PROCUREMENT OF POWER CONVERTERS

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ABSTRACT
High performance, modern technology, excellent reliability and low prices are among the key factors of to-day's power converter systems. Procurement of such equipment from industry is not an easy task. Depending on the many boundary conditions, each case will be approached in a different way. On the basis of more than two decades of experience, the problems encountered when acquiring a very large and complex system will be highlighted. Emphasis is put on dealing with problems in a professional and systematic way. The importance of careful preparation will be stressed, starting with a full analysis of the basic accelerator requirements, passing on to the preliminary inquiry, the technical specification and the call for tenders. At the end a few remarks are made on the contract, the manufacture and the testing.

1. INTRODUCTION

Procurement of power converters does not consist only of signing a commercial contract and at a later stage of handing over a bank cheque for payment.

Procurement is the art of conciliating numerous, often contradictory, requirements when acquiring a high-technology power converter system. The many technical facets of such a system have been described during this course. They show clearly that a converter does not only consist of a transformer, diodes and an Ampère-meter. A modern converter system embraces a very wide range of technical fields. The most important are: modern conversion technology, high precision d.c. current measurement, function generators, feed-back theory, interlocks, microprocessor-based performance supervision, real-time operating system and application software. The design team, which masters all these technologies, must also be competent to deal technically and commercially with the power converter industry which manufactures this wide range of products to ensure that they meet the specification. In most cases these firms are selected by competitive tendering. Commercial and general economical aspects play an important role. The constraints of a large accelerator project such as low budget figures, shortage of power converter specialists and a limited time scale transform the procurement of power converters into a real challenge.

Particle accelerators for High Energy Physics are always unique machines operating at the technological limit of all their components. This is particularly true for the power converters. Nevertheless, accelerator users expect high-performance equipment, reliable operation and in addition a considerable potential for future performance improvements.

Experience has shown that the team of power converter specialists responsible for the design and procurement of this equipment will be involved later in operation and improvement. This on-going responsibility
Regular visits to firms, although costly and time-consuming, are more efficient than the odd telephone call. At the factory you can judge visually the real situation.

7.3 Testing

Quality assurance during the contract is a continuous task. All inspections, burn-ins, type and routine tests have to be carried out and supervised conscientiously and thoroughly as stated in the specification. Even for large series, defects may creep in during production. Only complete inspections and tests of all the equipment assure good quality. Wherever possible, factory tests should reflect exactly the service conditions on site. Repairs or up-grades during operation are much more expensive than thorough factory tests. A little extra time spent in testing can save much additional cost and embarrassment later.

Despite all these precautions, early failures will appear during the first hundred hours of operation. Whenever possible, accumulate operating hours well ahead of the beginning of the accelerator commissioning.

8. CONCLUSIONS

Procurement of power converter systems requires expert knowledge in a wide variety of fields and special care to be paid to detail. Nevertheless, problems do not always arise where expected. Contracts which appear difficult at the beginning may run very smoothly whereas others, seemingly straightforward, lead to unexpected trouble.

And now good luck for your next procurement of power converters; an exciting challenge is ahead of you!
is quite different from standard industrial projects where design, procurement, operation, modifications and
repairs are done by teams from different companies, each one making money out of their business. This specific
accelerator situation is reflected in the design approach for the equipment as well as in the relationship to
industry.

In this chapter I will highlight the problems of procurement of power converter systems for a new
accelerator as seen by a CERN engineer. Our experience is based on collaboration with firms from CERN
Member States, established in this high-technology field. I will concentrate on technical and managerial
problems and will not cover points such as payment conditions, bank guarantees etc. They do not lack
importance, but they are outside the framework of this course.

2. THE OVERALL STRATEGY

In any accelerator project, the power converters are vital parts closely linked to the other accelerator
systems. The converters' performance is dictated on one side by the accelerator requirements and on the other by
the needs of the systems they feed with precise d.c. power. Many limits of responsibilities with the other
participants in the project have to be defined. Once these points have been settled, the system concept of the
power converters can be worked out and a detailed battle plan established, taking into account the numerous,
often contradicting boundary conditions.

As an example, let me quote the LEP magnet system. The required performance data are established in
close collaboration with the magnet designers and the beam optics specialists. The values of the currents and
voltages during filling, acceleration and data taking, as well as the tolerances under static and dynamic
conditions, are thoroughly discussed. Quite often an interactive process is required before reaching the final
figures.

The limits of responsibilities are established with the various specialists for the buildings, cooling, mains
distribution, controls, software, main control room, safety, access control etc. Precise definitions help in
writing clear and complete specifications and avoid expensive additional work during the installation and
commissioning phases.

Before working out the system concept and the battle plan, the boundary conditions have to be known.
They vary not only from project to project, but also during the project. The most important ones are listed
below, in a somewhat arbitrary sequence. The list does not pretend to be exhaustive.

- Competence, experience and size of the team of power converter specialists
- Time scale of projects
- Budget and budget profile
- Technical and financial risks the project management is willing to take
- Overall economic situation in the converter industry
- Interest of industry in participating in the project
- Technical know-how of firms interested in the tenders
- Project extensions, performance improvements
- Safety aspects
- Environmental aspects
- Electrical interference aspects (RFI, mains disturbances)
- Operational budget of the accelerator (manpower, money)
- Operations and maintenance crews.

Keeping in mind the performance to be achieved, the requirements for reliable and efficient operation, the geographical layout of the accelerator and the boundary conditions, the main strategic decisions can then be taken.

In the case of the magnet system these were:
- CERN specialists are responsible for the overall system concept
- They take on the entire performance responsibility
- The design of the equipment takes into account its complete life cycle
- Modern switch-mode technology is used whenever feasible
- Local intelligence based on extensive application of microprocessors is used on all converters
- A comprehensive quality assurance scheme is followed

The main reasons were as follows:

The composition of the LEP power converter team, its knowledge and experience allowed it to take the full responsibility for the design concept for all the converter systems. The team has a long-standing development tradition which allows it to transform new ideas into technically viable projects. This was true, in particular, for the converters of the magnets which cover a power range from 0.7 kW to 7000 kW. The team's intimate familiarity with all the problems of very high stability in relation to the operation of storage rings made it only natural to take on the responsibility for the vital aspect of performance.

CERN's continuously declining staff figures made it imperative to design and build equipment keeping in mind the operational requirements. A set of standard electronics for all power converters not only kept the initial cost low but also assured uniformity of documentation and ease of training for the operations and repair crews. Good diagnostics from remote and local control points, operational spares, and good reparability are important design features and were taken into account on an equal footing with excellent reliability. A rigorous, comprehensive quality assurance scheme was followed on all contracts. This included checks of the design, type tests, routine tests, burn-in and complete final testing.

Modern switch-mode technology was introduced on a large scale. Expected advantages were good power conversion efficiency, compact size and modular construction. This results on the one hand in smaller thermal losses to the buildings, hence smaller cooling requirements and on the other hand to smaller buildings. As the power output capabilities of switch-mode or resonance type converters were limited, the higher output powers were covered by mains commuted thyristor equipment.

Every power converter relies heavily on local intelligence, based on microprocessors. They control and supervise each converter in an autonomous way. The incorporated microprocessor transforms the current reference source (in our case a hybrid digital-to-analog converter) into a programmable function generator, handles the incoming and outgoing data stream to the control system and supervises in detail a large number of
internal converter functions. This allows not only the efficient diagnosis of faults from a distance, but also, as a by-product, the analysis of the behaviour of other accelerator systems.

The battle plan was dictated by the very limited financial resources allocated to the converter systems and the short time scale. The split of the overall task into various specifications was guided by technical as well as financial considerations. Each specification should only cover one main technology and therefore a sizeable number of firms should be interested in tendering. In this way, we could obtain attractive prices at an acceptable level of technical risk. Our team of specialists took on not only, as mentioned before, the responsibility of the overall system design, but also the writing of the precise technical specifications, the detailed design of the electronics for the feedback loops, the interlocks, the protection, the local microprocessors and the software.

The battle plan contained also a detailed internal planning. It fixed the dates for termination of the design work, specification writing, review meetings, sending out of tender documents, tender opening, visits to firms, order dates and duration of the various contracts, individual tests in the factory and at CERN, converter commissioning and the start of overall accelerator tests.

Experience has shown that our initial decisions were correct. We did stay within our budget limits; the equipment was ready on time, meets or exceeds the expected performance and runs in a reliable way. It is worth mentioning that the budget figures were established based on contract prices paid in the past. This means that we could beat inflation (in Swiss Francs) over a period of two decades.

3. RELATIONS WITH INDUSTRY AND UNIVERSITY

Relations with Industry and University are long-term efforts. In an International Organization one endeavours to cultivate relations throughout all Member States. This gives the opportunity to follow trends in technology and to learn about the capabilities of university departments and industrial companies. It is well known that products based on new technologies are often offered first by small or medium sized firms.

The best way of being informed about industry is of course to be in continuous business contact with it. Conferences, seminars and visits to companies give the opportunity to follow up old and create new channels of information. Ties with universities can be strengthened through development contracts or programmes of "visiting scientists", if such schemes exist in the purchaser's organization.

During the preparation stage of an accelerator project, contacts should be intensified. Special information seminars can be organized and detailed conference papers presented. A successful approach is a buyer's stand at a specialized power converter or power electronics conference or exhibition. A careful presentation with an overall project description, the expected performances and basic block diagrams will help to establish useful relations with the technical staff of companies. A preliminary inquiry is a further step in the right direction. More is said about this subject in one of the next sections.

4. RULES OF THE GAME

Profit is the rule of the game in industry. This may be in the form of cash, but also of a gain in know-how, the fact that a company penetrates a new market, gains publicity in participating in a large project and many more.
In order to create a clear situation, the technical specification as well as the commercial conditions have to be clear so that both parties can adhere to them and the contract can be handled in an efficient way.

All rules of the game should be known and discussed fully at the beginning of the project. Some of them are written, others are habits, therefore unwritten. As habits change, they undergo the same process. The written rules, such as financial rules, general rules of purchase etc. have to be studied carefully in order to fill in certain gaps or give emphasis to some particular problems. To find out all about the unwritten rules is certainly a demanding job. A course on "How to treat your boss" may give some useful hints.

The legal aspects are important too. You certainly have heard about the patent laws, national laws, labour laws, Roman law and English law, all of them taught at University level. But in everyday life, the "law of the jungle" has its importance. When deciding about payment conditions and schedules this point should not be forgotten.

5. CALL FOR TENDERS

5.1 Preliminary phase

Any important call for tenders will go through a preparation phase. This may take the form of a preliminary inquiry which informs industry about future requirements and at the same time serves as a market review. The main document of the preliminary inquiry is a short technical specification of the system or part of it, preceded by a concise overall view of the complete accelerator project. It is wise to split up the preliminary inquiry in the same way as one will do with the final call for tenders. A request for the firms' documentation and a detailed questionnaire allows technical and commercial information about the firms to be collected.

The preliminary inquiry may also be used for selecting companies. In this case the selection criteria have to be spelt out very clearly. They may include financial aspects such as turn-over in the field of converters as well as technical aspects, such as technical expertise in a specific field. It is important to mention that only firms replying to the preliminary inquiry and meeting the selection limits will be invited to the final tendering. The initial large lists will therefore be reduced to a "short list". Such a "short list" of firms has the advantage of inviting only manufacturers with expert knowledge. The selected tenderers from their side see their chances for success increased. At a later stage, the purchaser may request, before placing the contract, proof of the technical expertise of the tenderer making the lowest offer. This will take the form of a qualification prototype meeting the specification.

A follow-up of the preliminary inquiry may consist of visits to some of the firms which replied. Discussions with specialists will then be based on a written document which, although condensed, considerably increases the success of the visit. At this stage it is important to sound out design, development, production and quality control facilities. They are key factors for obtaining low price, good product quality and reliable delivery.

5.2 Tender documents

Numerous technical and commercial papers as well as various annexes form the file of tender documents. The technical specification is the most important one followed by the questionnaire. These documents have a
wide variety of functions in the course of their useful lives. Therefore a later section deals in detail with the technical specification and the technical questionnaire.

On the commercial side, the total quoted price is of course the most important financial information supplied by the tenderer. The price breakdown, which is always requested, should be such that its information allows the technical content of the offer to be cross-checked. Prices for the options and their validity have to be included. Tenderers' comments on the delivery schedule should be encouraged.

The tender documents must remind the tenderers about the selection criteria applicable and may indicate the tender opening procedure. To inform the tenderers about the internal administrative procedure after tender opening is a useful step.

A reasonable period of time should be given to the firms for establishing a technically sound offer. Direct information to the technical people may reduce the length of time documents lie on administrators' desks.

6. TECHNICAL SPECIFICATION

6.1 Preparation of the specification

Before writing a technical specification, it is worthwhile carefully documenting the basic information supplied by other groups of the project, as well as the design decisions and computations. This documentation should include a short description of the history, a discussion of the possible solutions and their pros and cons. Detailed design calculations can be added, the tolerances of the various components given and values for environmental conditions and reliability considerations written down.

A precise time schedule will be a “must” for the follow-up of the various stages of writing the drafts and the final versions of the technical specification, its annexes, questionnaires and the various additional documents.

6.2 The specification

The technical specification is used by many people and has to fulfil a wide variety of functions over its useful life. The most important are listed below:

- Firstly, it must provide quick and precise information to a potential supplier on the level of "Decision Makers". It must give technical content, quantities and time scale.
- Secondly, it serves as the basis of the tenderer's detailed technical offer and the "price tag". All the information needed for this purpose must be clearly spelt out.
- Thirdly, it is the main working document for the duration of the contract. It serves the design office, the production department and the subcontractors as well as the test and installation teams. Last but not least, it helps the engineer responsible for the contract, to get the product and services his organization ordered and will pay for!
The technical specification is a contractual paper and therefore has to be written with this aspect in mind. It will often be read on its own, separated from the other parts of the tender documents. It must be a complete document in itself and therefore will overlap with some of the other tender documents.

The structure of the specification reflects the multiple use of this document. It will therefore contain at least the following main chapters or annexes:

- Short summary (technical data, quantities, delivery schedule)
- Introduction to the accelerator project
- Description of the general environment (buildings, cooling, etc.)
- The hard core of the detailed technical specification of the product and services the tenderer has to supply.
- A technical summary list of all the numerical values of the equipment with their references to the chapters
- Quality assurance scheme to be applied
- Detailed testing procedure, type tests, routine tests including burn-in, definition of what is done in the factory of the contractor or subcontractors or at a special test facility
- Quality requirements for certain materials (cables, etc.)
- List of items delivered to the contractor for questions of standardization
- List of items to be purchased from a given supplier
- Documentation required
- Nomination of contract engineer
- Options: quantities, rate of delivery, validity
- Transport to and erection on the accelerator site
- Facilities on the accelerator site
- Testing on accelerator site on dummy and real load
- Guarantee work, rapidity of repair service
- Safety rules applicable
- Access conditions to the site, working hours, restrictions due to overall planning.

The "hard core", i.e. the real subject of the specification, must be treated in great detail. Block diagrams, circuits and numerical values, including tolerances, have to be given in a language familiar to specialists. Neither a design engineer for a power converter, nor a test engineer, will understand notions such as width of stop bands, betatron oscillations and the like. He must have information, figures and tolerances which are familiar to him and which he can achieve. Very often these are reached thanks to a special effort made first at the design then at the manufacture and finally at the testing stage. Accelerator requirements are often harder to meet than ordinary industrial ones.

A good drawing is more informative than a long description. Layout drawings with dimensions, figures with waveforms for currents and voltages will pass the message more easily. The specification will be read and used by people of different educational background and mother tongue than those of its author. Maybe future specifications will be in the form of "comic strips". Their chance of being studied in detail by everyone involved in the contract will increase considerably.
The annexes must be chosen carefully. They must include international recommendations (such as IEC standards), national and internal rules and prescriptions. They also cover safety aspects, measurement technology, environmental aspects, radiation protection, site access rules, local conditions for work permits, hotel accommodation etc.

A power converter contract will be handled by many departments of a firm. From outside it is difficult to know all the people and to follow the contract in an efficient manner. In this case a "contract engineer" is an essential person. It is vital to nominate such a person! He must have easy access to all the important people of the various departments and be in the factory most of the time. He will make sure that the client is continuously informed and that his requests will get through to the people concerned.

Flexibility, restructuring and subcontracting are part of the everyday vocabulary of modern industrialists. The question has to be asked where the equipment will be made and tested, with the full address of the manufacturing department. The same is true for the subcontractors. It is compulsory that manufacturing facilities as well as subcontractors can only be changed with the purchaser’s written agreement.

Delivery schedules should be realistic for both sides. Short delivery times increase the price. A delivery schedule which is too short will leave the purchaser with adventurous firms or no tenderer at all - two possibilities to be avoided. An early start will increase the chance of getting the product on time at a reasonable price.

Options are very useful and often a “must”. They make sure that additional spares or extensions of the project will have the same material for a known price. The duration of validity of the option clause as well as the rate of delivery must be indicated and should be in line with the main contract.

The technical questionnaire is also an important document. A great deal of attention should be devoted to its formulation. Questions should be formed in such a way that only a reasonable design study can answer them. The questionnaire is the first step in checking whether the offer meets the specification. It also allows comparison of offers from different tenderers. Requests for data-sheets, sketches etc. can be included as well as manufacturers of the components purchased, their type numbers etc. During the execution of the work, the questionnaire is an additional and useful tool for the contract supervision.

Guarantee clauses are defined in the general purchase conditions. They are formulated in such a way that they satisfy many different cases. For a specific application more details may be needed which have to be added to the specification. Repairs under guarantee may be such a case. How rapid must the intervention be? If a 24-hour repair service is requested, this has to be specified. Otherwise the manufacturer may have no stock of spare parts and will first have to manufacture or order the replacements for the broken components.

Most accelerator departments have a permanent operation/maintenance crew, which is responsible for the efficient running of the "machine", including the converters. This unloads the manufacturer considerably from his guarantee duties. Therefore, only equipment with systematic faults will normally be returned to the factory. The reduced extent of the guarantee may well be reflected in a substantial negotiated price reduction - an idea worth discussion.
Last but not least, the educational aspect of the specification writing is important to the design crew. By formulating, reading through and discussing the draft and the final specification, all members of the team go through a very useful learning process which will reflect itself in many improvements. The specification must be read as through the eyes of the tenderer. How will he interpret it? What is his solution for meeting the specification? May he offer, by strictly adhering to the text, a solution the user dislikes? In certain cases, less prescription may do more good!

7. **THE CONTRACT AND ITS FOLLOW-UP**

7.1 **Contract preparation**

Tender opening is always an exciting moment full of surprises. After careful analysis of the tenders by the design team, possibly assisted by people from outside, visits to the firms will follow. If time allows, the two or three most interesting firms should be visited, including their main subcontractors, in order to discuss the tender in detail. Thus the customer makes sure that the specification is fully understood and the offer is complete. The client will meet the company's contract engineer, the contact man for several months to come! References are very useful and should be checked thoroughly.

A further stage in the selection process, as mentioned earlier, ahead of the contract signature, may be the construction and approval of qualification prototypes. This will show whether the lowest tenderers are in a position to manufacture the goods to specification. Although this process may at first look time-consuming and expensive, in the end it often saves money and trouble.

The internal approval mechanism of the client's organization will choose the firms which satisfy all the selection criteria, taking into account the prices, offers which meet the technical specification, and the delivery times. The company's experience has been proven, if possible, by a successful qualification prototype.

The patent situation is, in general, covered in the conditions of purchase. There, the emphasis is put on the protection of new ideas which will arise during the execution of the contract. A point which is worth bringing up is the coverage by existing patents of the products the tenderer is proposing to use during the contract execution.

7.2 **Manufacture**

Regular contacts with the firm will be established from the very beginning. They will assure that the company's design follows closely the specification. They also make sure that difficulties, which may arise during the contract period, can be immediately spotted and corrective action taken. The main features of the specification have to be repeated again and again. If new people join the contract work, one has to be aware that not all of them will know all the details of the specification.

In the present industrial context, main contractors will purchase major items from subcontractors. Transfer of the information contained in the specification to subcontractors is of vital importance and it is worth checking carefully this aspect.