	5.6	5.70	5.3	5.04
Current(Amps) (simulation)	2.4	2.2	2.16	2.1
Current (Experimental)	2.5	2.2	2.18	2.2

V. COMPARISON OF RESULTS

Table- IV: Analysis of the results for Case-1

Parameter	Kalman	PI(conventional)	GA tuned PI	PSO tuned PI
Speed(Rpm) (simulation)	950	980	990	996
Speed (Experimental)	955	976	984	995
Torque(N-m) (simulation)	5.8	5.65	5.4	5.2
Torque (Experimental)	5.7	5.6	5.4	5.2
Current(Amps) (simulation)	2.75	2.64	2.5	2.2
Current (Experimental)	2.74	2.65	2.5	2.1

Case-1: The analysis is done at a full load current of 1.8A and torque of 6Nm at a speed of 1000rpm, as shown in Table-IV. From the analysis at full load and speed of 1000rpm, the change in speed for Kalman filter controller is 5%, the conventional PI controller is 2%, GA tuned PI Controller is 1%, and PSO tuned PI controller is 0.2%. Similarly, the change in torque for the Kalman filter controller is 16%, the conventional PI controller is 8%, GA tuned PI Controller is 1%, and PSO tuned PI controller is 0.4%. The change in current for Kalman filter controller is 52.7%, the conventional PI controller is 46.6%, for GA tuned PI Controller is 38.8%, and PSO tuned PI controller is 22.2%. Case-2: The analysis is done at 3/4 full load current, i.e., 1.35 A and torque of 6N-m at a speed of 1000rpm, as shown in Table-V. From the above analysis at full load and speed of 1000rpm the change in speed for kalman filter controller is 4%, conventional PI controller is 2%, GA tuned PI Controller is 1% and PSO tuned PI controller is 0.2%.The change in torque for kalman filter controller is 16%, conventional PI controller is 15%, GA tuned PI Controller is 4% and PSO tuned PI controller is 1%. The change in current for kalman filter controller is 77.7%, conventional PI controller is 62.8%, GA tuned PI Controller is 60% and PSO tuned PI controller is 55.5%.

Table- V: Analysis of the results for Case-2

Parameter	Kalman	PI(conventional)	GA tuned PI	PSO tuned PI
Speed(Rpm) (simulation)	960	980	990	995
Speed (Experimental)	965	975	980	980
Torque(N-m) (simulation)	5.8	5.75	5.2	5.05
Torque (Experimental)	5.6	5.70	5.3	5.04
Current(Amps) (simulation)	2.4	2.2	2.16	2.1
Current (Experimental)	2.5	2.2	2.18	2.2

VI. EXPERIMENTAL HARDWARE SETUP

Fig. 11. Experimental setup for hardware

VII. CONCLUSION

The desired response of the sensor less Vector controlled Induction Motor (SVC-IM) is obtained by an experimental setup. The controller implementation for the generation of the PWM signals is the key role. High speed digital signal processors (DSPs) with micro controllers available in the present market are made use of and compared to the past DSP technologies which were used to realize the several SVC-IM schemes, i.e. KF, PI, GA and PSO respectively. However, it creates issues related to the time delay and execution of the PWM signals, etc., as a result system becomes complex. The issues are addressed by a new approach and are implemented to overcome the issues related to the execution time, namely Field Programmable Gate Array (FPGA) processors are suggested in the present market. Moreover the programming is done using very high speed hardware descriptive language (VHDL).

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