Supporting the technology-push of a discontinuous innovation in practice

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The hydraulic power generation business is usually faced with continuous innovation, meaning that progress is rather made in small than in large steps. Nevertheless, there are currently some examples of discontinuous innovation, the *Powerformer*-technology being one of them. The implying difficulties for successful innovation are internal communication and linking the technology to the most suitable markets. In order to proficiently push the *Powerformer*-technology onto the markets, an appropriate procedure is identified and implemented to practice.

First, a SWOT-analysis is used for assessing the competitive product concept of this discontinuous innovation. This contributed the specific calls for action. Second, the identified procedure for leveraging this technology-push aggregates the technology choice tool, road-mapping and a process for technology commercialization. As a result, specified market segments, a market penetration schedule as well as development and design aims were defined. This paper intends to give a practice example on how the mentioned methodologies were applied for the technology-push of a discontinuous innovation.

1. Introduction

1.1. ALSTOM Power Hydro

ALSTOM Power Hydro has a business volume of one billion Euro and employs approximately 5000 coworkers. ALSTOM Power Hydro is the world market leader in hydro business with an installed capacity of over 240 GVA on generators and 120 GVA on turbines. ALSTOM Power Hydro is composed of five strategic divisions as shown in Fig. 1.

The division 'Generators' is subdivided into geographically separated business units, which are supported by the Technology Center staff in terms of technical assessment, custom made solutions and optimization of layout. A special task is attributed to the Sweden business unit, which is in charge of acquisition, engineering and the sale of the so-called *Powerformer* innovation. The production lines of the 'Generators' division are organized centrally, serving all the different business units. The mentioned organization is shown in Fig. 2.

In addition to the above described common tasks, the Technology Center is responsible for development and maintenance of calculation software, it is involved in optimization and unification of the product components as well as for the interdisciplinary work in complex assignments throughout different divisions. The technical part of contract offerings of the business units are controlled by the Technology Center, too. Furthermore, the Technology Center is concerned with the technological improvements and developments, in order to meet the requirements and

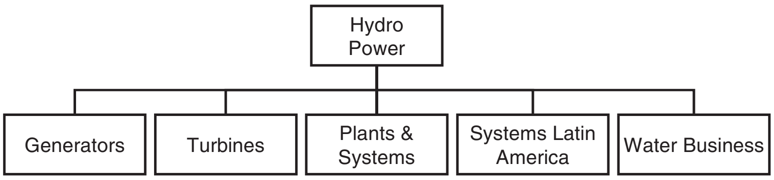

Figure 1. Organizational structure of ALSTOM Power Hydro.

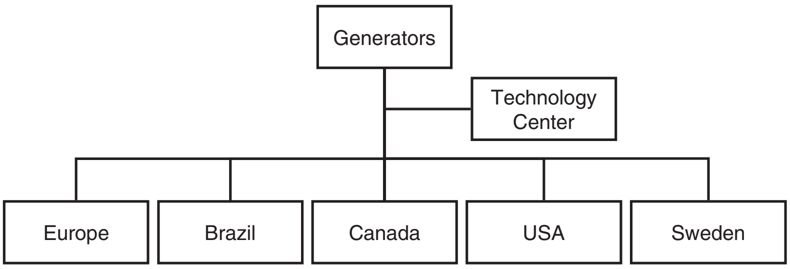

Figure 2. Organization of the 'Generators' Division.

long-term trends of the market. Herein, the *Powerformer* innovation plays a crucial part, representing a novel product combining both, a generator and a transformer unit in one device.

1.2. Hydro generator market

The most important economical influence on the development of the energy market is the price of the primary raw materials, such as oil, uranium, gas and coal. Compared with thermal power stations, hydraulic power stations represent larger investments. This becomes obvious when we look at the infrastructure expenditures for dams and pressure pipes. However, in operation, no costs for fuel arise with hydraulic power stations, thus increasing prizes on raw materials lead to higher operating costs for thermal power stations. Therefore, assuming that the worldwide requirement of electrical power doesn't become smaller, additional projects in the hydraulic market could become economically interesting in future.

The optimal operating point of a hydraulic turbine depends on potential energy, flow rate and revolutions. Therefore, depending on the geological and geographical situation at the power plant site, generators with different revolutions and power are required. The fundamental concepts have already been developed a hundred years ago. Since then the synchronous machine has been enhanced and modified to its present form. The generator product itself is technically mature, which results in a degree of efficiency up to 99%.

Today's product development effort concentrates on the reduction of costs. This is achieved by the use of new materials, improved procedures of calculation and therefore a reduction of the elements of uncertainty. Additionally, reducing costs requires improvement of the production process control, more efficient project management and finally a standardization of the products.

The electrical generator market has a very long life cycle. It often occurs, that machines are replaced after 40 years, only. Therefore, in contrast to other types of products where a customer has the possibility to experience several product life cycles in a few years time, this isn't the case in the hydro generator market. Furthermore, a breakdown of a generator immediately causes large production losses and leads to disastrous financial effects. Per machine and day the costs can rise up to a million Euro. According to this the customers in the market behave conservatively. They only rely on proven technologies. These market characteristics intensify the problems innovation usually encounters. Altogether the hydraulic market isn't an ideal field for innovations, and the innovation theories of the industrial goods market are not easily applicable here. Despite this, as we will see further on, there still are innovative ideas in this sector, the *Powerformer* being one of them.

1.3. Cooperation ETH – ALSTOM Power Hydro

The abbreviation ETH stands for Swiss Federal Institute of Technology. As a part of this science and technology university, the ETH-Chair for Technology Management and Entrepreneurship (TMU-ETH) tries to strengthen the link between industry and the high tech world. This includes education, technology spill-over and implementation of adequate management approaches. Driven by the spirit of continuous paradigm changes in competitive markets, the TMU-ETH aims to deliver highly industry-related and applicable results and solutions.

ALSTOM Power Hydro and the TMU-ETH agreed in performing a cooperation to realize and strengthen the *Powerformer* innovation. While the technological competency lies fully within ALSTOM Power Hydro, the TMU-ETH assisted within the decision making process, introducing insights from technology and innovation management. The *Powerformer* technology represents a technology-push situation. In this respect, it can be an additional benefit to recognize ways on how to structure the proceeding for bringing a technology-push successfully on the market. Especially, this kind of situation brings along great internal and external barriers which have to be overcome.

The approach and experience described in this contribution was performed in cooperation by both entities, ALSTOM and the ETH. Herein, the practical application of innovation management methodologies and the herewith made experiences are especially highlighted. It can be understood as an in-depth validation example taking into account the chosen methodologies. In order not to disclose sensitive data, technical, organizational and market related details are only disclosed to a necessary degree for understanding the overall procedure.

2. Technology

2.1. General remarks on hydro generators

The power capacity of a generator is proportional to the product of voltage and current. One of the most important limiting factors in construction of such generators is insulation. This is the case due to a rising electrical field in relation with the rising power capacity and density. High electrical fields call for good insulation in order to prevent a short-circuit within the generator. Therefore, better insulation systems have been developed in order to build generators with higher power capacities and densities.

The maximum allowable strength of the electrical field can be used as a measure of hydro generator performance. Most of the construction details of a hydro generator relate to this figure. Plotting the evolution of this performance parameter against a time scale generates an S-curve approximately. This evolution of the maximum allowable strength of the electrical field per mm of insulation is shown in Fig. 3. The present overall voltage limit for the application of conventional technologies lies within the range of 3 kV/mm.

In conventional hydro generators the stator coils consist of so-called 'Roebel'-bars, which are embedded in the slots of the laminated stator core. These bars are composed of rectangular copper wires, which are surrounded by an insulation of epoxy resin and mica. The electrical field strength plotted as it appears along the circumference of a conventional bar and a cable is compared in Fig. 4. Because of its rectangular shape high electrical field peaks are generated at the corners of the bar. These corners are the critical geometry, for which the insulation has to be dimensioned, lowering the overall performance.

As was explained before, the generator performance is highly dependent on the maximum electrical field strength allowable. In the usual layout geometry the corners of the rectangular bars have a negative impact for the hydro generator performance. The resulting low voltages

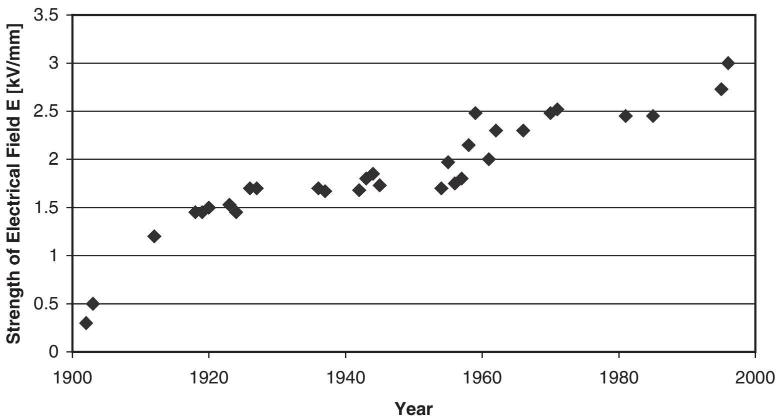

Figure 3. S-curve of the electrical field strength in generators.

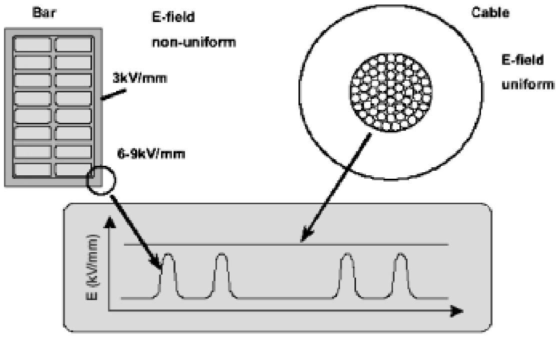

Figure 4. Pattern of the electrical field strength in 'Roebel'-bar and cable.

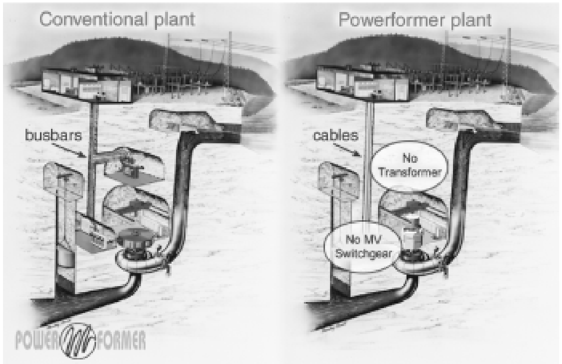

Figure 5. Comparison of a conventional plant and the benefits of the *Powerformer* technology.

make a transformer unit necessary, in order to transform the electrical power into high voltages for transportation. It is economically better to transport electricity at high voltages and a low current for long distances (Coulon and Jufer, 1998). Depending on the network these voltages vary between 65 kV and 400 kV. As these voltages can't be reached in generators using the classical insulation technology, the given voltage of the generator has to be transformed by a transformer unit.

2.2. Functional principle of the Powerformer

The fundamental idea of the *Powerformer* developers is to use cables with a circular diameter instead of rectangular bars. The technical performance of the generator product benefits from this constructional approach. Additionally, high voltages can be generated with this approach, making transformer units obsolete.

These insights are not new, and several attempts were undertaken during the last 80 years to realize such a technology in Italy, the USA and the USSR. The attempts didn't succeed due to different factors. Most critical was the power density of such machines, which was overall lower. Also critical is the construction process quality, as already tiny deficiencies in the insulation lead to short-circuits ruining the machine.

The successful development taken place recently benefited from the cutting-edge insulating technology available only since the nineties, and the high experience of ALSTOM in qualitatively outstanding assembly processes. Voltages of up to 400 kV can be reached in a *Powerformer* using XLPE as an insulation material (Dettmer, 1998). This corresponds to the level of usual power grid voltages.

Alstom successfully implemented the first *Powerformer* in the city of Porjus, feeding energy into the Swedish power grid since 1998.

2.3. Added value of the Powerformer

The outstanding benefit of using the *Powerformer* technology is the generation of power at grid voltages without a transformer unit. Some of the benefits coming along with this fact positively affect the protective concept, the infrastructure needed and a simpler building concept. Considerable investment expenses can be saved therefore in infrastructure, transformer and surrounding systems. Additionally, the power plant's reliability is improved, as two components which could potentially fail are replaced by one. For these reasons the implementation of the *Powerformer* idea is an innovation bringing along a change of paradigm. Fig. 5 gives an overview of the main differences comparing a conventional power plant to a *Powerformer* plant.

2.4. Remarks on the discontinuity of this innovation

A discontinuous innovation can be defined as an innovation bringing either a factor of 5-10 times in product performance or a significant ($>30\%$) reduction in cost (Leifer, 1997; Leifer and Rice, 2000). The Powerformer clearly has the potential to cut the investment cost for a generator-transformer pair by more than 30%.

Additionally, a discontinuous innovation often is concerned about exploiting the potential of totally new markets (Morone, 1993; Christensen, 1997). Due to its compact construction and economic feasibility also for smaller scale power plants, the Powerformer is a product supporting decentralized power generation markets.

3. Definition of aims

3.1. SWOT-Analysis

At the beginning of the cooperation, a SWOT-analysis (Züst, 2000) was performed in order to recognize the current status and the implying difficulties of the *Powerformer* technology. This kind of analysis is popular, intuitively, easy to understand and simple to apply. The individual arguments are best gathered with the help of experts from different fields. Aims are then deduced from the summary of the SWOT-analysis (SWOT, Strengths-Weaknesses-Opportunities-Threats).

The SWOT-analysis points out that the *Powerformer* innovation does not only have external challenges, but also needs internal improvements. Here, in particular the concentration of know-how in only one department is relevant, as well as the internal competitive situation, which may result from the sale of a *Powerformer* unit. The high dependency on further cable development belongs to the external challenges. This is the case, as further improvement of cable and insulation technology will have a positive impact on further *Powerformer* development. Furthermore, the SWOT-analysis discusses the implementation of this innovation and its difficulties taking into account the conservative market environment. Weakness/Threat combinations of technical nature were clearly shown within the detailed SWOT-analysis. These threats have been discussed in detail. Other relevant combinations of weaknesses in connection with the conservative market were revealed and identified in detail. The question raises, whether it is possible or not to find market segments with less conservative and sceptical customers.

This SWOT-analysis is an important precondition for the work performed hereafter. It is a first methodical milestone in order to clarify the call for action and its implying priorities.

3.2. Aims

As shown, one main challenge is to find markets and market sectors, which do not show the revealed weakness/threat combinations. This could be markets, where a decision in favor of the *Powerformer* outperform the investment risk perceived by the customer. This insight is in line with the tenets discussed by Christensen (1997).

As a next step, it should be clarified how the products for these markets have to look like, whether they can be manufactured with the existing technical possibilities or whether new ones have to be developed.

In sum, a procedure has to be found which systematically identifies and successfully links potential markets with the given technology. Its further development and its market introduction should result from this. An execution of the procedure seeming the most appropriate will be conducted. The elaborated solution must enable a structured approach to answer the following questions:

- Are there markets in which the benefits of the *Powerformer* technology can be applied as an important customer benefit, whereas the perceived financial risk for the customer is smaller?
- How do such different products look like?
- Can the desired products be manufactured with the existing technical instruments?
- Can the involved technological competencies be acquired?
- Which technical development would still be necessary?

4. Methodical solution approaches

4.1. Technology choice tool

Meyhack *et al.* (2002) developed the so-called technology choice tool, a methodology for assessing technologies and giving a structured overview of its potentials. Originally, this structured method for technology evaluation is bound to treat the case of a market-pull, where a specified customer demand is formulated. Seven meta-criteria are defined as shown in Fig. 6.

A check list involving several arguments assessing the potential within each meta-criteria is performed on the technology at stake. Now following, a short highlight of the systematic is given.

4.1.1. Potential of acquisition. Can we acquire a technology ourselves or is it possible to develop it? Are the required resources available?

4.1.2. Potential of implementation. Is the technology suitable for use? Does it match the strategy of the enterprise?

4.2.3. Potential of use. The technological potential of use is analyzed, independent of whether the technology is accepted by the customer or not.

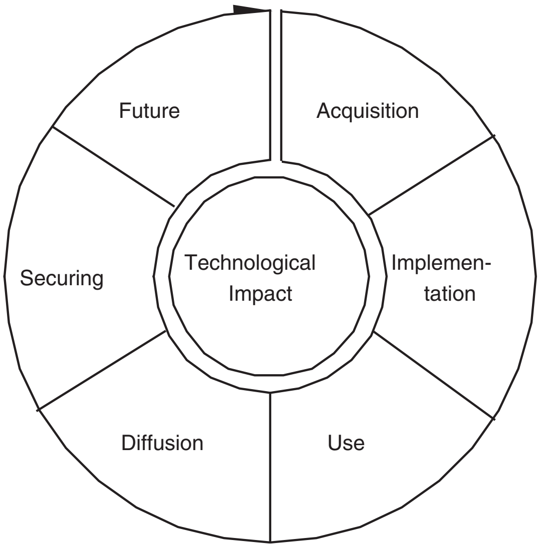

Figure 6. Seven meta criteria for technology evaluation.

4.1.4. Potential of diffusion. How do the chances and risks of market diffusion of this technology look like?

4.1.5. Potential of securing. Can the involved technological know-how, intellectual property and technology standards used be protected in the future?

4.1.6. Potential of the future. Which possibilities can the technology open up in the future?

4.1.7. Potential of technological impact. Under this aspect technological effects on the society, taking into account intended as well as unintended ones can be summarized.

4.2. Technology Roadmapping

The literature of roadmapping in general and technology roadmapping in particular is extensive. As a tool for strategic innovation planning, technology roadmapping has been mentioned in several practice based publications (Barker and Smith, 1995; Bray and Garcia, 1997; Galvin, 1998; Groenveld, 1997; Strauss *et al.*, 1998; Willyard and McClees, 1987). This well-known tool was used more and more in the last years, while the terminology is not always used in the same way. Meanwhile many provisional documents are called roadmap.

Within the technology roadmapping metaphor, a company is considered in a way as a vehicle, which is on a journey through partly well-known, partly unknown areas, and its leadership (i.e. the driver) has to be supported in navigation (Möhrle and Isenmann, 2002). Phaal *et al.* (2001) deliver a good insight on technology roadmapping, too. In their publication they present an overview of eight classes according to their technology roadmap model, and correspondingly give a graphical split-up into eight classes. This classification implicates that the *Powerformer* application corresponds to a product planning, multiple layer technology roadmap. This roadmap is composed of different layers and links products with markets and technologies. The analysis of Phaal *et al.* (2001) taking into account approximately 40 different roadmaps showed that this type is also the most common one. A generic diagram of this type is pictured in Fig. 7. Time is shown on the abscissa and the breakdown in layers on the ordinate. In our case we will use three layers: Market, product and technology. If necessary a fourth layer could always be added, which would contain the R&D projects. The layer of the market reflects the purpose (know-why), namely to supply a market and to draw financial profit of it. In the lowest layer are the resources (capacity and know-how) of the company. The middle layer fulfils the task of connecting the two other layers. The product development (know what) is located there.

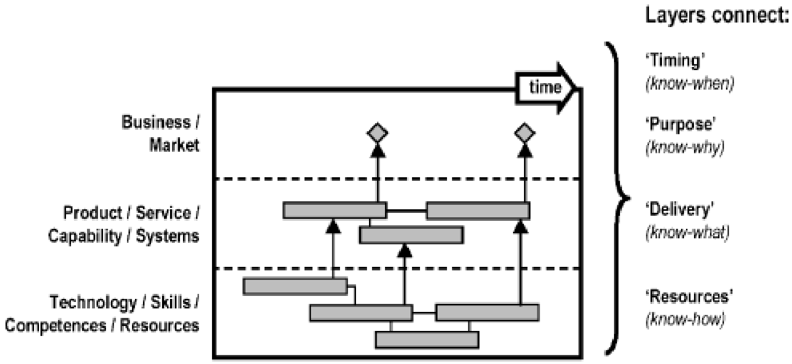

Figure 7. Generic technology roadmap, following Phaal *et al.* (2000).

Phaal *et al*. (2000) also describe a procedure on how to create the technology roadmap, subdivided into four steps: Four different workshops are suggested, with exponents possessing different competencies within the company, in order to guarantee that all relevant aspects are covered.

In the 'market workshop', the markets which have to be supplied, are identified. They should be described and isolated on the basis of important characteristics. It should be analyzed, which are the requirements of the market and which the motivation of the customer. Furthermore requirements on the business are defined.

In the 'product workshop' the required product characteristics are identified, which permit a supply of the defined markets. It is decided whether different products and product families are needed or not and which product specifications are needed.

The 'technology workshop' is closely connected to the product workshop. Herein, it has to be clarified, which technologies the company should possess, in order to be able to manufacture products with the desired characteristics.

Finally in a fourth workshop, called the 'charting workshop', the three previous workshops are interconnected and the Technology Roadmap is developed. For this purpose some questions have to be answered, as for example: 'Do we already possess the technology X to guarantee the product characteristic Y?' and 'If not, how much time will the development or procurement of this technology take us?' In this way the technology roadmap is developed through a balanced discussion. Then, milestones have to be identified, finally programs have to be launched. The procedure described can or should be adapted to the prevailing conditions of the company. It is possible and sometimes even necessary to improve the roadmap in several steps as it is shown in Fig. 8.

One of the drawbacks of roadmapping is that it mainly relies on existing markets and existing technologies. It tends to narrow down the creative perspective (Kappel, 2001). The proceeding described above corresponds to the market-pull process shown in Fig. 9 on the right side. Even if the market-pull process is more common, the complementary technology-push process still ex-

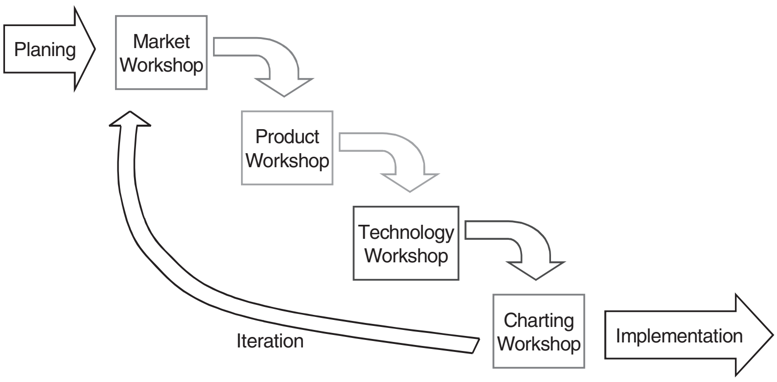

Figure 8. Chronology of the workshops, following Phaal *et al* (2000).

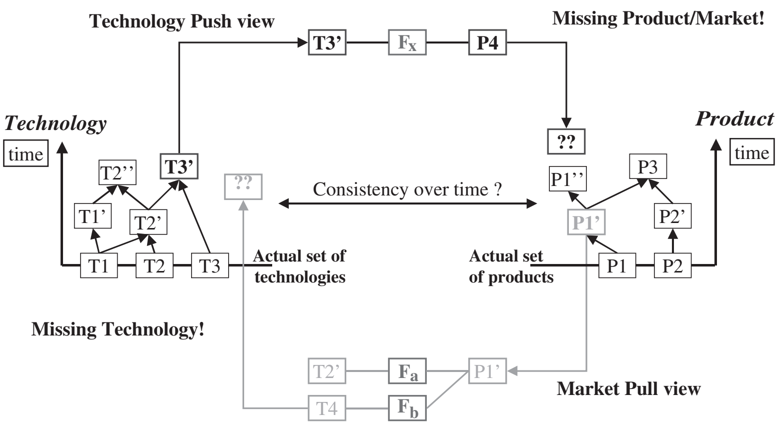

Figure 9. Technology-push and market-pull, following Möhrle *et al.* (2002).

ists. This process is shown on the left side in Fig. 9. In this procedure, the enterprise has a certain technology, for which an appropriate market does not exist yet. In a way the market has to be created (or identified), which requires much larger efforts than to supply an existing market with products. However this version offers the company the possibility to keep the monopoly in the new market sector for a certain time, with the help of adequate protective means. More information on this subject and a classification of technology roadmaps structured after a push and pull process can be found in the study of Kostoff and Schaller (2001).

Different conditions have to be fulfilled, in order to accomplish the roadmapping process which successfully leads to a useful roadmap. After analyzing 2000 companies in England Phaal *et al.* (2001) come to the following conclusion:

- First of all, a clear company requirement is needed
- Secondly, the initiative needs the full commitment of management.
- Thirdly, it is important to win the right people from relevant fields of the company.

One of the most important challenges seems to be the problem of obtaining relevant information. The inquiry also reveals that one of the most difficult challenges is to keep the roadmap alive. The roadmap can be generated and improved in several steps. If a satisfying document has been developed it should still be revised and updated from time to time.

4.3. Commercialisation of technologies

Hauschildt (1993, p. 16) shows a seven step idealization of an innovation process. The steps building the ideal model are idea, observation of an effect, research, development, invention, introduction and utilization. At the core of the model lies a product-bound view. However, it is rather technology based and addresses the market only in the last step. Therefore, the aspect of linking new markets to a technology-push can not be addressed very specifically.

Bullinger (1994) presents his innovation process model, which has great congruencies with the ontogenetic approach of Ropohl (1979). The steps of the innovation process described by Bullinger (1994) are invention, innovation, diffusion and adoption. It is stressed, that adoption means the implementation of an innovation to other purposes than the first diffusion was based on.

In their work, Ebner and Walti (1996) introduce a cyclic innovation process, which is constituted of visioning, strategy, market research and then a research specification. Increasingly, chaos is substituted by efficiency within the designed process. Six detailed process steps lead from detection, definition, development, detailed product specification to a prototype and market success. The shown process can be used for products as well as for production processes, but not for organizational innovation which might also be necessary with a discontinuous innovation. Fig. 10 gives an overview of the described innovation process.

Jolly (1997) analyzes the innovation process and its organization on the basis of development and use of technologies. He not only involves the issue of development, but also continues towards the commercialization of the technology. Jolly organizes the development process from the idea to the commercial application as a sequence of five sub-processes, adding value throughout the process. Additionally, an activity to mobilize resources having organizational consequencies takes place between the sub processes. An overview of the total process is shown in Fig. 11.

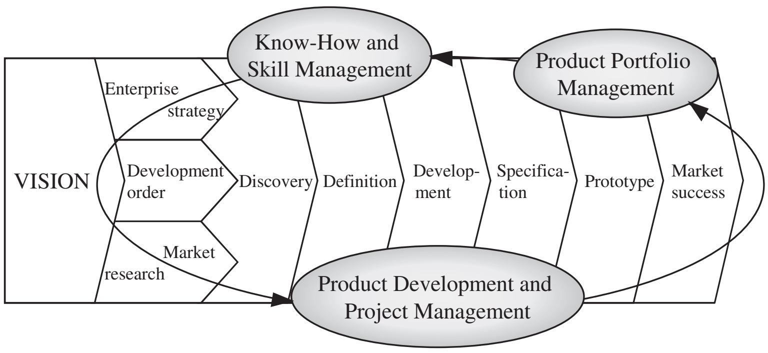

Figure 10. The innovation process, following Ebner and Walti (1996).

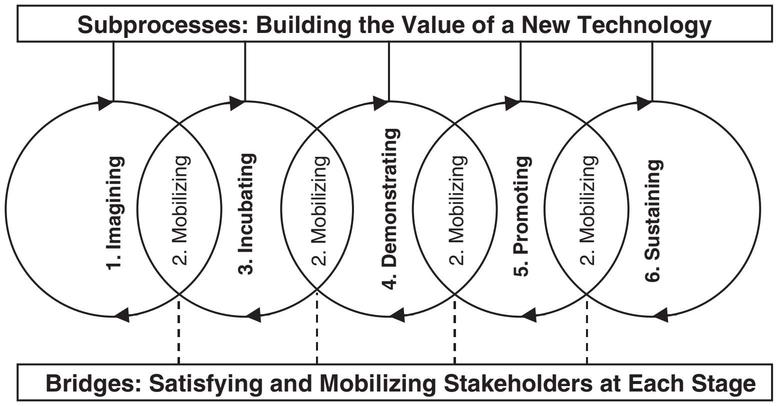

Figure 11. Process of technology commercialization, following Jolly (1997).

4.4. Real options

An option gives the right, however not the obligation, to transact an investment up to a given time at a certain price. Enterprises in the oil and natural gas industry buy licenses, which give the company the right to use a certain block for a given time period. The enterprise however is confronted with large uncertainties. On one hand, it is not clear how profitable and accessible the sources are and on the other hand no one knows how the petroleum price will develop in the future. A standard NPV evaluation method can not measure up with this situation. Instead of calculating the value, that the block would have when using immediately, one can try to keep the option, to use the block in the future, when circumstances become better (improvement in drilling technology, increased petroleum price). To estimate the value of this option, real options calculations can be performed (Amram and Kulatilaka, 1998; Copeland and Keenan, 1998; Fischer, 1996; Leslie and Michaels, 1997; Teach, 2003).

4.5. Tips

The TIPS Methodology was invented 50 years ago by G. S. Altschuller. TIPS or TRIZ, as it is often called deduced from its original Russian title, is an acronym for 'Theory of Inventive Problem Solving'. The methodology was deduced based on a systematic patent analysis and best applies for mechanical issues.

TIPS consists of analyzing the physical contradiction, where different parameters have to be optimized in order to innovate successfully. Categorized solution approaches bring mere problem thinking closer towards practical solution options. Software packages exist to support this process with a data base and easy to use graphical interfaces.

Therefore, TIPS is a generalized innovation algorithm in order to find different creative solutions to mechanical or system problems. Additional information on TIPS can be found in Altschuller (1999), Fey and Rivin (1997), Kaplan (1996) and Sickafus (1997). Besides, Möhrle and Isenmann (2002) describe possible involvement of TIPS into roadmapping.

4.6. Controlling

Controlling is rather a supporting or underpinning process, nevertheless a very important one. The controlling aspect has to be applied in connection with another instrument. In addition to roadmapping or the above described innovation processes, controlling can be used to keep up with set targets.

For example, in connection with the roadmapping process, controlling can be used to guarantee the continuity of the generated roadmap. During the development of the roadmap figures should be defined in the individual sections. Later on it can be determined on such a basis, if the project is on the selected track or not. Including this, projects and developments can be numerically seized, controlled and evaluated.

Discussion of different aspects within this topic can be found in recent literature. The measurement of impact of development work is discussed by Godener and Söderquist (2004), Hagedoorn and Cloodt (2003), Hauschildt and Schlaak (2001), Kerssens-van Drongelen and Bilderbeek (1999) and Thamhain (2003). The efficiency for reaching such an impact with R&D organizations is the subject of the contributions of Dyckhoff and Allen (1999) and Galende Del Canto and Suarez (1999).

4.7. Prioritization of solution approaches

The solution approach to choose should serve the need of finding new applications for a given technology and to clarify how such an innovative application could be realized. The evaluation of different procedures and approaches to this topic showed, that the technology choice tool, technology roadmapping and the innovation process are solution approaches that best suit this case. These three methodological approaches ensure a structured and balanced way in order to find new markets and the enterprise internal drive to support the innovation. Additionally, the controlling aspect must also be taken into account, in order to ensure the operative implementation and monitoring.

Real options is not applicable in the beginning, as there is insufficient data in this case, treating a 'technology-push' situation. When markets and market introduction is nearby, a real options calculation may be very valuable for prioritizing different market penetration scenarios.

TIPS, is a very technically oriented method offering inventive support, and can therefore be applied on a more detailed level during the technical development effort. Herein, the special development of a wind-*powerformer* product might benefit from TIPS.

Table 1 shows the solution approaches, and summarizes their prioritization.

5. Practice implementation

5.1. Chosen procedure

Despite the fact that the technology choice tool was elaborated to handle a market-pull, this procedure was found useful to support a structured discussion for the evaluation of the *Powerformer* technology-push.

The chosen solution approaches are implemented in a combination, which is found suitable for the discussed case. The procedure suggested by Phaal *et al.* (2000) was performed, and enriched with the technology commercialization procedure from Jolly (1997). The four stages 'market', 'product', 'technology' and 'charting' where done one after the other, taking into account the elements of the Jolly (1997) technology commercialization.

The Jolly (1997) commercialization steps have a common link with the Phaal *et al.* (2000) procedure, and additionally show underlying activities necessary for each workshop stage. It has proved to be very valuable for internal communication and to profoundly prepare the discussions in the workshops. It highlights the importance of the different stakeholders and shows the character of each stage in an enriching way. For example by explicitly stating activities as 'demonstrating', 'incubating' or 'promoting'. The following Fig. 12 shows, how the interaction and combination of both procedures was seen by the participating stakeholders.

Additionally, control parameters such as market estimates, technical performance requirements and time expectations where defined at the end of each stage. These were deliverables for each workshop, which helped ensure that the chosen direction was followed by the succeeding stage.

The next paragraphs show how the discussions profited from the chosen procedure, and which results where generated. In general about six participants joined the different workshops, where three were permanent members and the other three were invited according to their competence. It was important to get power-promoters into the workshops, in order to have management support. Details about markets and technologies are omitted, in order not to disclose sensitive information.

5.2. Market workshop

The market workshop is the first step towards commercialization, and is called 'imagining' by

Table 1. Summary of discussed solution approaches.

Solution approach	Applicable	Comment
Technology Choice Tool	Yes	Supports a structured discussion
Phaal et al. (2001)	Yes	Technology-push case can be treated correspondingly
Jolly (1997)	Yes	Commercialization of new technology.
Controlling	Yes	Development process monitoring
Real Options	No	Necessary input data is not yet available
TIPS	No	For later special development useful, at the moment too technical

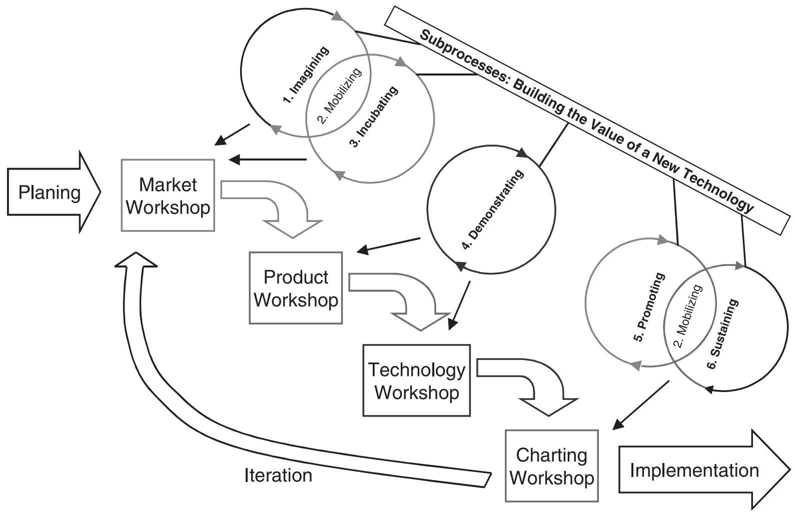

Figure 12. Combination of technology roadmapping and innovation commercialization procedure of Jolly (1997).

Jolly (1997). As described before, it is important that this workshop has a high degree of interdisciplinary contributions.

In this 'technology-push' case, the first imagining activity was done by technicians in their laboratory. This competence was enriched with people from product management and marketing know-how. Taking into account the 'promoting' step, not only possible markets and applications should be identified within the market workshop, but also how these markets can be served in a sustainable manner, adapting it to different upcoming needs. A roadmap is a living document, and this philosophy can be incorporated from the very beginning. The active market processing has to be taken into account, too. This has to be realized in the first step, as suggested by Jolly (1997) with the term 'sustaining'.

The SWOT-analysis shows, that the current market is very conservative and is a problematic introduction field for the *Powerformer*. Besides objective comparisons between the new and the old technology, also soft factors play an important role. This has to be taken into account, when searching new markets and applications for the *Powerformer*. Therefore, markets are discussed, where buyers are more investment friendly, and several possibilities where found together with the experts involved in the discussion. Not only the markets where denominated, but also control parameters where named, such as market volume, turnover, price, costs and basic product requirements. The defined markets are called Market 1 through 4.

The next question is, if all the markets should be served or if a selection should take place. Taking into account the Jolly (1997) process, this corresponds to the 'incubating' step. The technology choice tool was performed at this point with the interdisciplinary group present, in order to discuss the seven meta-criteria of the *Powerformer* technology in respect to the defined markets. This lead to a well structured discussion on feasibility and attractiveness of this innovation effort.

5.3. Product workshop

The product workshop should enable to define individual product features, which have to be fulfilled to serve the defined markets 1 through 4. Firstly, current product specifications have to be taken into account and to be compared if they fulfill a large part of the desired features. Then, a development effort estimate can be undertaken. Also, additional technologies might be needed or taken into account depending on the market discussed. Finally, the needed prototype description was elaborated within this workshop.

5.4. Technology workshop

After the product workshop, a further step into realizing the *Powerformer* innovation was discussing technical issues within the technology workshop. The high voltage cable technology is a crucial element within this innovation, and the applicability of the experience gained with existing prototypes was further elaborated. The need for a new prototype built to proof and investigate the newly needed performance and product requirements was discussed herein. This step incor-

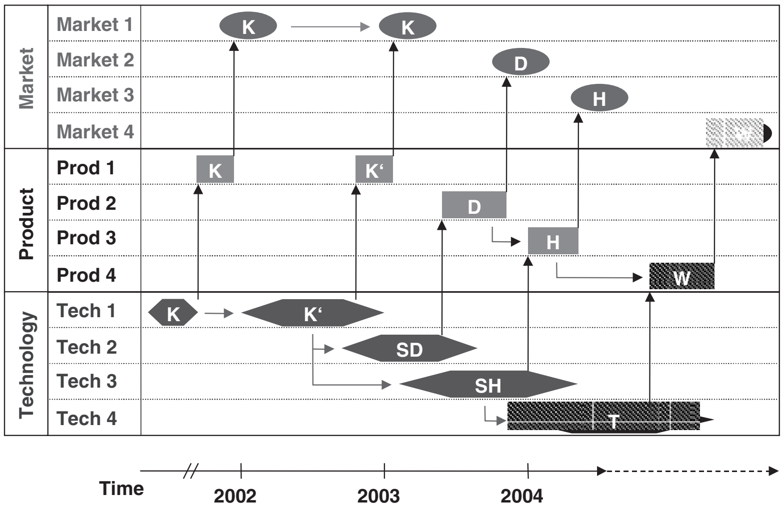

Figure 13. Roadmap visualization.

porates the 'demonstrating' argument within the Jolly (1997) procedure.

5.5. Charting workshop

Taking into account the four identified markets, four different approaches are shown in the roadmap type overview of Fig. 13. It shows the result of the charting workshop. As herein an interdisciplinary competence is needed, the representatives from the other workshops are involved in the charting workshop, too. Besides defining the responsible person for the innovation at stake, also aspects of resources allocation have to be considered more thoroughly at this point.

The fourth market is hypothetical, as this market is far from being developed, and there are some technological shortcomings to be improved. Nevertheless, this market is already mentioned, in case that its importance will become greater in the future. This strategic option is therefore taken into account within this roadmap visualization.

The last two steps of the Jolly (1997) commercialization procedure can now be identified as 'sustaining' and 'promoting'. While new markets are penetrated in a staged procedure, this should ensure the sustained success over time. The promotional aspect is important for market penetration especially. Besides, with this action plan ready also internal promoting can be undertaken, to convince stakeholders within the company.

In terms of Controlling, the charting workshop is a crucial point, as during this workshop the major milestones towards the intended aims are set and graphically shown. Also performance figures are set for project control and further product specification. This can be easily transformed into the stage gate process, which is applied for incremental innovation in many enterprises. This circumstance helps to introduce this disruptive innovation as 'smooth' as possible into an organization.

Table 2. Market and product overview.

Market	Revolutions	Voltage	Performance
Market 1	K Rev./min	K kV	K kW
Market 2	D Rev./min	D kV	D kW
Market 3	H Rev./min	H kV	H kW
Market 4	W Rev./min	W kV	W kW

5.6. Control

As already stated, the market and product workshop defined product requirements in order to ensure the applicability of the innovation in certain markets. These requirements are put into a market overview table, as shown in Table 2. This table is filled in during the first three workshops, and provides the basis for the benchmark and control activities during the realization phase.

6. Summary

At the heart of the cooperation between ALSTOM Power Hydro and the TMU-ETH lies the will to successfully push the *Powerformer* technology on the market, as well as to face the difficulties of internally and externally promoting such a discontinuous innovation. The *Powerformer* is a technology with disruptive character, which proofed its technical feasibility and has further development potential on the markets.

A SWOT-analysis showed, that the *Powerformer* project not only has to cope with external commercialization problems, but that design improvement potential could be deduced from this analysis, too. The insights collected from the SWOT-analysis lead to the aim of investigating appropriate solution approaches for the encountered challenges. On one hand, new markets should be defined within a specified process, on the other hand, the link from technology towards the market should be described properly.

After a prioritization of possible solution approaches, a combination of the technology choice tool proposed by Meyhack *et al.* (2002), technology roadmapping and the process of technology commercialization following Jolly (1997) was chosen. The resulting procedure involving four different workshops proved to be useful in practice for this disruptive technology. In order to be able to monitor the ongoing success of the development, control parameters for markets and technical performance where defined as part of the output.

The herein described effort supports 'unconventional' thinking while at the same time integrates power promoters. Both aspects are crucial for the success of a disruptive innovation, as not only the technology demands a new way of thinking but also the markets. The necessary further treatment of a disruptive innovation within the boundaries of a given organization is prepared by the suggested procedure.

References

Altschuller, G. (1999) *The Innovation Algorithm: TRIZ, Systematic Innovation and Technical Creativity*. Worcester MA: Technical Innovation Center.

Amran, M. and Kulatilaka, N. (1999) *Real Options – Managing Strategic Investment in an Uncertain World*. Boston MA: Harvard Business School Press.

Barker, D. and Smith, D.J.H. (1995) Technology foresight using roadmaps. *Long Range Planning*, **28**, 2, 21–28.

Bray, O.H. and Garcia, M.L. (1997) Technology roadmapping: the integration of strategic and technology planning for competitiveness. Portland (OR), *Proceedings of the Portland International Conference on Management of Engineering and Technology*, PICMET'97.

Bullinger, H.-J. (1994) *Einführung in das Technologiemanagement*. Stuttgart: Teubner.

Christensen, C. (1997) *The Innovator's Dilemma*. BostonMA: Harvard Business School Press.

Copeland, T.E. and Keenan, P.T. (1998) Making real options real? *McKinsey Quarterly*, 3.

Coulon, F. and Jufer, M. (1989) Introduction à l'électrotechnique. In *Traité d'Electricité*, **Volume I**. Lausanne: Presses Polytechniques Romandes.

Dettmer, D. (1998) The heart of a new machine. *IEEE Review*, November, 255–285.

Dyckhoff, H. and Allen, K. (1999) Theoretische Begründung einer Effizienzanalyse mittels Data Envelopment Analysis (DEA). *Zeitschrift für betriebswirtschaftliche Forschung*, **5**, 411–434.

Ebner, M. and Walti, A. (1996) Innovationsmanagement als Antwort auf den zunehmenden Wettbewerbsdruck. In Gassmann, O. and von Zedtwitz, M. (eds), *Internationales Innovationsmanagement*. München: Vahlen.

Fey, V. and Rivin, E. (1997) *The Science of Innovation: a Managerial Overview of the TRIZ*. Michigan: TRIZ Group.

Fischer, K. (1996) Realoptionen: Anwendungsmöglichkeiten der finanziellen Optionstheorie auf Realinvestitionen im In- und Ausland. Dissertation Universität Hamburg-Harburg.

Galende Del Canto, J. and Suárez González, I. (1999) A resource-based analysis of the factors determining a firm's R&D activities. *Research Policy*, **28**, 8, 891–905.

Galvin, R. (1998) Science roadmaps. *Science*, **280**, 5365, 803.

Godener, A. and Söderquist, K.E. (2004) Use and impact of performance measurement results in R&D and NPD: an exploratory study. *R&D Management*, **34**, 2, 191–219.

Groenveld, P. (1997) Roadmapping integrates business and technology. *Research Technology Management*, **40**, 5, 48–55.

Hagedoorn, J. and Cloodt, M. (2003) Measuring innovative performance: is there an advantage in using multiple indicators? *Research Policy*, **32**, 8, 1365–1379.

Hauschildt, J. (1993) *Innovationsmanagement*. München: Franz Vahlen.

Hauschildt, J. and Schlaak, T.M. (2001) Zur Messung des Innovationsgrades neuartiger Produkte. *Zeitschrift für Betriebswirtschaft*, **71**, 2, 161–182.

Jolly, V.K. (1997) *Commercializing New Technologies*. BostonMA: Harvard Business School Press.

Kaplan, S. (1996) *An Introduction to TRIZ: the Russian Theory of Inventive Problem Solving*. Southfield MI: Ideation International.

Kappel, T.A. (2001) Perspectives on roadmaps: how organizations talk about the future. *Journal of Product Innovation Management*, **18**, 39–50.

Kerssens-van Drongelen, I.C. and Bilderbeek, J. (1999) R&D performance measurement: more than choosing a set of metrics. *R&D Management*, **29**, 1, 35–46.

Kostoff, R.N. and Schaller, R.R. (2001) Science and technology roadmaps. *IEEE Transactions on Engineering Management*, **48**, 2, 32–143.

Leifer, R. (1997) Organizational and managerial correlates of radical technological innovation. *Portland International Conference on Management of Engineering and Technology*, pp. 134–137.

Leifer, R. and Rice, M. (2000) *Unnatural acts: building the mature firm's capability for breakthrough innovation*. Washington DC: AAAS Science and Technology Policy Yearbook, pp. 131–154.

Leslie, K.J. and Michaels, M.P. (1997) The real power of real options. *McKinsey Quarterly*, 3.

Meyhack, O., Raurich, V., Tschirky, H., Kappes, S. and Schumann, F. (2002) The technology choice tool: a tool that underpins strategic thinking in R&D and innovation management. Leuven, R&D Management Conference.

Möhrle, M.G., Specht, D. and Behrens, S. (2002) Management von Innovationen und neuen Technologien im Unternehmen. in: *Gabler Lexikon Technologiemanagement*. Wiesbaden: Gabler.

Möhrle, M.G. and Isenmann, R. (2002) *Technologie-Roadmapping: Zukunftsstrategien für Technologieunternehmen*. Berlin: Springer.

Morone, J.G. (1993) *Winning in High Tech Markets*. Boston MA: Harvard Business School Press.

Phaal, R., Farrukh, C.J.P. and Probert, D.R. (2000) Fast-start technology roadmapping. University of Cambridge.

Phaal, R., Farrukh, C.J.P. and Probert, D.R. (2001) Technology Roadmapping: linking technology resources to business objectives. University of Cambridge.

Ropohl, G. (1979) *Eine Systemtheorie der Technik – zur Grundlegung der Allgemeinen Technologie*. München: Hanser.

Sickafus, E. (1997) *Unified Structured Inventive Thinking –- How to Invent*. Michigan: NTelleck.

Strauss, J., Radnor, M. and Peterson, J. (1998) Plotting and navigating a non-linear roadmap: knowledge-based roadmapping for emerging and dynamic environments. Singapore, Proceedings of the East Asian Conference on Knowledge Creation Management.

Thamhain, H.J. (2003) Managing innovative R&D teams. *R&D Management*, **33**, 3, 297–311.

Teach, E. (2003) Will real options take root? *CFO Magazine*, **7**.

Willyard, C.H. and McClees, C.W. (1987) Motorola's technology roadmap process. *Research Management*, **30**, 5, 13–19.

Züst, R. (2000) *Einstieg ins Systems Engineering – Systematisch denken, handeln und umsetzen*. Zürich: Verlag Industrielle Organisation.