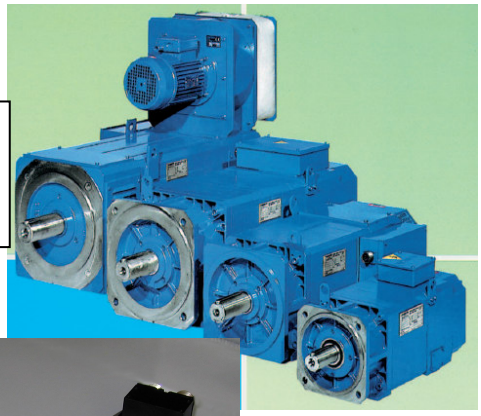
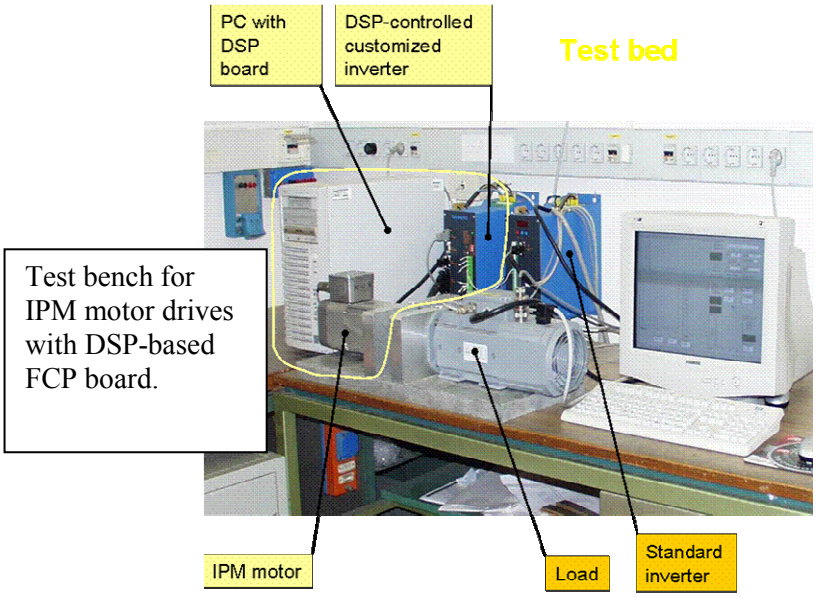
Modulo 2:

	FORM N.: 1 PROGRAM EVALUATION FORM
3	Program Title
	ELECTRIC DRIVES
3	Coordinator
	Silverio Bolognani
3	Task of the Program
	The program is devoted to theoretical studies and experimental validations of topics related to the design and the applications of electrical drives. To this purpose electrical motors and control systems for industrial, civil and commercial drives are analysed, designed, prototyped and tested in the Electric Drives Laboratory (EDLab) of the Department. The Laboratory was started in the first 90's years to strengthen the research work on electric drives, that before was carried out almost in theoretical form, and to acquire and perform research projects ordered by industrial companies. In the first half decade the activities were mainly oriented to the motor control (fuzzy logic control, sliding mode control and sensorless control for drives were among the topics considered). Then studies on the design of electric motors dedicated to drive applications were initiated and they were at first oriented to Surface mounted PM (SPM) synchronous motors. Successively Interior Permanent Magnet (IPM) and pure reluctance (REL) synchronous motors as well as induction motors (IM) have been studied, designed and prototyped in the Laboratory. Both rotating and linear version were considered. Most of them have became products, put on the market by the industrial companies that ordered their design (see figure below). Induction motors for inverters   Re-design of PM motor (left) for high torque/volume. In parallel the research work on the drive control was enforced by equipping the Laboratory of some

Fast Control Prototyping (FCP) test benches (next figure) in order to validate experimentally the designed control algorithms. High performance dSpace FCP boards (www.dspace.de) combined with Matlab/Simulink® are the basic equipment for control prototyping. Sensorless speed control for Surface mounted PM synchronous motors, flux-weakening algorithms for IPM motor drives, novel PWM techniques and other themes were developed up to a preliminary industrial level.



Recently the two main fields of activities, design of controls for drives and design of motors for drives have been often involved on common projects with the aim of optimizing the results of each of them according to the requirements of the other, for the best overall performance of the system.

The activities of the Research Program on Electric Drives have been hardly promoted in the industrial area and many times they are carried out by the friendly support of industrial partners. Technical-scientific workshops were organized in the industrial district of Vicenza (near to Padova) to meet industrial people and to stimulate common projects; the Coordinator of the Program was for a long time Member of a Working Group of CPV (Centro Produttività Veneto, an Agency of the Chamber of Commerce of Vicenza for continuous education and technology transfer), and President of an Association of local Industries in the Power electronics and Electromechanical fields. In order to make more effective the research activity especially for the industrial customers, one year ago the Laboratory has been certified according to the quality standard UNI EN ISO 9001-2000.

In spite of the limited number of staff component permanently dedicated to this Research Program, several research projects (also financed by EC) have been concluded in the last years. In addition to the applied research projects, a non negligible basic research activity is performed, supported by University and Ministry funding and by a Departmental surplus fund derived from concluded projects of the Program being considered.

Many of the research results have been and are used to improve and to update the contents of the courses on the fields of *Design of electrical machines* and of *Electrical drives fundamentals and applications*. Now the teaching activity serves specialized courses on design of electrical motors (Laurea degree in Electrical Engineering) and on design of drive control (Laurea degree in Automation Engineering) as well as non-electrical Laureas as Aerospace Engineering and Management Engineering, where more attention is paid to motor and drive applications, rather than motor and drive design.

3	Specific projects (see also Annex1)
	In the period being considered the following Specific Projects have been concluded, completely

performed or started.

European Craft Project: "*Submersible electrical motor*", aimed to develop a 6 inches, high efficiency squirrel cage submersible asynchronous motor, designed for 45 kW (50% higher than the maximum rating power of the motors manufactured by the industrial proposer of the project) to be used in connection with pumps within 6 inches wells, improving at the same time characteristics of reliability, environmental compatibility and reduced maintenance which are even more important for systems operating at high depths. The project started on June 2002 was concluded successfully in 2004 by testing a prototype of the motor with positive results. Finite element analysis combined with an optimization procedure was used to design the motor in cooperation with mechanical designers of the Department of Mechanical Engineering.

National Project PRIN 2000 – *"Application of Synchronous Motor Drives to High Efficiency City-Scooters",* aimed to study and develop PM synchronous motor drives for electrical scooters for the urban cycle. In addition to the design of the motor, some other topics have been faced in EDLab as the design of the flux-weakening control of the drive. The project was carried out in the period 2001-2002 in collaboration with the Universities of Cassino, Rome, L'Aquila, Parma, Udine and Polytechnic of Torino. Prof. S. Bolognani was the national coordinator. Interior Permanent Magnet synchronous motors with new rotor configurations exhibiting Ld>Lq were developed in EDLab for this application, with advantages in terms of overload and flux-weakening capability (patented).
For the presentation of the scientific results and prototypes of the whole national project, the 2003 Workshop "AC motor drive technology" was organized in collaboration with CPV and held in Vicenza. Invited speaker was prof. B.K.Bose.

National Project PRIN 2001 – "*Energy efficiency improvement in electric drives for home and civil appliance*", aimed to analyze and suggest new design criteria for both the electrical machines and the electrical drives, in order to increase the power efficiency, in particular for home appliance systems (i.e. refrigerators, wash-machines, ...) that use electrical motors and electrical drives, with power under 1 kW. The project was carried out in 2002-2003 in collaboration with University of L'Aquila, Polytechnic of Torino and Polytechnic of Milano.
The use of Soft Magnetic Composite materials and new configuration of the stator of PM motors were investigated in EDLab to meet the task. A prototype of motor was realized by an industrial partner and some results transferred to next Research Contracts.
For the presentation of the scientific results and prototypes of the whole national project, the 2004 Workshop "AC motor drive technology" was organized in collaboration with CPV and held in Vicenza. Invited speaker was Dr. V.Stefanovic.

National Project PRIN 2003 – *"Innovative electric drive for power steering*" with the general task of studying, designing and realising electric motors and drives suitable for a car power steering of the EPS or SBW type (that are full electric power steering). The project was carried out in the years 2004-2005 in collaboration with the Universities of L'Aquila, Bologna and Udine, and Polytechnic of Torino.
A continuation of the project has been planned in EDLab (supported by surplus funds) to complete the tests of the motors installed into the mechanical assembly designed by the partners of the University of Bologna and to test the electric motor drives on a test bed reproducing realistically the mechanical reaction of a steer system.
The designed steer-by-wire system requires two electric drives: a) The first drive is used to perform the steering action. For the sake of reliability two twin motors, separately supplied, are mechanically linked to the steering rack. b) The second drive generates the torque feedback on the steering wheel. IPM synchronous motors with innovative rotor configurations are used for the steering actuator while a SPM synchronous motor, with fractional-slot windings, is used for the torque feedback.
The IPM motor drives should exhibit some peculiar features:
(1) Smooth torque with minimum ripple
(2) High efficiency
(3) Fault-tolerance, which is an imperative requirement in electric motors for steering application. In particular each IPM motor has to exhibit very low braking torque in case of a short-circuit fault to

allow the second motor to be able to temporary manoeuvre the vehicle. Precise criteria have been determined to design the IPM motors for a limited short-circuit current and low braking torque. The design criteria have been verified by experimental validations.
(4) Minimum package size and weight (so that a rotating motor with gearbox has been preferred to a direct drive system).

As regards the control, the design of the algorithms for a coordinated control of both PM motor drives have been developed and tested. The IPM motor drive requires an accurate position control to achieve the desired steering angle. At the same time, the feedback motor has to be commanded by a suitable torque feedback control for an appropriate steering feel. An intensive work is still in progress to model the mechanical dynamics of the steering system. The behaviour of the steering system will be implemented in a test bed for a realistic test of the drives performance.

National Project PRIN 2005 – *"Permanent magnet synchronous motor drives for direct drive applications in ship propulsion"* that will concern on the study, design and testing of electric and mechanical components for a naval propulsion unit, using a synchronous permanent magnet motor direct coupled to the propeller. The aim of this project is also to define an electro-mechanical design methodology, strongly integrated with both the control and the dynamics of the driven load. The project has been proposed and financed during 2005 and is the concrete continuation of some preliminary works done on the subject in the period being considered, in collaboration with researchers of the Dept. of Mechanical Engineering in Padova and researchers of the University of Helsinki. Direct drive sub-jet propulsion system for high speed crafts is the solution that will be examined during 2006-2007. At now industrial partners for prototyping the drive seem available.

Departmental Project – "*Innovative motors and controls for electrical drives*". The project was initiated by the Department and financed by surplus funds of the Electric Drives Laboratory, resulting from concluded Research Contracts. The aim of the project is twofold: to support basic researches and to support preliminary start-up studies (some of them are later proposed for more consistent or applied projects).
In the period being considered the following topics were mainly examined (for those still in progress, more details are given) :

- *Sensorless control of SPM synchronous drives* in particular with reference to the tuning of the Extended Kalman Filter algorithm and to extend the application of the latter to non-sinusoidal bemf motors and IPM motors also in the flux-weakening region.

- *Sensorless position control of IPM motor drives*. The technique based on the injection of a high-frequency voltage signal superimposed to the steady-state voltage is investigated. It has been realized that the accuracy of the rotor position detection depends strongly on the rotor saliency which is affected by the rotor geometry, saturation and cross-coupling. As an original contribution, it has been found that the inset motor is a very suitable machine for this control technique. Its rotor saliency is not very high, but the saturation of the rotor iron is low so that a rotor saliency can be detected even at high currents. This implies that the sensorless technique can be effective even under overload operating conditions. An inset motor has been manufactured to confirm the predicted performances and to compare them with those of an IPM motor using the same stator. This research attracts the attention of prof. Seung-Ki Sul of National University of Seoul and a collaboration with him have been started. The results of this common research have been submitted to two International IEEE Conferences planned for 2006.

- *PM linear motors design*. Several studies on PM linear motors have been carried out in collaboration also with Prof. J.Corda. A new configuration of a tubular PM motor has been designed with windings and PM excitation on the same side, while the other side (let's say the cursor) is passive (patented).

- *PWM inverter control*. FPGA based controllers were developed also with random frequency and dead-time compensation capabilities.

- *Time optimal control of current and torque in IPM synchronous motor drives*. Different version of the algorithm, with increasing performance and implemented both in DSP and FPGA devices, have been developed. The last version allows any torque step variation to be obtained in the shortest time by proposing the optimal voltage vector to be applied to the motor according to Pontryagin's theory. Experimental tests confirm the theoretical predictions.

For the presentation of some of the results of this project, the 2005 Workshop "AC motor drive technology" (focused on Linear motors for industry applications) was organized in collaboration with CPV and held in Vicenza. Invited speakers were Prof. I.Boldea and N.Schofield.

In addition several confidential Research Projects have been ordered to EDLab by industrial companies. The complete list of them is attached. Some of them have common requirements to be satisfied even if applications are different. Apart from the most recent ones (and a few number of them whose conclusion has been postponed), they are terminated and they have produced in some cases innovative contributions for both industrial R&D and for scientific publications.
Hereafter a selection of the most significant results and/or topics under study is given.

PM Motors with Fractional-Slot Windings - *The topic is related to two industrial research contracts for low-power PM motor drives for home-appliances and has been already faced in PRIN03*
In the last years, stators with fractional-slot winding for PM machines are becoming more and more attractive. This is due to two main reasons. The first one is that a fractional-slot winding allows very short end windings to be achieved, especially by the solutions of coils wound around a single tooth. The second one is that the effect of the increase of MMF harmonics introduced by the fractional slot winding is minimized by the low magnetic permeability of the PMs in the rotor.
The activity includes:
- development of a suitable theory for the study of the fractional-slot windings,
- criteria to investigate the winding feasibility,
- criteria to find the MMF harmonics,
- tests on fractional-slot winding motor prototypes.

The theory of fractional-slot winding based on the classical theory of the star of slots, as originally proposed by Richter to study the back EMF of the first harmonics, has been extended to study also the back EMF harmonics of various order as well as the harmonics of the MMF distribution. An original contribution is the extension to single-layer winding.
Special windings (and the rules for their design) is under study. In particular :
- windings yielding minimum torque ripple, required in many applications to reduce the application noise (home appliance, machine tools, ...);
- windings yielding null mutual coupling among the phases, that are required in fault-tolerant motors;
- windings yielding minimum stress on the rotor PMs.

Fault-Tolerant Motors and Drives - *The topic is related to i) a study on aerospace applications of drives (basic research), ii) National Research Project PRIN05 on electric ship propulsion system. It and has been also already faced in PRIN03 and before.*
Fault-tolerant capability is a key issue in a set of applications in which the electrical motors and drives are employed. The fault-tolerant systems have to satisfy two requirements.
(1) The first is the capability to confine the fault to the damaged component and to isolate it without propagation to the entire system;
(2) The second is the capability to be operated even under faulty conditions;
It has been found that to satisfy the first requirement, the motor has to be conveniently designed with a large leakage inductance to limit the short-circuit current below a given threshold. Some motors have been designed and prototyped. To this aim, the results obtained from the analysis of the fractional-slot windings have been used, since these windings naturally exhibit a high leakage inductance.
As far as the second requirement is concerned, the designs of the motor and the inverter cannot be kept distinct, and different solutions can be adopted. A multi-phase motor drive can be designed, e.g.

a six-phase or a five-phase motor without significant increase of the motor cost and with a limited increase of the converter cost.
Further drive design issues include:
(a) an electrical separation among the phases: each motor phase fed by a full-bridge converter.
(b) a physical separation of phases, in order to prevent a phase-to-phase fault: each phase coils wound around a single tooth, with a single coil side per slot. This is possible only with a fractional-slot winding motor.
(c) a low mutual inductance among the phases, to prevent that healthy phases energize the fault.
(d) re-configurable converter topology and control, in order to adapt them to the different faulty situations.
Four motor prototypes have been designed and built in the Laboratory:
Two of them are induction motors, designed with six-phase windings (really they have a double three phase winding). In case of fault of one of windings, the other can continue to operate, at reduced power.
The other two motor prototypes are five-phase PM machines, with fractional-slot winding, and they use a double-layer and a single-layer winding respectively. The windings have been designed with a proper leakage inductances to reduce the short-circuit current to 1.5 times the nominal current, and with no mutual inductance. A five-phase full-bridge converter is under construction.
The current control strategies in case of fault of a five-phase motor drive have been analysed. Three faults have been considered: (i) continuous open-circuit of one phase, (ii) continuous open-circuit of two phases, (iii) continuous short-circuit of one phase. Several tests are in progress.

Reduction of the Torque Ripple in Synchronous IPM and Reluctance Machines - *The topic is related to two industrial research contracts for low-power PM motor drives for home-appliances and it has been already faced in PRIN03 and in linear PM motors.*
A common problem of synchronous machines with anisotropic rotor is their high content of torque ripple. The interaction between spatial harmonics of the electrical loading and the rotor anisotropy causes a high torque ripple that is intolerable in the most of applications.
Classical remedies are
1) the rotor skewing (stepped-skewing in PM motors with the rotor split in two or more parts, each of them skewed with respect to the others);
2) a suitable choice of the number of flux-barriers with respect to the number of stator slots per pole;
3) the pole shifting: the flux-barriers are shifted from their symmetrical position (in this way, a sort of compensation of the torque harmonics is achieved);
As an original contribution, a novel strategy for synchronous motors with flux-barriers in the rotor has been developed. It is based on a two-step design procedure: At first the flux-barrier geometries that cancel the torque harmonic of one order are identified. Then, couples of flux-barriers of different geometry are combined together so as to put the remaining torque harmonics in opposition. This second step is achieved in two ways: (i) by adopting laminations of different kind; (ii) by adopting different flux-barrier geometries in the same lamination. The first solution has been called "Romeo and Juliet" configuration; the second one is called "Machaon" configuration, the name of the butterfly with two large wings and two small wings.
Promising results have been reached analytically and by simulations. Five motors have been then prototyped to verify the analytical predictions:
(1) IPM motor with 2 flux-barriers per pole that are equally spaced (as found in literature),
(2) IPM motor with 3 flux-barriers per pole that are equally spaced (as found in literature),
(3) IPM motor with 2 flux-barriers per pole with the innovative structure "Romeo and Juliet",
(4) IPM motor with 2 flux-barriers per pole with the innovative structure "Machaon",
(5) IPM motor with 2 flux-barriers per pole with all different barriers (the name of this configuration is "Chimera"). This motor is an immediate extrapolation of the rotor with pole-shifting.
The experimental tests carried out up to now, substantially confirm the predictions: the torque ripple of all the configuration is very low at any current level. Patent will be required.

High Torque-to-Inertia Ratio - *The topic is related to an industrial research contracts for high performance PM motor drives.*
This research was promoted by an industrial company that asked the design of a motor exhibiting

high dynamic performance, required in many applications, such as machine tools, packaging machines, positioning machines and so on. The motor has been designed for a high ratio between the torque and the rotor inertia. PM motors are suitable solutions to meet such a requirement. A SPM motor has been chosen, even if an IPM motor with tangential magnetization has been also considered for its higher air-gap flux density.
A stator with separated teeth was adopted: each single tooth was separated from the other, allowing the coil to be wound around it with a very high filling factor. Then, the teeth were assembled together to form the final stator.
An analytical model of the SPM motor is used to find the best configuration in term of the maximum torque-to-inertia ratio on the constraint of given stator outer diameter.
After the design optimization, two prototypes have been built (one is shown in the first figure of this report). The first one was an SPM motor, while the second one was an IPM motor with tangential magnetization. The two prototypes were tested both in EDLab and in the company laboratory. The results were really satisfactory. Both the prototypes reach a torque-to-inertia ratio about two to three times that of the standard brushless PM motors. The maximum acceleration (without load) with a stator current three times the rated current reaches a value equal to 87000 rad/s^2 by the IPM motor, a little lower than the SPM motor that reaches a maximum acceleration of 91000 rad/s^2.

High Torque Direct-Drive PM Motors and Drives- *The topic is related to i) two industrial research contracts for lift and crane applications, ii) PRIN05 on ship propulsion.*
High torque, direct-drive systems, used for lift, hoist, winch and crane, yield lower plant cost, reduced spaces and negligible maintenance. In addition, the machine room in elevator system can be eliminated.
Two different types of surface-mounted permanent-magnet motor for direct-drive elevator systems were designed: the first one with external stator and the second one with external rotor.
The SPM motor appears adequate for such an application, exhibiting a very high torque-to-stator joule losses ratio, that is suitable for the intermittent duty, required by the considered application. In addition, the high magnetic air-gap allows a linear torque vs. current curve up to very high currents. The key characteristics and the design criteria have been studied analytically to the aim of achieving general results. Afterward, FEM simulations have been carried out to improve the design, considering torque ripple, local saturations, and so on, which are not considered in the analytical study.
The two motors have been manufactured by the companies. Experimental results compared with the predicted ones show a good agreement.
For the lift application, torque, speed and position control has been also faced. Vector control is used and the critical specification of controlling the cabin position when the brake action is removed at any door closing in under study.
The activity on this topic is now moved to the design of a PM motor for ship propulsion.

High Speed PM Machines - *The topic is referred to i) two industrial research contracts for hand tool and home appliance applications; ii) an University financed Research Project on distributed electric energy generation)*
The research has been carried in order to design two PM machines:
(1) a two-pole motor for a hand tool.
(2) a four-pole generator for local energy generation on trucks.
For the first application, the required speed was 30 krpm and the motor power about 1 kW. Different topologies were investigated, including slotted and slotless stator, laminated and sinterized stator, Ferrite and NdFeB magnets. The geometry of each topology has been optimized taking into account thermal, mechanical and magnetic limitations of the materials. After this research, the most promising solutions have prototyped: a slotted machine and a slotless machine, both of them with a NdFeB magnet rotor. Flux density in various parts of the machine has been measured and compared with the analytically computed one, obtaining a good agreement. The slotted stator-laminated solution has been chosen and industrialized by the industrial customer.
For the second application, a flux-weakening capability was required. The maximum speed was fixed to 12 krpm. The maximum-to-base speed range is about 3.5. A further constraint is fixed by the maximum back EMF at the maximum speed, in order to prevent too high voltage. The external dimensions were also fixed, so that an optimization of the rotor structure was necessary to satisfy the

	requirements. The machine rotor was optimized so as to achieve a high torque density, but with a limited torque ripple, to avoid vibration and acoustic noise. A first prototype of the electrical generator was manufactured and tested. The results are quite good, even if a better quality lamination should be adopted in order to reduce the iron losses at the highest speeds. The activity on this topic is now moved to the design of a 60-100 krpm PM generator to be applied in a microturbine system for electric energy generation. This is a research project financed by an University fund, involving also other research groups of the Department on other pertinent topics. Industrial supports for this activity is also foreseen. **Speed Sensorless IM Drives -** *The topic is referred to an industrial research contracts for home appliance applications.* The design and implementation of a speed sensorless control of an induction motor drive for washing machine is the topic of the project. The three-phase motor drive exhibits a large constant power region and a maximum operation speed of 18 krpm. Exhaustive study and comparison of different control solutions have been performed in the last months of 2005 in order to point put potentials and pitfalls of each of them, in particular regarding the parameter sensitivity. Cost and complessity of the implementation have been also evaluated. A novel scheme, obtained by improving existing solutions proposed in the literature, has been developed and it is now under implementation by one of the FCP station of the Laboratory.
4.b	Personnel
	Faculty staff involved in the Program is composed by - *Silverio Bolognani* (Full Professor) - is a native of the Trento province, in the North of Italy. He received the Laurea degree in Electrical Engineering from the University of Padova, Italy, in 1976. In the same year, he joined the Department of Electrical Engineering at that University, where he was involved in the analysis and design of thyristor converters and synchronous motor drives. After that, he started the Electrical Drives Laboratory where a variety of researches on brushless and induction motor drives are carried out in the frame of European and National research projects. He is presently engaged in researches on advanced control techniques for motor drives and motion control and on design of ac electrical motors for variable speed applications. He is author of more than 200 papers on electrical machines and drives. - *Nicola Bianchi* (Associate professor) - *Gabriele Marchesi* (Associate Professor – part-time) The following PhD students have carried out/ are carrying out their activity in EDLab: - Francesco Tonel (2001-2003): Analysis and Design of PM linear motors for drives. - Fabio Luise (2001-2003): Analysis and design of electric motors for submersed and special applications. - Giorgio Grezzani (2003-2005): Analysis and Design of IPM synchronous motors. - Matteo Tomasini (2004-2005): Advanced Control Algorithms for Electric Drives. - Michele Dai Prè (2005): Analysis and Design of Faul-Tolerant Electric Drives. - Luca Sgarbossa (2005): Electrical Drives for Mechatronics Applications. Research activities are also supported by temporary staff, recruited among the new graduated Engineers through grants or short-term contracts. In the period being considered the laboratory has been served by temporary personnel for a total of about 180 man-months (36 man-months/year) with a cost to the projects of about 220.000,00 € (44.000,00 €(year). Technician service for the Laboratory is generally assured by PhD and temporary staff. Recently the small group of technicians of the Department has been reorganized and one of them, Mosé Castiello, is part-time dedicated to the Electric Drives Laboratory.

5.b Funds

Average-per-year and Total-per-year funds of the Program are given in the Table below. Multiyear funds are classified according to the initial year of the project.

RESEARCH FUNDS						
	2001	**2002**	**2003**	**2004**	**2005**	**Average per year**
	€	€	€	€	€	€
UE	0	0	110880	0	0	**22176**
MIUR funding	41316	0	39600	0	46000	**25383,2**
University basic research (ex 60%)	3615	3539	3448	3570	3949	**3624,2**
University contributions for national and specific projects	7747	0	10300	0	19800	**7569,4**
Industry research contracts & contributions	58500	70000	108000	24000	81000	**68300**
TOTAL per year	**111178**	**73539**	**272228**	**27570**	**150749**	**127052,8**

6 Equipments

The Laboratory is equipped with:

n. 1 *Automatic Motor Test Bench for Static Measurements* – It has been designed and realized mainly for automatic tests of synchronous motors. The motor under test is supplied by means of a dedicated current-controlled inverter while the braking motor is supplied by means of a standard inverter. The first inverter is commanded by a current hysteresis control, so that any current waveform can be forced in the motor phases. The standard inverter-fed motor drives the motor under test at a very low and constant speed through a high ratio gear. Both the motor drives are commanded by a DSP board programmed by a PC. A torque-meter is used to measured the shaft torque; an encoder and three Hall current sensors measure position and currents. Possible programmed tests are:
- measurement of the cogging torque versus rotor position,
- automatic detection of the d-axis and q-axis of the rotor,
- measurement of the current vector angle to carry out the maximum torque at given current,
- measurement of the torque versus rotor position at given dc stator current,
- measurement of the torque ripple under load,
- measurement of the torque for different combinations of d- and q-axis currents,
- measurement of the differential inductances injecting a high-frequency voltages.
- measures on induction motors are in preparation

n. 1 *Automatic Motor Test Bench for Dynamic Measurements* – It has a similar structure of previous test bench by the gear is absent and the motor under test is driven at a appropriate speed. Voltages applied to the motor are also measured. Possible programmed tests are at now:
- automatic detection of the d-axis and q-axis of the rotor,
- measurement of the flux-current characteristics,
- measurement of motor efficiency.

n. 3 *Torquemeters* (2, 5, 20 Nm)

n. 1 *Motor prototyping station* – It allows motor windings and motor assembling to be performed.

n. 1 *dSpace 1003 FCP dsp-based board* – It command a couple of brushless motor drives (one plays the role of motor and one of load) axially connected an by elastic joint. Joint elasticity, motor and load inertia and backlash can be adjusted for experiments of motion control.

n. 3 *dSpace 1103 FCP dsp-based boards* – They may control ac motor drives of different type for drive control experiments.

n. 2 *dSpace 1104 FCP dsp-based board* – One is dedicated to the motor test bench; The other may control ac motor drives of different type for drive control experiments.

	High performance and general purpose oscilloscopes as well as different evaluation boards and common laboratory instrumentations are also available. In addition EDLab can use proprietary and commercial software packages for motor analysis.
7	Collaboration with other research Institutions
7.a	Many research projects, mainly in the field of motor control, have been carried out with the effective collaboration of *Mauro Zigliotto*, Associate Professor of the University of Udine since November 2000, former Researcher of DIE and staff component of EDLab. In addition some projects have been developed in collaboration with Prof. *Bruno Atzori* and Researcher (PhD) *Giovanni Meneghetti* (UE Contract), Prof. *Vittorio Quaggiotti* and Prof. *Ernesto Benini* (Ship propulsion) all with the Department of Mechanical Engineering and Prof. *Alessandro Paccagnella* and Assistant Researcher (PhD) *Marco Ceschia* of the Department of Information Engineering (FPGA applications) all of the University of Padova. National Research Projects (PRIN) were carried out in collaboration with other Italian Universities as reported above in describing the Specific Projects.
7.b	S.Bolognani and N.Bianchi have been serving International Conferences as member of the Steering or Technical Committees. Collaborations for common activities and publications are/have been taken with: Antero Arkkio - University of Helsinki Brian. J. Chalmers – University of Manchester Edward C. Lovelace – SatCon Technology Corp. Ion Boldea – Univeristy of Timisoara Michael Egan – University College Cork Nigel Corda – University of Newcastle Patricia Jansson – Hoganas Co. Peter Vas – University of Aberdeen Robert D. Lorenz – University of Wisconsin-Madison Seung-Ki Sul – University of Seul Shigeo Morimoto – Osaka Prefecture University Tapani Jokinen – University of Helsinki Thomas M. Jahns – Univerity of Wisconsin-Madison
9	Other activities relevant to the Research Program
	In order to stimulate the interest to the topics of Research Program and to improve the contacts to Industrial partners, EDlab co-organized editions 2001, 2003, 2004 and 2005 of the Workshop “AC Motor Drive Technology” in Vicenza, with the participation also of invited authoritative international speakers. In 2001 N.Bianchi and S.Bolognani were invited as speakers in a Post-graduated Seminar at the Helsinki University of Technology. Notes were prepared and distributed to the students. In 2004, N.Bianchi co-organized with T.Jahns the Tutorial Course "Design, Analysis, and Control of Interior PM Synchronous Machines" during the 2004 IEEE Industry Applications Society Annual Meeting, Seattle, USA. S.Bolognani is Chairman of the IEEE North Italy IA/IE/PELS Joint Chapter. Several seminars were organized in Padova and Vicenza in collaboration with CPV, IEEE, AEIT with

invited international speakers (Williamnson, Rajashekara, Jansson, Boldea, ...)

Bolognani was invited as speaker special sessions or panels in international conferences (IECON, EPE, EPE-PEMC...).

As a consequence of the rule "one paper-one participation" almost generally imposed by the international conferences, people of the Laboratory have been registered to about 50 participations to Conferences in the last 5 years.

11 Research Products (see also Annex 2)

11.b

RESEARCH PRODUCTS						
	2001	**2002**	**2003**	**2004**	**2005**	**Total**
Papers on Journals	3	3	5	5	1	17
Chapters in book	1	1		2		4
Books/Notes/Reports	5				1	6
Papers in Proceedings of Conferences	5	19	10	10	13	57
Patents				2		

The list of publications is attached.

11.c

1. S.Bolognani, L.Tubiana, M. Zigliotto, "Extended Kalman Filter Tuning in Sensorless PMSM Drives", IEEE Trans. on Industry Applications, vol.39, no.6, pp., Nov.-Dec. 2003.
2. N. Bianchi, S. Bolognani and F. Luise, "Potentials and Limits of High Speed PM Motors", IEEE Trans. on Industry Applications, vol.IA-40, No.6, Nov.-Dec. 2004, pp. 1570 - 1578
3. S.Bolognani, M.Tomasini, L.Tubiana, M.Zigliotto, "Design and Implementation of a Minimum-Time Torque Control for IPM Motor Drives", Conference Records of IEEE Industry Application Society, IAS 2005, IEEE Catalog No.05CH37695C, ISSN: 0197-2618, pp. 304-310, Hong Kong, PRC, 2005.
4. N. Bianchi, S. Bolognani, and M. Zigliotto, "Design Hints of an IPM Synchronous Motor for an Effective Position Sensorless Control", in Proc. of IEEE Power Electronics Specialist Conference, PESC'05, Recife, Brazil, 13-16 June 2005, 7 pages, CD-Rom
5. N.Bianchi "*Finite Element Computation of Electrical Machines*" CRC Press 2005.

ANNEX N.1:
TO PROGRAM EVALUATION FORM N. 1

Program Title

ELECTRIC DRIVES

List of publications in the period 2001-2005

2001

1. S.Bolognani, M.Zigliotto, M.Zordan, "Extended-Range PMSM Sensorless Speed Drive Based on Stochastic Filtering", IEEE Trans. on Power Electronics, Vol. 16, No 1., pp. 110-117, January 2001
2. N. Bianchi, S. Bolognani, "Optimal Motor Design for Flux-Weakening Applications" in Innovative design and optimisation of electrical machines, Post-graduate Seminar, Helsinki University of Technology, 26 Feb - 3 Mar 2001, Otaniemi Espoo, Finland, ISBN 951-22-5367-4 ISSN 1455-2485.
3. N. Bianchi, S. Bolognani, "Finite Element Method for Electrical Machines Analysis and Torque Ripple in Permanent Magnet Machines" in Innovative design and optimisation of electrical machines, Post-graduate Seminar, Helsinki University of Technology, 26 Feb - 3 Mar 2001, Otaniemi Espoo, Finland, ISBN 951-22-5368-2 ISSN 1455-2485.
4. N. Bianchi, S. Bolognani, "Innovative Optimisation Techniques in Electrical Motor Design" in Innovative design and optimisation of electrical machines, Post-graduate Seminar, Helsinki University of Technology, 26 Feb - 3 Mar 2001, Otaniemi Espoo, Finland, ISBN 951-22-5370-4 ISSN 1455-2485
5. N. Bianchi, S. Bolognani, S. Cervaro, L. Malesani, M. Zigliotto, "Brushless Motor Drives for Ventilation", in Final Report of MURST-PRIN 1998 (#9809322667) "Electrical Drives Adopting Motors of the Synchronous Type for Commercial/Residential and Industrial Applications", CLEUP Ed. – Padova maggio 2001, Cod.Lib. 193-2, Pt.3, pp.1-22.
6. N. Bianchi "Motori a magneti Permanenti a Bassa Ondulazione di Coppia", Workshop on AC Motor Drive Technology, 8° edizione, Vicenza, 7-8 Maggio 2001, Pt. 8, pp.1-43.
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8. N.Bianchi, S.Bolognani, F.Luise, "Design of a SPM motor for a hydrofoil", in Proc. of 4rd International Symposium on Advanced Electromechanical Motion Systems, Proc. of ELECTROMOTION 2001, Bologna (Italy), 18-19 giugno 2001, CD-Rom.
9. N. Bianchi, S. Bolognani, F.Tonel, " Design Criteria of a Tubular Linear IPM Motor ", in Proc. of IEEE International Electric Machines and Drives Conference, IEMDC 2001, Boston (USA), 18-20 June 2001, pp.1-8.
10. N.Bianchi, S. Bolognani, F.Tonel, "Design Considerations for a Tubolar Linear PM Servo Motor", EPE-Journal, Vol. 11, n.3, pp.93-98, 2001.
11. N. Bianchi, S.Bolognani, *Metodologie di Progettazione delle Macchine Elettriche*, CLEUP Editrice, Padova 2001, ISBN 88-7178-529-0
12. N. Bianchi, *Calcolo delle Macchine Elettriche col Metodo degli Elementi Finiti*, CLEUP Editrice, Padova 2001, ISBN 88-7178-528-2
13. N.Bianchi, S.Bolognani, M.Zigliotto, "High Performance PM Synchronous Motor Drive for an

Electrical Scooter", IEEE Transactions on Industry Applications, vol.37, no.5, pp.1348-1355, Sept./Oct.2001.

14. E.Benini, N.Bianchi, S.Bolognani, F.Luise, V.Quaggiotti, "Design of a SPM motor for a hydrofoil", in *Proc. of 4rd International Symposium on Advanced Electromechanical Motion Systems, ELECTROMOTION 2001*, Bologna (Italy), 18-19 giugno 2001, CD-Rom.

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15. N.Bianchi, B.J.Chalmers, " Axially Laminated Reluctance Motor: Analytical and Finite Element Methods for Magnetic Analysis", in *IEEE Trans. on Magnetics*, Vol.38, no.1, January 2002, pp.239-245
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68. N. Bianchi, S. Bolognani and F. Luise, "Potentials and Limits of High Speed PM Motors", IEEE Trans. on Industry Applications, vol.IA-40, No.6, Nov.-Dec. 2004, pp. 1570 - 1578
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ANNEX N. 2:
TO PROGRAM EVALUATION FORM N. 1

Program Title

ELECTRIC DRIVES

List of confidential Reserch Projects (year of stipulation of the contract)

Customer	Subject	Scientific Responsible	Amount (euro)	Duration (months)
2001				
ABB Service S.R.l.	Analisi delle forze elettromagnetiche agenti in un relè magnetico	N.Bianchi	12,000.00	9
INN. TEC. S.r.l.	Progetto di un motore elettrico per pompe di circolazione per automobile	S.Bolognani	20,660.00	6
KRONA S.p.A	Studio di fattibilità, progettazione e prototipazione di una sospensione magnetica per porta scorrevole	S.Bolognani	15,490.00	9
DE ANGELI PRODOTTI S.p.A	Studio di fattibilità, progettazione e prototipazione di motori con avvolgimenti in alluminio	S.Bolognani	10,330.00	9
2002				
FINMEK S.p.A.	Studio di soluzioni per l'alimentazione e il controllo di motori brushless trifase per applicazioni in elettrodomestici	S.Bolognani	10.000,00	12
ELECTROLUX ZANUSSI S.p.A	Studio di soluzioni per l'alimentazione e il controllo di un attuatore lineare per compressori frigoriferi	S.Bolognani	16.000,00	3
LAFERT S.p.A.	Progetto di uno statore in materiale composito magnetico dolce per motore a magnete permanente superficiale	N.Bianchi	6.000,00	5
CREI. Ven	Progetto di motore a magnete permanente ad alta velocità	N.Bianchi	25.000,00	9
MAGNETIC S.p.A	Analisi di diverse configurazioni di motori brushless ad elevate prestazioni dinamiche	N.Bianchi	13.000,00	6
2003				
ELECTROLUX ZANUSSI S.p.A	Verifica sperimentale di un algoritmo di controllo sensorless per un attuatore lineare	S.Bolognani	6.000,00	6
P. M. S.r.l.	Studio e progetto di un generatore lineare alternativo a magneti permanenti	S.Bolognani	16.000,00	12
SICCE S.p.A	Studio di un azionamento sensorless per motore monofase a magnete permanente	S.Bolognani	8.000,00	6
E.M.G. Elettromeccanica S.p.A.	Software per lo studio di motori asincroni monofasi	N.Bianchi	5.000,00	12

ABACUS d.o.o.	Indicazioni sul progetto di alternatore trifase a magnete permanente	N.Bianchi	15.000,00	6
PFM S.p.A.	Studio e ottimizzazione di alcuni algoritmi di controllo per un sistema di pesatura e dosaggio multitesta per macchine confezionatrici Responsabile scientifico	S.Bolognani	24.000,00	12
DALDOSS ELEVETRONIC S.p.A.	Progetto di motore a magneti permanenti superficiale per ascensori a trazione diretta	N.Bianchi	30.000,00	8
TRASFO PROJECT S.R.L.	Studio di induttori di potenza per alta frequenza con materiali magnetici dolci non laminati	N.Bianchi	4.000,00	3
2004			108.000	
MAGNETIC S.p.A.	Progetto di un "torque-motor" a magneti permanenti	N.Bianchi	10.000,00	6
EUROMAG S.r.l.	Studio e ottimizzazione della struttura elettromagnetica di misuratori magnetici di portata	S.Bolognani	14.000,00	12
2005				
DALDOSS ELEVETRONIC S.P.A.	Studio, progettazione e implementazione di un controllo digitale per azionamento brushless per impianti di sollevamento	S.Bolognani	11.000,00	7
ELECTROLUX HOME PRODUCTS ITALY S.P.A.	Studio e validazione sperimentale di un controllo vettoriale sensorless di un azionamento con motore asincrono per lavabiancheria	S.Bolognani	33.000,00	10
ITACO S.r.l.	Stimatore di coppia per motore sincrono a magneti permanenti incluso il funzionamento in deflussagio	S.Bolognani	10.000,00	5
SOGA S.p.A.	Studio, analisi e progettazione di un generatore brushless a magneti permanenti per applicazioni a velocità variabile	S.Bolognani	15.000,00	8
EEI Equipaggiamenti Elettronici Industriali S.r.l.	Studio, analisi e simulazione di un controllo sensorless per generatore asincrono a campo avvolto	S.Bolognani	12.000,00	6