

Electronic Instrumentation System for Protection and Control of a Voltage Converter

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This paper presents the development of an instrumentation system for protection and control of a three-phase induction motor based on a MOSFET inverter, as well as the study of the effects caused in terms of Electromagnetic Interference and the measures to counteract them. The system allows the acquisition of a number of relevant operational quantities in the system, duly isolated of the power system.

Keywords: MOSFET, variable speed drives, electromagnetic compatibility

1. Introduction

This paper presents the study of an electronic power drive for a rotating electrical machine and the problem of generation of electromagnetic interference (EMI) and remediation of the caused problems in the robustness and accuracy of operation of the system. Each time more, in the industry and other sectors the use of ac motors in tasks that require speed control increases. In the automobile industry, for example, they are already quite used, for electrically moved glasses, for power steering, for water pumps, etc.. The increasing introduction of this type of engines will stimulate the necessary introduction of modern control converters what will imply a bigger amount of EMI generation and all the associated problems. The system under development was specified to be flexible, allowing advanced forms of control of a three-phase induction motor, and appropriate, for example, to be, applied in the control of a traction motor of an electric vehicle operating on batteries. The system should have the functionalities to allow the acquisition of diverse relevant quantities from the power circuits towards the control law module, using for example the acquisition systems developed in [1]. In the development of this system, primordial importance to the problem of the electromagnetic compatibility (EMC) was given, because it was our previous experience that only in this way it should be possible to overcome a classical lack of stability and of robustness that less well developed system possess, specially in the laboratory experimentation phase.

2. Description of the system

In figure 1, the system complete is represented, in terms of a block diagram depicting its main functions. The system supply is done by the block "DC Rail", obtained in the laboratory with resource to an auto-transformer, a three-phase bridge and a reservoir capacitor in parallel, obtaining at its output a voltage of about 114V at full load. The block "DC current sensor", is the one that allows the measurement of the DC rail current, with the purpose of detection of the occurrence of an overload or a short circuit in the system. The value of the instantaneous current is acquired by the block "Current Limit detector", that allows detecting a defined as limit value, sufficient to be considered an overload and activate a fault signal as a consequence. This fault signal is sent to the block "Signalling and Memory", that allows keeping a memory of the occurrence of the fault as well as to signal it through one led and to send an inhibiting signal to the block "Control buffer and gate signals".

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Immediately before the feeding to the motor, the block "Phases current sensor", allows to measure the current in each phase of the motor supply.

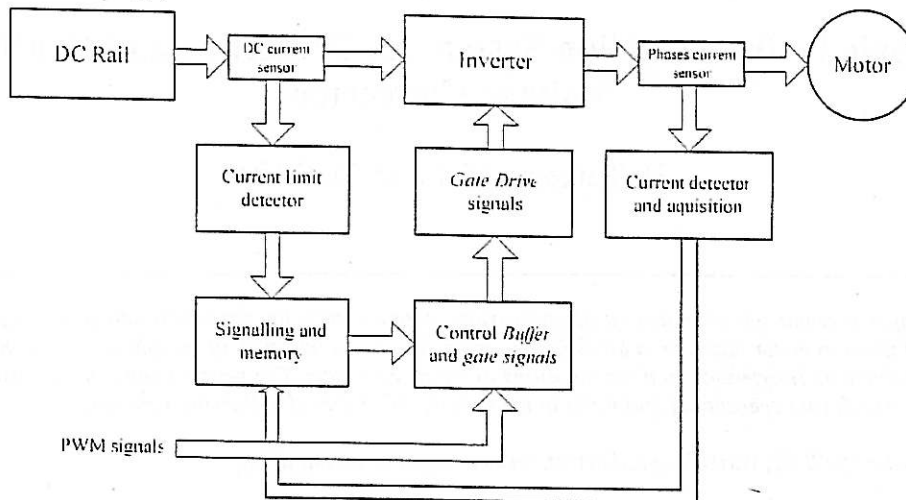


Figure 1 – Block diagram of the developed system.

The values of the 3 phase currents are acquired by the block "Current detector and acquisition", which allows, besides the acquisition of the currents, the detection of the occurrence of overload or short circuit in this side of the system as well, and sends a corresponding fault signal to the block "Signalling and memory".

The signal sent by its turn from the block "Signalling and memory" to the block "Control buffer and gate signals", forces the latter to inhibit, by stopping the PWM signals that normally pass through towards the block of "Gate drive signals", allowing it to put the inverter MOSFETs out of conduction. The control law sub-system that generates the PWM signals is not considered in the scope of the present work. It has been developed in our laboratory as an evolving module to control different experimental power inverter systems.

The "Inverter" block represents the developed power inverter that is constituted by six MOSFET, forming a full three-phase inverter. The used engine, is a squirrel-cage induction motor with nominal ratings of 1,1KW, nominal composite voltage of 70V, 16A, and 7,7Nm.

It was our aim to develop a low-cost system therefore efforts were made in order to simplify the electronic design of the system. One sector where simplification was achieved was the supply circuit of the gate drive circuits of the MOSFETs, which are fed from the DC rail by means of special simple regulated rectifier circuits. This allows a substantial reduction in terms of costs, relatively to the use of, for example, DC-DC converters. The use of optical couplers for the transmission of the gate signals introduce the necessary galvanic isolation between the power side and the signal side of the system. In figure 2 the supply circuit of gate drives for one of the arms of the three-phase inverter is depicted. The integrated circuit is a double optical coupler with a high common-mode rejection ratio at high dv/dt values between the isolated sides of each coupler.

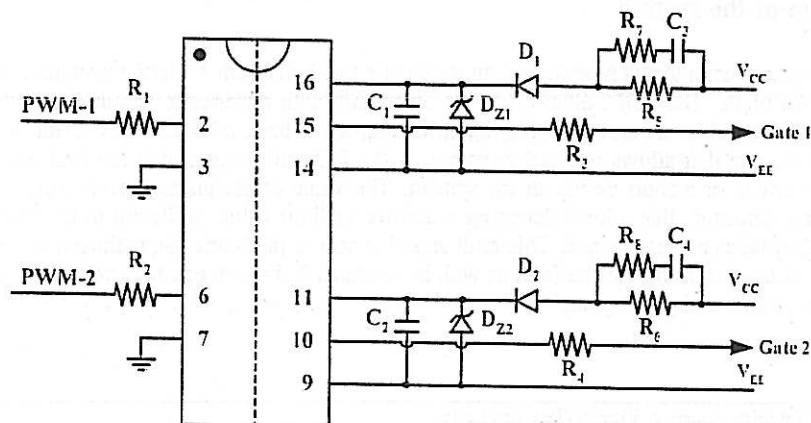


Figure 2 – Supply circuit of gate drives derived from the DC rail.

The circuit of figure 2 represents part of the block "Gate drive signals", which is constituted by two identical circuits more. Signals PWM-1 and PWM-2 are supplied by the block "Control buffer gate signals". The signals Gate 1 and Gate 2, are the signals sent to the MOSFETs' gates. In figure 3, the oscillogram of the occurrence of fault (descending transition of channel 1) and the removal of the high signal at the gate of one of the MOSFET of the inverter (channel 2)

is presented. In figure 4 the exit of conduction of one of the MOSFETs of the inverter through the measurement of tension V_{DS} is presented (channel 2), after the detection of occurrence of a fault (channel 1).

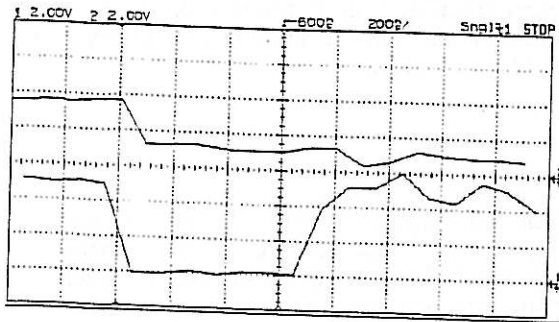


Figure 3 – Fault signal (ch1), gate signal (ch2)

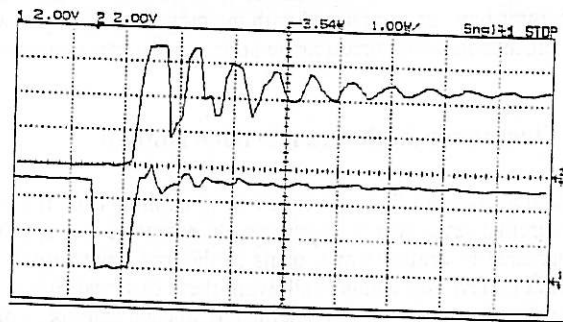


Figure 4 – Fault signal (ch1), V_{DS} voltage signal (ch2)

As we can verify for figure 4, the time that elapses until the MOSFET leaves conduction completely is of approximately $0,8\mu s$, measured from the instant that the FAULT signal (channel 1) is at 50% of its maximum value, in the descending transition, until voltage V_{DS} at the terminals of the MOSFET (channel 2) goes up approximately to the value of the voltage of the DC rail.

Another important design aspect was the remediation of the problems raised by the noise provoked by the electromagnetic interference through induction or coupling to the sensitive circuits.

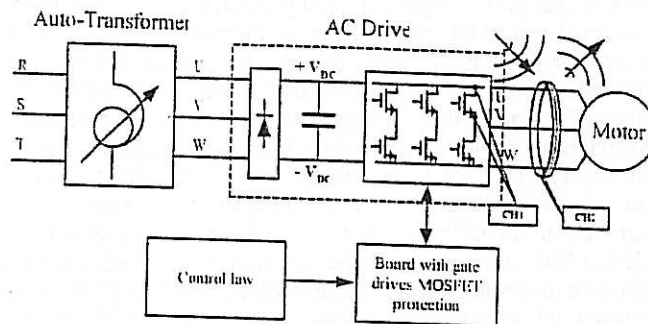


Figure 5 – Configuration for measurement of the noise introduced by dv/dt provoked by the commutation of the MOSFETs.

The noise provoked by the inverter is typically composed of spike pulses induced by the power circuits. To observe and measure this noise we acquired some waveforms following the method recommended in [2]. In a balanced system the sum of the three currents in the phases conductors would have to be null in theory, so the observed signals are the noise residual current that appears in the sum of currents of the phases of the motor in the real system. Thus, in figure 6 we can verify the appearance of the noise that happens at the entrance and exit of conduction of each MOSFET, provoked by the large and fast variation of the voltage at its terminals (dv/dt), through the parasitic capacitances inherent to the system.

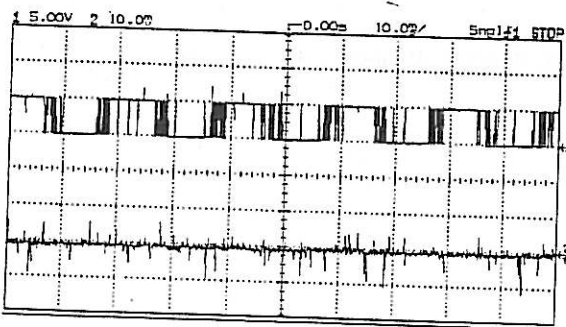


Figure 6 – Common mode noise (ch2), voltage V_{DS} (ch1).

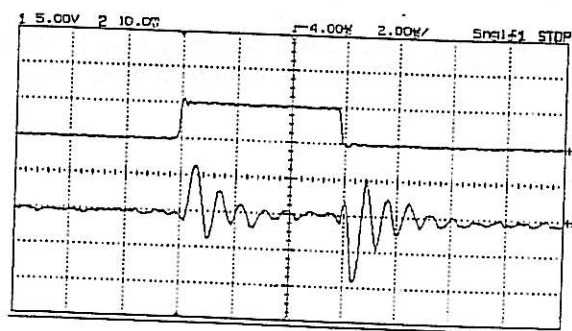


Figure 7 – Expanded common mode noise (ch2), voltage V_{DS} (ch1).

As can be verified, the peaks in the common mode noise (channel 2) occur when the particular MOSFET switch between ON and OFF states (V_{DS} in channel 1). It is possible to observe with detail that the signs of dv/dt and of the peak of the noise current are equal. For the acquisition of these images, at channel 1, a differential voltage probe was used, that allowed to do the measurement of voltage at the terminals of the MOSFET (V_{DS}) with an attenuation of 20x. In channel 2 a current probe, supplies a voltage value proportional to the current measured with a sensitivity of 10mV/A. The probe magnetic circuit was placed around the three conductors, as is shown in figure 5. These oscillograms have been acquired with the motor at 1500 rpm with no load. Therefore we can see here that for a fraction of a microsecond the common mode noise current can almost reach 2A, in peak value.

3. Electromagnetic interference control

The methodology that was followed in dealing with the problem of interference caused by the fast signals at the power circuits level was to progressively assemble the system and observe in successive tests and observations the noise induced in critical signal paths of the low power modules as well as the eventual effects caused at the control logic circuits level operation. Following these observations successive measures were taken in shielding of cables and circuit boards as well as in referencing circuits and shields to ground conductors.

The effects of the EMI counter measures were observed quite clearly in the oscillograms and in the measurements. In terms of system operation, the initial fragility that was apparent in the insufficient stability, lack of smoothness and occurrence of faults with no other explanation, was steadily replaced by a greater robustness and smoothness of running of the machine, due to the effects of the screening of the cables and circuit boards together with the conduction of the noise currents to the ground, as foreseen.

4. Conclusion

One of the aims of this work was to approach a subject of great prominence today, that is the control of motors for traction of electric vehicles with lower voltages of DC rail in the case of use of batteries. Mainly in the control of three-phase induction motors, but valid also for single-phase. Embedded in this subject, and not of less importance, is the problem of EMC, where each time more it is tried to attenuate the EMI effects. With the increase of studies and works carried through on the control of induction motors, there started to appear diverse problems associates to the forms of control of the motor. With special prominence to the use of voltage inverters, that require the use of semiconductors as for example the MOSFET and the IGBT, which obtain switching times of the orders of tens of nanoseconds (high frequency), for high voltages and currents, provoking great amounts of electromagnetic noise. This noise made necessary the introduction of certain rules in use of these inverters, leading to the appearance of norms that impose its reduction, after it has been verified that EMI noise, can endanger the security of people and equipment. In the case of electric vehicles, it can directly influence in various ways of security of the vehicle, and of the accessory systems such as ABS, air-bags, etc. The observation and introduction of countermeasures for EMI has proven that this type of phenomena can be successfully controlled in the laboratory while preserving a high degree of quality and advanced functionality in the electronic power drive system. The counter measures consisted basically in screening the cabling of the system conductors and of the circuit boards with a carefully designed referencing scheme.

5. References

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