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An Embedded Diagnostic System for Wheelchairs Brushless Drives Monitoring

P. Lombardi, C. G. Giaconia, V. Di Dio
Dipartimento di Ingegneria Elettrica, Elettronica e delle Telecomunicazioni, Università degli Studi di Palermo
Viale delle Scienze, ed. 9 – 90128 Palermo, *(Italy)*

***Abstract*--The implementation of a microcontroller based monitoring system for the diagnosis of a brushless synchronous motor drives is presented. It finds its primarily interest on motorized wheelchair for disabled people. The embedded system mainly controls all the principal parameters of the electrical drives together with the power supply system. Pre-failure and failure conditions are routinely logged and, depending on the malfunction severity, alarm messages are created and sent to a remote base station by using the GSM wireless network.**

***Index Terms*— Electrical Traction, Diagnostic, Microcontroller.**

I. Introduction

During the last years there has been an increasing interest, both at national and european level, toward the research on biotechnologies and more generally on human health care. The improvement of life conditions for disabled people is, of course, one of the most important issue for researchers; and the integration of different technologies seems to be the right way to achieve serious improvements over the existing solutions.

A lot of research on mobility of disabled people and related systems has been carried out both for individual and collective solutions. In particular the individual ones almost always adopt electric drives as their preferred traction system. Other combustion based engines in fact aren't suitable for indoor spaces thus seriously limiting the disabled freedom.

Nowadays, the commercial electric wheelchair are equipped by DC motor drives.

Synchronous brushless electric motor drives, supplied by three-phase CRPWM (Current Regulated Pulse Width Modulated) inverters, are recently gaining the interest of the scientific community; it is well known in fact that they completely overcome all the problems due to brush-ring coupling affecting the DC motors [1-4].

The present work starts from the adoption of a synchronous brushless electric motor drives for a motorized wheelchair and shows the design and implementation of the diagnostic and protection control system for the above mentioned application.

In particular it had been already clarified in some preceding papers [5-7] the underneath strategy adopted for diagnosis and protection, together with a first PLC based implementation trying to minimize the overall dimensions of the control system.

The new release here presented is a microcontroller based solution whose performance outperforms the former one by improving the compactness, the power consuming requirements and the overall cost.

A laboratory test rig has been set up within the authors' Department in order to verify the behavior of the new release. The set up shows the brushless electric motor drive, the microcontroller diagnostic system and the some lab equipments capable to stimulate every fault condition and to measure the corresponding system reaction.

II. The Electric Wheelchair Prototype and the Diagnostic System Design Approach

Today's electric wheelchairs for disabled use continuous current motor drives with permanent magnets and speed reduction gears applied to the wheel hub. Continuous current motors guarantee high efficiency and an easy control, but they suffer of several drawbacks mainly related to their native high speed regime and they subsequent need a reduction usually implemented with an endless screw cinematic, thus lowering the effective overall efficiency. Furthermore the brushes-collector system constitutes a necessary electro-mechanical switch whose good working conditions critically depends on quite frequent maintenance.

These above mentioned reasons pushed the scientific community to envisage the adoption of electric motors with sinusoidal current supply. In particular brushless synchronous motors with axial flux guarantee at least three intrinsic advantages:

1. the whole functional and constructive principle leads to a low rotation speed thus an optimized torque can be obtained without the use of a speed reduction gear;
2. their constructive shape allows the use of the rotor as the wheelchair's wheel (the so called motor-wheel) so completely eliminating the differential gear and directly implementing this function within the main controller;
3. finally a brushless motor is based on permanent magnets and it has no electro-mechanical switch hence a low maintenance is necessary, motor downtime is greatly reduced while increasing the overall efficiency during its uptime condition. These

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characteristic also have a positive impact on battery life and its self-sufficiency.

In order to carry out some experimental tests, a laboratory test rig has been set up within our Department, in which the motor used is a radial flux one, being the feature not relevant to the trials purposes.

A three-phase CRPWM inverter supplies the motor, which is able to fed sinusoidal currents. Moreover, thanks to the position transducer the motor is fed with a currents system whose space vector is orthogonal to the rotor flux (brushless drive). The primary source of energy is realized with a regulated DC generator having a nominal voltage of 24 V, equal to the usual one produced by two lead acid batteries in series connection, but keeping the capability to change the voltage output in order to simulate fault conditions.

The design approach, also named Diagnostic and Protective System (DPS), has been conceived to give clear evidence to pre-fault and fault conditions of all the system components.

In particular the evaluation of the working conditions of the wheelchair electric drive has been classified into four main classes [6, 7]:

1. normal working conditions within the specification limits;
2. temporary degradation or loss of function or performance, which are self-recoverable;
3. temporary degradation or loss of function or performance which requires operator intervention or system reset;
4. degradation or loss of function which are not recoverable due to the damage of equipment (components) or to the software failure or to the loss of data.

A more detailed description of this approach has been reported elsewhere [7] and it is summarized in table I where 'P' and 'F' stand for Pre-fault and Fault conditions on Storage Battery (SB), Converter (C) and Motor (M) respectively.

TABLE I: DETAILED LIST OF FAULT AND PRE-FAULT CONDITION ON SELECTED PARAMETERS.

	Anomalous condition indicators	Anomalous conditions		Threshold Levels	Identification	
SB	Storage battery voltage (V_B)	1	Storage battery under voltage	$V_B^* = 22.4V$	$V_B<V_B^*$	P
	Storage battery current (I_B)	2	Intermittent supply	$t_s^* = 1s$	$I_B = 0$, for $t_s>t_s^*$	P
C	Heatsink temperature (T_h)	3	Heatsink overheating	$T_h^* = 125°C$	$T_h>T_h^*$	P
	Voltage references (V_{ra}, V_{rb}, V_{rc})	4	Loss of the voltage references	$V_r^* = 0.2V$	$V_{ra}+V_{rb}+V_{rc}>V_r^*$	F
	Control schedule supply voltages (V_c)	5	Control schedule malfunctioning	$V_c^* = \pm 12$ V $V_c^{**} = \pm 14$ V	$V_c < V_c^*$ or $V_c > V_c^{**}$	F
	Driver supply voltages (V_d)	6	Driver malfunctioning	$V_d^* = \pm 12$ V $V_d^{**} = \pm 18$ V	$V_d < V_d^*$ or $V_d > V_d^{**}$	F
	LEM supply voltages (V_l)	7	LEM malfunctioning	$V_l^* = \pm 3$ V $V_l^{**} = \pm 7$ V	$V_l < V_l^*$ or $V_l > V_l^{**}$	F
	Output voltage hysteresis comparator (V_h)	8	Hysteresis comparator malfunctioning	$V_h^* = \pm 10$ V $V_h^{**} = \pm 14$ V	$V_h < V_h^*$ or $V_h > V_h^{**}$	F
	Current value in the DC bus (I_{hDC})	9	Short circuit in a converter leg	$I_{hdc}^{**}= 30$ A	Electromagnetic switch	F
	Voltage ripple in the DC bus (V_{ripple})	10	Open circuit in a converter leg	$V^*_{ripple} = + 0.5$ V	$V_{ripple}>V^*_{ripple}$	F
M	Motor voltages (V_{Ma}, V_{Mb}, V_{Mc})	11	Short circuit on the motor windings	$V_M^* = 2.4$ V	V_{Ma}, V_{Mb}, $V_{Mc}<V_M^*$	F
	Motor currents (I_{Ma}, I_{Mb}, I_{Mc})	12	Loss of a motor-phase	$t_M^* = 0.5$ s	I_{Ma}, I_{Mb}, $I_{Mc} = 0$ for $t_M>t_M^*$	F

III. IMPLEMENTATION OF THE ELECTRONIC BOARD

Due to the particular conditions imposed by the wheelchair application our studies has been focused to design an embedded system with low electrical power dissipation, low weight and compactness. In order to minimize the used space we chose a microcontroller embedding on board almost all the needed peripherals for the implementation of the diagnostic system [8]. The 8 bit microcontroller PIC 18F452, from Microchip, integrates a USART (Universal Synchronous Asynchronous Receive and Transmit) interface, a 10 bit Analog to Digital (A/D) conversion module, several timers and plenty of program and data memory in order to run the firmware and keep the data coming from the field [9]. Fig.1 shows the internal block diagram of the embedded system.

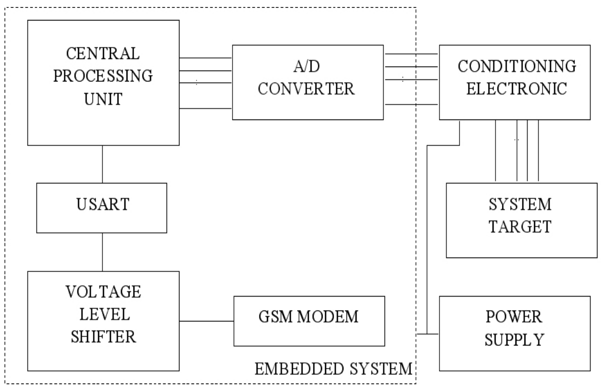

Fig. 1. Block diagram of the embedded electronics system.

Thanks to the use of such a device the external electronic has been reduced to the only discrete components needed to interface the controlling system to the electric drive operating at 24V. Moreover discrete devices also implement the electronics conditioning of several parameters as reported in the following table II:

TABLE II: RELEVANT SENSING PARAMETERS AND THEIR CORRESPONDING ELECTRONICS TRANSDUCERS.

Parameter	Electronic Transducing Method
Motor windings Voltages	Positive Peak detector
Motor windings Currents	Negative Peak detector
DC bus Ripple	Level shifter & Peak detector
Reference Voltage	Analog adder & Peak detector
Hysteresis comparator max Voltage	Peak detector
Input current to driver	Current sensor
Temperature of the power Stripfet	Semiconductor Sensor LM 335

Since the brushless motor results the most delicate element of the whole system, it is necessary to quickly detect fault conditions by reading voltages and currents on every winding; this has been made with several peaks detectors easily implemented with a classic diode-capacitor circuit followed by a level attenuator that will center its output within the microcontroller input dynamic range.

As for the currents circulating within the motor windings, an amplifier acting as an adder has been used and a negative peak detector followed, thus making clear the detection of an open circuit condition on the motor windings.

Ripple events in DC bus of 3-phase full bridge inverter are clear implications of fault conditions in one or more converter's arms. In order to bring to the controller a voltage parameter indicating ripple amplitude, a zener diode was used to subtract a fixed value to DC bus voltage, thus shifting the signal within the dynamic range of the A/D converter. A simple peak detection circuit followed, so allowing the microcontroller to convert analog signal in digital value.

Fault conditions on the MOSFET, driving the electric motor, are identified by monitoring heatsink temperature and by comparing it to the threshold value suggested by the manufacturer's absolute maximum. A semiconductor temperature sensor in a plastic package (TO92 type) can afford the required precision, giving an output signal linear with the case temperature.

Sinusoids, generated by the electronic driver as a reference for motor windings currents, are key parameters for the digital section of the electronic power driver. Hence by summing the three sinusoidal signals related to each motor winding current, with a general purpose operational amplifier, a voltage signal will be obtained and it will fall when one of the three signal is not generated, thus indicating the lack of reference condition detected by the digital core of diagnostic system. In order to evaluate the output voltage of hysteresis comparator in high logic level condition, the system features a peak detector for each signal path related to a motor winding, and a subsequent reduction of the obtained voltage, thus fitting the microcontroller's dynamic input range.

Another frequent source of fault in electrical propulsion systems is a bad wiring connection to the battery operated power supply. A current sensor has then been used to detect current changes from the battery wires. This sensor is implemented by suitably amplifying the voltage drop on a small sense resistor.

Finally all supply voltages internally obtained through voltage regulators (control schedule's, MOSFET driver's, DC link's etc..) or brought by external sources (battery) are monitored and evaluated by the microcontroller's A/D converter.

An analog multiplexing systems capable to switch among all the electrical circuits parameters is used to the purpose. Even if the microcontroller features internally multiplexed analog inputs, an external multiplexer (shown in Fig.2) [10] was included in the diagnostic system in order to increase analog microcontroller's inputs while leaving available controller's general purpose I/O pins for future developments.

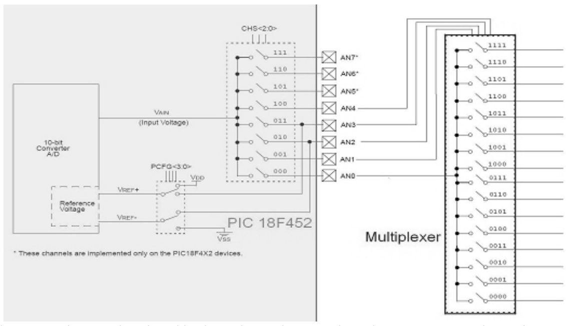

Fig.2: Schematic detail showing the analog input expansion through multiplexing.

All these analog parameters, coming from the multiplexer, are cyclically digitalized and each digital value is compared with its related threshold reference value which provides a maximum and/or minimum limit for its normal working range.

These values are usually kept within a non volatile memory integrated on the microcontroller's chip. The polling method is implemented within the microcontroller through the firmware written in assembly language and loaded in the program memory.

The control system starts by enabling the GSM modem (located within the board) through a pulse signal and when it returns an "enabled" acknowledge signal, the firmware sets it for registration on the available GSM network (see Fig.3) through standard AT commands sent by the USART peripheral interface [11,12]. In the mean time the field parameters are routinely tested and when a fault is detected, the controller sends to GSM modem a stream of AT commands, inducing it to SMS the exact fault diagnosis.

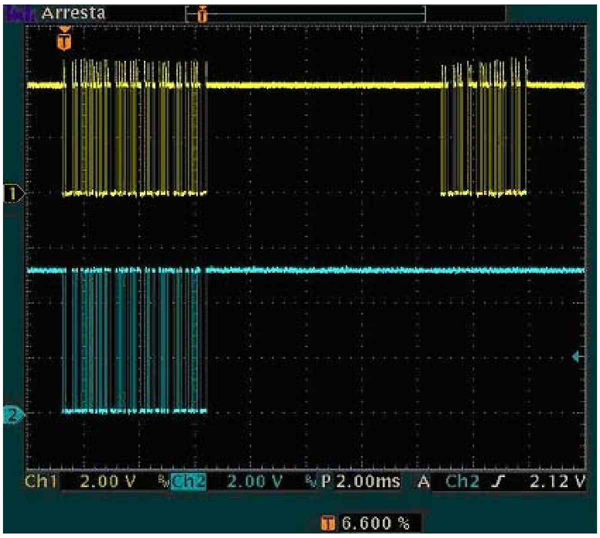

Fig.3.: Oscilloscope traces of transmitted (up) and received (down) GSM signal.

It's expected that the wheelchair could continue its motion if the detected event is a pre-fault condition. Finally the microcontroller's firmware was realized taking care of the timing optimization in order to avoid idle periods while in the executing phase.

In Fig.4 a picture of the implemented device is shown (the microcontroller is located on the rear side of the board).

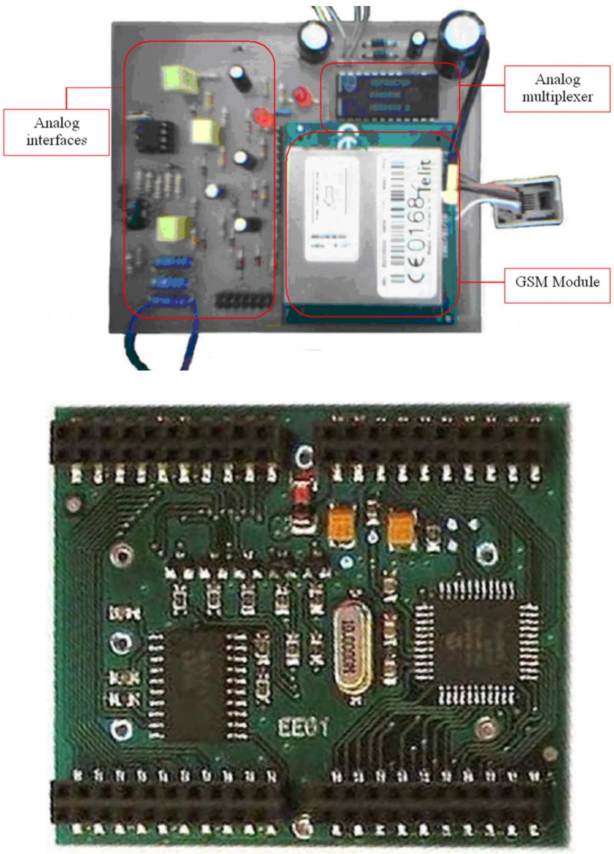

Fig.4: (a) Top view of the implemented embedded system and (b) rear view of the module holding the microcontroller.

IV. Conclusion

This paper described a microcontroller based DPS of an electric drive for wheelchairs.

The aim of the work tried to implement a more robust and reliable diagnostic system while simplifying the disabled people interface.

The proposed solution reaches some objectives already fulfilled with the preceding PLC-based solution as the reprogrammability, the ability to detect fault and pre-fault conditions and to send the relative messages through a GSM network

In addition the embedded system here presented has lowered the overall cost, weight and the external dimension of the DPS.

This has been implemented with an 8 bit microcontroller core, from Microchip and a multiplexing systems capable to switch among all the electrical circuits parameters. A complete diagnosis loop takes less than 0,4 sec in the worst case; so the whole monitoring system reacts quite quickly to possible malfunctions.

The microcontroller is located on a board together with a GSM Module. The firmware also implements a selection among various precompiled SMS messages and writes them on the input buffer of the GSM module depending on the activated alarm (if an out-of-range measurement has been monitored).

An analog interface has been built in order to implement the needed electrical conversion between all the electrical parameters and the valid input range of the A/D converter. The whole diagnostic system is characterized by a power dissipation less than 500mW, mainly due to the GSM module; a total weight of 90g and overall dimensions of 100x80x10 millimeters.

Finally the developed methodologies for fault and pre-faults conditions on the DPS are valid in a more general case where electric drives are to be used.

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