Gas Turbine Powerhouse

The Development of the Power Generation Gas Turbine at BBC - ABB - Alstom

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Foreword

Gas turbines have become one of the most important engine types for electric power generation on a global scale – either as simple cycle installations or to a rapidly increasing extent as part of combined cycle power plants. This development is the result of many inherent advantages of this technique in comparison to alternatives – not the least its superiority in the category of cost of electricity.

During more than a century engineers of the Swiss development centre of A.-G. BBC Brown Boveri & Cie., from 1988 onwards ABB Asea Brown Boveri Ltd. and since 2000 Alstom Power Ltd. in Baden, Switzerland have significantly contributed to the achievement of today's advanced gas turbine concept and its successful integration in combined cycle applications. The present book provides a comprehensive and detailed insight on both technical and business aspects of the long-term genesis of this unique high technology product. This rather rare description of the development history of a thermal turbomachine puts also special attention on the human touch – a characterisation of leading engineering personalities of the time and the corresponding teamwork; triumphs and drawbacks accompany this fascinating professional account over decades – from a Swiss company nucleus of less than thousand to a global industrial company with several ten-thousands of employees. Numerous historical 'firsts' in gas turbine technology for power generation are highlighted – as summarized in Section 7.1 – ranging from the first realisation of the industrial, heavy-duty gas turbine in the 1930s to today's high technology gas turbine products, which combine excellent performance, extraordinary low environmental impact with commercial attractiveness.

Twenty years after Ernst Jenny's commendable book on 'The BBC Turbocharger' follows now the 'Gas Turbine Powerhouse' with a comprehensive description of gas turbine developments for power generation at BBC–ABB–Alstom. The book outlines not only the corresponding activities in gas turbine design and related disciplines, but covers also the historic development milestones of the major components – axial compressor, combustor, turbine and turbine cooling; the latter area with surprising, so far unknown revelations. The author Dietrich Eckardt provides a rather rare combination of technical and historic-economic insight, using engineering experiences of more than 40 professional years in turbomachinery research and gas turbine development, both for aero and power generation applications. The inclusion and thorough assessment of a broad variety of new sources and archive materials unveiled many interesting details of the gas turbine history, not the least surprising connections during the early parallel development of industrial and aero gas turbines.

On Friday 7 July 1939, 10.10 h started at Baden, Switzerland the full load certification test of the first power generation gas turbine for the utility plant at Neuchâtel, Switzerland – the first step of what has become a global success story and as such, a well-documented cause to celebrate this key event 75 years ago. This plant remained in service for 62 years – not bad for the first such order ever. The book provides the details to understand this engineering 'miracle', at best for the pride of present and the encouragement of future generations of engineers in this fascinating field of advanced technologies.

Baden, June 2013

Juerg Schmidli

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The writing of history, historiography,
is the 'doing of history', and engineers
should make sure that the historiography
of engineering is not left entirely to historians.
Recognition of this activity by the profession is very important.[1]

1 Introduction

This book tells the story of the power generation gas turbine (GT) from the perspective of one of the leading companies in the field over a period of more than 100 years and written by an engineer. With a global economic crisis imminent – triggered and accompanied by virtual stock market bonanzas and a few years after the illusions of a 'new economy' visibly failed – the time has come to reflect on real economic values based on engineering ingenuity and enduring management of technological leadership. For more than 120 years, engineers of the Swiss development centre of A.-G. Brown Boveri & Cie., ABB Asea Brown Boveri Ltd. from 1988 and Alstom Power Ltd. in Baden, Switzerland (CH) since 2000 have significantly contributed to the art of turbomachinery design in general.

In the history of energy conversion, the gas turbine is relatively new. The first utility gas turbine to generate electricity at Neuchâtel[2], Switzerland ran at full power at Baden, CH on 7 July 1939[3] and was developed by Brown Boveri. The scope of this book starts somewhat earlier to explain influencing ideas and consequently foregoing developments contributing to this invention. It then describes the steady and impressive engine growth from the first local 4 MW emergency power unit until present-day advanced configurations that generate power for large metropolitan areas with unit sizes above 300 MW. This was no success story throughout, especially not in view of the actual business fortunes achieved. There were changes in the company affiliations of the various branches, changes in product portfolio and also some development dead ends. But a few of the original BBC product lines managed to stay in the frontline of advanced superior technology even from present global perspective.

1 Presumably, this quotation has several fathers; the author, Werner Albring, put his encouragement in these thoughts, see also Footnote 7 for the whole context.

2 Neuchâtel is the capital of the equally named Swiss canton in the French-speaking part of Switzerland, some 150 km south-west of Baden. The city of 30,000+ inhabitants is sometimes referred to by the German name Neuenburg, since it originally belonged to the Holy Roman Empire, and later Prussia ruled the area until 1848.

3 Interestingly, the first gas turbine flight also took place in 1939 – only 51 days later. A Heinkel He 178 aircraft, jet-powered by a HeS3B engine of (only) 600 kN thrust, developed by Hans-Joachim Pabst von Ohain (1911–1988) took off on Sunday, 27 August from Rostock-Marienehe, D. In England, the 1930's invention and development of the aircraft gas turbine by the British Royal Air Force (RAF) engineer officer Sir Frank Whittle (1907–1996) resulted in a similar British flight in 1941. As will be outlined in a separate documentation, BBC was indirectly involved in both sides' developments of jet engines with advanced all-axial engine configurations, as they contributed their superior compressor design know-how.

In the meantime, the sheer duration of certain engineering developments over several decades allows interesting historic observations and deductions on inherent business mechanisms, the effects of technology preparations and organisational consequences. A look into the past bears revelations on the impact of far-reaching business decisions. The positive influence of strong, courageous and visionary personalities becomes visible to the same extent as the negative consequences of hesitation and idle waiting. These prospects of an in-depth review of its own historic background have led a number of companies to launch similar assessments. BBC started from a modest nucleus to become one of the largest engineering companies worldwide with operations in around 100 countries. In 1990, it had more than 220,000 employees under the label of ABB. The engineering conglomerate was and still is amazingly innovative and successful in a broad variety of engineering product ranges: DC and AC (direct and alternating current) motors, turbo-, diesel and water generators, transformers, high-voltage transmission and grid equipment, switches and relays, steam turbines for power and ship propulsion including related gearboxes, steam-generating Velox boilers and power generation gas turbines, electric and gas turbine drives up to and including complete railway and streetcar systems, turbocompressors for the iron and steel industry, but also for aero engine applications, turbochargers, wind turbines, electro boilers and furnaces, nuclear power plant equipment, high-frequency radio and telecommunication equipment, liquid-crystal displays, vacuum tubes and semiconductors, power plant controls – to name just the most important. These product ranges comprise development activities as well as manufacturing and service operations in general.

Only one of these areas found comprehensive documentation in a stand-alone book so far: The BBC Turbocharger[4]. In 2002 an ASME paper[5] with a review of 'ABB/BBC Historical Firsts' in advanced gas turbine technology got some attention. It was then indeed Ernst Jenny, the author of the successful turbocharger book who became a strong proponent of the idea to write a follow-on history of gas turbine development[6]. Industry history, especially that of Germany and Switzerland in the context of the 2nd World War, received the special attention of professional young historians in recent years. We owe them many fundamental clarifications and also sometimes rare technical 'golden nuggets' as a result of their unrelenting, in-depth ploughing through archive materials. When it comes to the technical interpretation of their findings, pure historians sometimes reach their limits, however. In line with this thinking Werner Albring[7], the 'nestor' of German fluid mechanics at TU Dresden for years provided strong encouragement to this project.

4 See Jenny, The BBC Turbocharger

5 See Eckardt and Rufli, ABB/BBC Historical Firsts

6 Actually, the launching date of this book project can be exactly reconstructed. We met the late Ernst Jenny on 5 April, 2003 on the occasion of Georg Gyarmathy's 70th birthday (who passed away too soon on 24 October, 2009 at the age of 77). Gyarmathy, himself a former BBC director and successor to Traupel's chair for Fluid Machinery at ETH Zurich (1983–1998), was interested in technical history where he especially promoted the role of his Hungarian fellow countryman, the inventor G. Jendrassik, who built a small all-axial gas turbine and made early suggestions to apply the gas turbine for aero propulsion.

7 Prof. Dr. Werner Albring (1914–2007), was head of the Institute of Applied Fluid Mechanics at TU Dresden from 1952 until 1979 and author of one of the most intelligible textbooks on fluid mechanics. After his retirement he wrote several outstanding papers on the history of engineering and science (Helmholtz, Hagen, etc.) and in this context is known for his credo that qualified engineers should return to a responsible leadership role in view of the complex environment in industry and society, http://www.albring.info/

In fact, this is not the first approach to the subject. Our files contain a collection of material for a 'Swiss History of the Turbomachinery Industry' which was obviously planned in 1978/79, but the idea was dropped with the disruption of the BST industrial venture[8] at that time.

As had already been reported in the addressed ASME paper[5], one of the most intriguing aspects of the early BBC gas turbine history is the frequent in-depth involvement in parallel aero engine developments. Correspondingly, astonishing findings were made in the meantime as a consequence of further investigations and they would disrupt in full breadth the general scope of this stationary GT company history. A full roll-out has to wait for a follow-on publication.

	Book Survey					**BBC/ABB/ Alstom**
Year	**Company** Section 2	**Headings**	**+ GT Key Components**	**++ Other Contents**	**Section**	**Historical Firsts**
1900	*02.10.1891* WW I BBC Brown, Boveri & Cie.	GT Forerunners		- Turbomach. & Turbocharg. - Early GT Attempts - Holzwarth etc. GTs	3	1893 1st AC Th. Powerplant 1895 1'000th Dynamo 1900 BBC Mhm. 1905 BBC centr. compr. for Armengaud-L. GT 1923 2-st. Turbo-Charger 1931 All-axial VELOX turboset 1936 Houdry 'GT' 1939 4 MW Utlty. GT Plt. Neuchâtel 1948 40 MW GT Plant Beznau 1957 4x27 MW All-GT PP(record) 1970 BBC #2 in GT PP sales 1980 12-st. trans. compress., PR=16 1984 GT with premix. comb. 1994 165 MW high-eff. GT24 1997 365 MW CC GT26, 58+%
		→ The 1st Power Gen GT 1927-1945	I Axial Flow Compressor	- Turbom. Dev. - Prom. Engs. - Early BBC GTs	4	
1950	WW II *31.12.1987*	Gas Turbine Technology Developmt. 1945-1988	II Combustor	- GT Dev.mt. - Prom. Engs. - Compet. Des. - Mech.Design - Prod. Sites - Special Projects	5	
2000	ABB Power Generation Alstom Power	CCPP GT Techn. Breakthroughs since the 1990s	III Cooled Turbine	- GT24/GT26 - Prom. Engs. - Comb.Cycle - Palmarès	6	

Figure 1-1 *Survey of the book structure*

Figure 1-1 illustrates the structure of this book in graphic form. The left-hand scale covers the period from the formation of BBC until today, with the various Company names shown

8 BST Brown Boveri-Sulzer Turbomaschinen AG was founded in 1969 as a joint venture between BBC Brown Boveri & Cie., Baden CH and Gebrüder Sulzer AG, Winterthur CH (after Sulzer had already decided to cooperate with Escher Wyss AG before) as part of a necessary concentration process to become more competitive e.g. with a common, standardized product portfolio (Section 5.1.3). The effort failed and BST was already resolved again on 1 July, 1974. It appears that the planning for a joint Swiss turbomachinery history was a relict of foregoing BST times. Existing materials and correspondence – see BBC, Geschichte des Schweizer. Turbomaschinenbaus, 1982 – between 07/1978 and 09/1979 foresaw BBC contributions from Cl. Seippel, L.S. Dzung and H. Pfenninger, but the parties obviously agreed to stop the effort after Prof. W. Traupel's excuse that the 3rd edition of his own book had higher priority.

over time in the next column. The history of this succession of companies from BBC Brown, Boveri & Cie. via ABB Power Generation Ltd. to the present ALSTOM will be told in Section 2. Sections 3 to 6 in principle follow the chronology, with a few exceptions. Section 3 outlines in short the centuries of collecting experience in turbomachinery, a description that normally starts with the introduction of the reaction principle by Heron of Alexandria. I tried not to follow the trodden path and looked for some lesser known examples with reference to the gas turbine and the Swiss location.

Edward Constant[9], the author of one of the most comprehensive and well-researched books on GT history, differentiates between a first, aborted gas turbine revolution (1900-1920, Stolze, Armengaud) and a second, successful attempt, mainly led by BBC in the 1930s.

I have maintained this structure in Section 3, where all 'early attempts with the GT principle' belong to the first category. Section 4 describes the path to the 1st power generation gas turbine at Brown Boveri, Baden, Switzerland in the timeframe from approx. 1927 until 1945. Besides a description of the actual development activities, the text focuses on the decisive component for the GT development success: the axial flow compressor. This principle of a combined chronological and subject-oriented order has been carried through in the following sections. In Section 5, the GT's 'middle component' – the combustion chamber – has been linked to the development period for the BBC gas turbines between 1945 and 1988, the end of BBC as an independent, stand-alone company after 97 years. The narration about the 3rd GT component along the flow path – the cooled turbine – then follows in Section 6 in the context of the most recent technology breakthrough – the success of the combined-cycle power plants after 1990. This presentation has a certain benefit, since the individual GT component histories are kept together, letting the inherent development rationale become more transparent. Moreover, with a few exceptions, like e.g. the first introduction of a transonic compressor design in the 1980s, this deliberately chosen structure fits the development highlights touched on surprisingly well:

- The successful realisation of the axial compressor was *the* precondition for the BBC success towards the 1st utility gas turbine in the 1930s. Vice versa, the lack of an efficient compressor unit was in most of the foregoing efforts the reason of failure.
- The intermediate phase from 1945–1988 saw at its backend the breakthrough of BBC's unique low-emission combustion technology.
- Finally, the highly demanding, integrated turbine designs with the combination of advanced aerothermodynamics and sophisticated production technology only materialised after 1990; but they also triggered reflections on the recently rediscovered, early beginnings of BBC's turbine blade cooling technology in the 1930s.

Besides this repetitive link of section headings/contents and the 3 key GT components in the core Sections 4 to 6, each of these chapters with varying emphasis contains a treatise of

- the developments during that period,
- the relevant organisational changes,
- the most prominent, dominant engineering personalities,
- the relevant market observations and – where applicable
- the competitive developments.

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9 See Constant, The Origins of the Turbojet Revolution

In a short final Section 7 'Les Palmarès', the historical 'firsts' in power generation technology by BBC/ABB and Alstom are listed in chronological order, together with a list of the responsible GT Development Directors in Baden, CH during the covered period of nearly 90 years and of the dedicated members of the GT Development 'Hall of Fame' which since 1995 is awarded annually for individual, outstanding contributions to the gas turbine development activities.

This book is written to be read from start to finish as a continuous story, once in a while interspersed by summarising description and analysis. Details and lengthier excursions have been shifted to the Footnotes on the same page, where the patient reader may find a few 'nuggets'. I hope that the interaction of the various elements of the story as described above will not confuse but rather enlighten the readers together with the presumed advantages as the narrative proceeds. References to the used literature have been collected in the comprehensive Section 8 'Bibliography'.

On the other hand, anyone who prefers to use the book as a kind of reference is recommended to turn to the Index listings – of Names, Section 9 and of Subjects, Section 10. Section 11 shall assist understanding with a comprehensive list of used 'Nomenclature and Abbreviations', followed finally by Section 12 – a short portrait of 'The Author'.

At the end of these introductory remarks, special thanks go to Juerg Schmidli and Peter Rufli from Alstom Power, Gas Turbine Development in Baden, Switzerland for defining frame and pace of this project in a generous manner. This work was considerably facilitated by a thorough preparation of the relevant, notwithstanding huge literature body for this task. The Alstom-internal database 'GT History References' in the meantime covers nearly 1'200 objects (papers, journal articles, books) that have been collected, digitised and put into a searchable form by Robert Marmilic, who herewith prepared the reliable foundation of this project. The numeration of this database is also given in the attached Bibliography in brackets [...], as an extra-benefit for Alstom-internal readers. Several colleagues contributed extensively from their own broad development experiences and by carrying out a careful proof reading of the manuscript. Mrs. Joanna Stone helped to smooth the English text and so considerably alleviated the 'readability' of engineering explanations; the endeavour to produce English technical diction was followed in the tradition of former, internationally established house publications such as 'Brown Boveri Review'. Special thanks are owed to Claude Seippel's son Olivier (1926-2012), also employed in various functions at BBC, who helped to revive personal memories of his father, especially by providing insight into the BBC part of Cl. Seippel's diary notes.

Invaluably, the great resources of the ABB Historic Archive, Baden-Daettwil, CH (Docuteam Tobias Wildi, Mrs. Raffaela Luetolf and Norbert Lang) and of the ABB ZX Test Dept. Archive (Bernhard Schoenung, Hueseyin Coskun) have been made available for these studies – with thanks to ABB HR Management (Renato Merz, Volker Stephan). Mrs. Cornelia Bodmer maintained contact to the ETHZ Library, squeezing rare information sources out of NEBIS[10]. What could not be made available in Switzerland was still in reach of the ever-ready specialists of the MTU Aero Engines, Information Services team in Munich, Germany (Helmut Schubert, Reinhard Glander, Mrs. Sabine Hechtl), in the meantime probably the

10 ETHZ on-line catalogue: NEtzwerk von Bibliotheken und Informationsstellen in der Schweiz (Swiss libraries network).

best-assorted library for gas turbine and turbomachinery issues in Europe. The powerhouse graphic[11] on the book cover is by, and courtesy of Mark Welsh, Jersey City, NJ, USA. Finally, the author wants to thank a number of present and former colleagues for significant help; they spent considerable time and energy digging deeply into their memories, archives and files to reconstruct the past in as much detail and colour as possible: Jan-Erik Bertilsson, Franz Farkas, Fredy Haeusermann, Jaan Hellat, Wolfgang Keppel, Hanns-Juergen Lichtfuss, Uwe Schmidt-Eisenlohr, Martin Schnieder and Konrad Vogeler.

No one can be an expert on such a long period and on so many different technical subjects as addressed in this book. Notwithstanding, the broad external support and a thorough study of the available sources, deficits and drawbacks in the presentation of the comprehensive materials cannot be ruled out. The overall responsibility for this book, the selection of contents and the picking of individual aspects, technically and otherwise, its pros and cons, inherent correctness and hopefully not too many flaws remains with the author – and his necessarily subjective view on this fascinating profession. Clearly believing in the 'wisdom of the many' I look forward to receiving comments and proposals for improvements. In this respect the book may find many generous readers who enjoy the intended broad, nevertheless concise approach to nearly one hundred years of unique, technical company history.

Baden / Munich, October 2013

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11 © Mark Welsh. The illustration stands here to visualise **the** powerhouse in generic form; actually, it represents the Hudson & Manhattan Railroad Powerhouse designed as a 'technical cathedral' by John Oakman and erected 1906–08, at the time of first gas turbine trials and 30 years in advance of the first practical introduction of GT power generation. http://jclandmarks.org/campaign-powerhouse.shtml

2 Survey

The following survey covers 120 years of uninterrupted company history; may the next three figures suffice to provide an initial idea thereof. Figure 2-1 shows the historic development from the early beginnings in the late 19^{th} century until the present Alstom in a condensed graphic form as a 'company tree'. The ancestry unites famous names from all over Europe that have left traces in one form or another. The relevant links and intersections will be discussed in the following chapters of the individual company histories as they evolve along the mainstream of GT development.

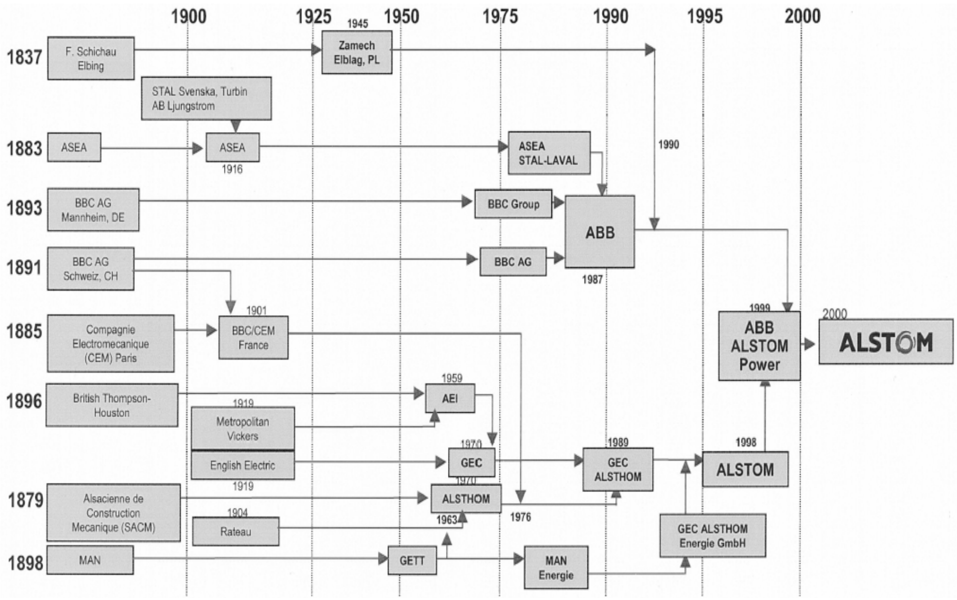

Figure 2-1 *Alstom company tree*

The whole industrial structuring process of course did not follow a straight and consequent course. There were drawbacks and detours. Economic and political crises[1] and management disappointments alternated with unforeseen successes over longer periods, all of this interrupted by the two world wars. The personnel numbers over time reflect these unpredictable events, nevertheless with a surprisingly stable growth trend over several decades.

1 The example of the economic figures for BBC Mannheim during World War II, Figure 2-12, shows that even a global political crisis could develop considerable economic momentum for BBC.

Figure 2-2 illustrates this trend on a global scale. While the BBC personnel grew rather steadily to a total of 50,000+ until the mid 1950s, the subsequent variations are much more pronounced and dynamic. At first, the number of employees nearly doubled until 1980. This was followed by stagnation and decline until BBC's official end in 1987. Next, the newly founded ABB Asea Brown Boveri in the 'Era Barnevik'[2] initiated another duplication boost with mergers and acquisitions to reach a top value of 220,000 ABB employees worldwide before 1995, followed by a steep decline of 27 percent in the following five years which saw substantial divestments, also including the transfer of the power generation business (and the addressed gas turbines) to Alstom S.A. in the year 2000. Thereafter, the reference employee numbers became somewhat uncertain, but to simplify matters, the present Alstom and ABB figures combined show an apparent recovery of the personnel numbers to approx. 200,000 in total for the year 2010.

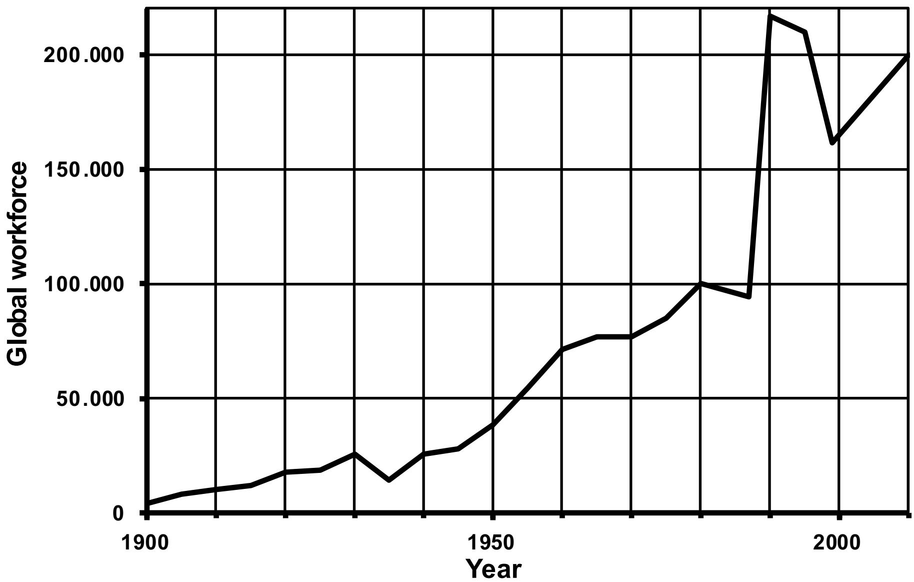

Figure 2-2 *BBC–ABB–Alstom global development of personnel numbers*

Figure 2-3 shows the corresponding employment figures for Switzerland alone, where the Brown and Boveri workforce may have comprised approx. 800 people in 1900. The Swiss employment followed the global trend in general, so that up to the 1960s the employment

2 Percy N. Barnevik, born 1941, CEO of Asea (1980–87) and of ABB (1988–1996), ABB Chairman (1997–2001). *'During his 8 years as CEO of Asea followed by the 9 years as CEO of ABB, the company achieved an increase of stock value of 87 times or 30% average per year over the 17 years. The net profit increased 60 times and sales 30 times. Based upon these extraordinary results, Barnevik received a one-off payment of 148 million Swiss Francs when he retired as CEO in 1996. In 2002, six years later under a second succeeding CEO, ABB's stock market value plummeted from 54.50 Francs in 2000 to just under 15 Francs. Barnevik recognized his involvement on this matter, both agreeing to repay half the amount of the payment and resigning from the advisory board.... Since 1999,... he has received special attention in the media for his work with entrepreneurship, Self Help Groups, and microfinance among women as a way out of poverty. By the end of 2007, 272,000 women have been organized and trained and have started 106,000 small enterprises.'* (Quote Wikipedia)

at the Swiss mother company consistently represented 25 percent of the total. Thereafter, the Swiss content decreased – slowly at first – and is now at a level of close to 5 percent only.

The companies BBC–ABB–Alstom have always been at the forefront of technological development over time. Proof of this statement over a company history of more than 100 years is not easy, though. An indicator may be the number of patents granted annually in the name of the various companies over time, Figure 2-4.[3] Since there is always a time shift of several years between patent filing and approval, there is no complete correlation with the development of the global workforce, Figure 2-2, but the coincidence is striking. A first innovation peak occurs for BBC between 1930–1934 with the axial compressor and the corresponding Velox boiler developments, Sections 4.2 and 4.3.1. During WW II and the early 1950s, innovation progress appears to stagnate, and a somewhat delayed recovery back to the 1930s level can be only realised by the mid-1960s. The best BBC values occurred between 1975–1980. Thereafter, quite strangely, there is a decrease in patenting activities, almost as though a certain innovative exhaustion anticipates the coming end of the company. Possibly, this trend was also caused by a change in the company's patenting policy for cost reasons.

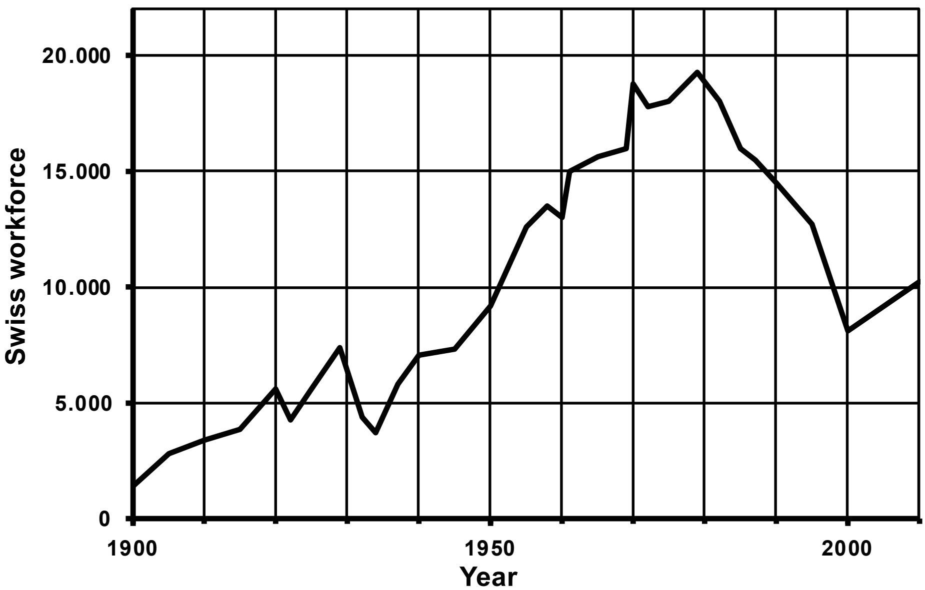

Figure 2-3 *BBC–ABB–Alstom personnel development in Switzerland*

3 The data result from mid-2010 <espacenet> searches in the database of the European Patent Office; they cover the complete industrial product portfolio of the investigated companies. Not shown is the first BBC decade in the 1890s, during which the young company already received 31 patents, presumably most were for inventions of C.E.L. Brown, equally distributed in the years 1893 and 1899. Up until the mid-1930s, BBC filed patents solely in the name of the company. Thereafter the name of the inventor is also noted in most cases.

The drawback of this decision could still be felt 15 to 20 years later, when the company realised that e.g. the IPR Intellectual Property Rights protection of Alstom's GT 'base fleet' and of corresponding spare parts showed painful gaps in its defence against attacking product 'pirates'. The last decade of the 20th century saw an unparalleled IPR growth trend for both ABB and Alstom[4], followed by a similarly steep downturn by a total of forty percent in the number of issued annual patent grants until 2005/2006, before rising numbers can be observed again.

In a combination of Figure 2-2 and Figure 2-4, Figure 2-5 illustrates the development of innovation power over time and thus eliminates the sheer workforce impact on patent output. The peak of engineering creativity between 1929 and 1934 becomes clearly visible with nearly 20 patents per 1,000 employees annually. The subsequent steep decline is only interrupted by a short, war-related spike in 1942. The slow post-war recovery has already been mentioned, culminating in a flat, nevertheless solid ridge over 20 years at a level of minus forty percent below the peak values of BBC's high time some 45 years before. Again, the steady decrease covers nearly the complete decade of the 1980s until a pronounced low, before another peak accelerated by energetic engineering activities in power generation marks the success of sustainable research and development efforts.

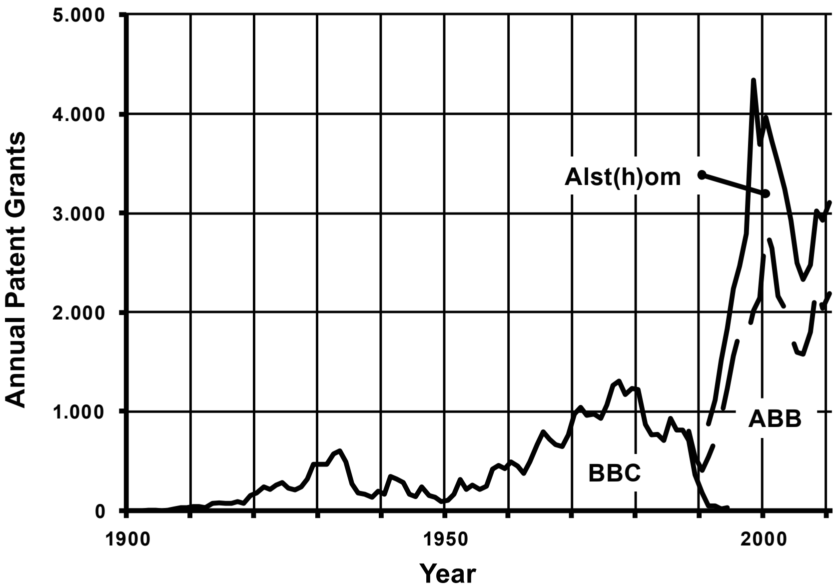

Figure 2-4 *Technology growth: annual patent grants for BBC–ABB–Alstom*

[4] Though Alstom only bought ABB's power business in 2000, for comparison purposes it is worthwhile extending the Alstom view over the foregoing decade as well. This confirms that the growth in the number of patents granted to ABB was no standalone phenomenon. Consequently, the Alstom figures also comprise the corresponding Alsthom results before the name change in 2007.

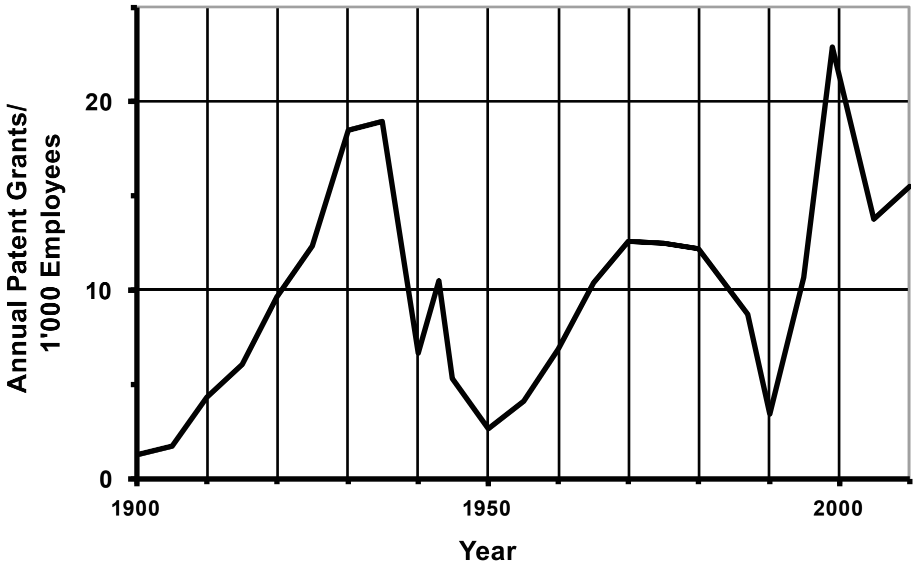

Figure 2-5 *Power innovation over time: annual patent grants per 1,000 employees of the global BBC–ABB–Alstom workforce*

2.1 Short Company History – Power Generation

BBC and its successor companies are part of the history of technology that gave rise to the greatest inventions of the past century. Gas turbines and more generally 'turbomachinery' emerged in the wake of early electrification. Interestingly, the names of those pioneering companies are today still amongst the leading players:

In 1867, the German Werner von Siemens presented the first 'dynamo' after having discovered the principle of electrodynamics. In 1879, Thomas A. Edison invented the light bulb, establishing the basis for the creation of the powerful General Electric (1895). Already before 1891, the year of BBC's foundation, Charles E. Brown had succeeded in two historic strides to demonstrate the possibility of transmitting AC power over longer distances:

- First in Switzerland, between Kriegstetten and Solothurn[5] (8 km, 25–40 kW) in the year 1888
- and then in 1891 by transmitting 220 kW over the record distance of 175 km in Germany from a hydraulic power station on the Neckar River at Lauffen, 80 km upstream of Heidelberg, to an electric exhibition site in Frankfurt-on-Main via a 15 kV power line and thus, unheard of minimal losses.

After Ferraris at Turin (approx. 1885) and Tesla in the USA (1887) had discovered the principle of the rotating electric field, propagating the usage of alternating current, several de-

[5] The end user Sphinx Werke AG was a turning shop working for the local watch industries and preferred the expected, low-vibration electric drives for precision manufacturing over the established roughly running steam engines. See Lang, Brown and Boveri, p. 24.

signers focussed on the three-phase AC motor. For the Frankfurt electricity exhibition Charles E. Brown built the 40 pole 200-kVA-generator for Lauffen at MFO MaschinenFabrik Oerlikon, Section 2.1.1, while the corresponding motor at Frankfurt was developed by Dolivo-Dobrowolsky, AEG Allgemeine Electricitäts-Gesellschaft. The three-phase Alternating Current (AC) generator contributed considerably to the success of the new company, when this ingenious design became part of a power generation turboset with steam turbine (ST) drive from 1900 onward.[6] Instead of producing the required magnetic field in the stator or in rotors with salient poles, Brown's design for the first time generated it in a solid, fast rotating smooth rotor, on which the field coils were arranged in milled grooves.

Similarly, Brown's two unique oil-cooled transformers used to step up the voltage to 15 kV for transmission were an essential contribution to the rapid spread of electricity applications. This configuration reduced losses to an absolute minimum – and the young pioneer and his new works gained an international reputation, Figure 2-6.

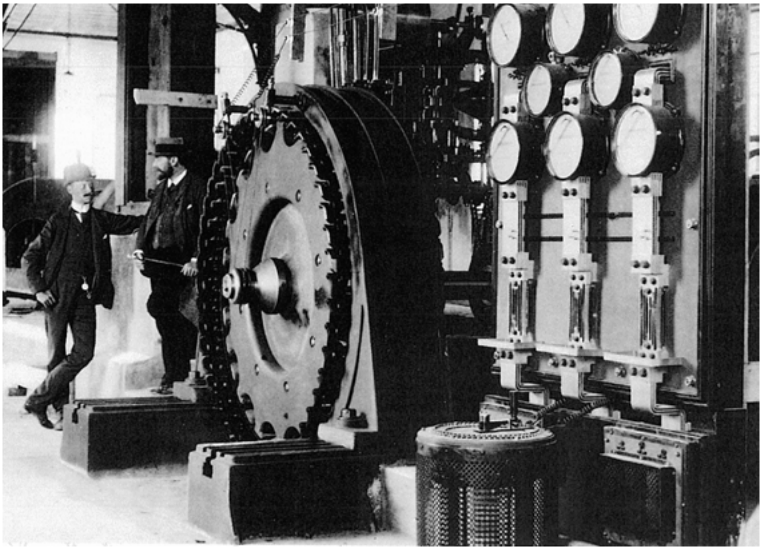

Figure 2-6 *BBC AC generator and 'control centre' at Lauffen for power transmission to Frankfurt, approx. 1891 © ABB*

From this moment on, driving power no longer had to be generated and consumed at the same site. An electric cable could now link the source of energy with the place at which it was utilised; centuries of restricting mechanical transmission equipment and consequently, of only slow industrialisation were over. And also, the master of all electric trades had been proven wrong:

> *"Fooling around with alternating currents is just a waste of time. Nobody will use it."*
> – Thomas A. Edison, ca. 1880

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6 For the early BBC history and the pioneering works see Lang, Brown and Boveri. For the decisive business-generating combination of Brown's high-speed AC generator with a steam turbine drive, see Footnote 13 and Figures 2-8 and 2-9.

2.1.1 BBC Aktiengesellschaft Brown Boveri & Cie., 1891–1988

On 2 October 1891 the following entry was made in the commercial register of the Swiss Canton of Aargau: *'Charles E. L. Brown of Brighton, England and Walter Boveri of Bamberg, Germany, both residing in Baden, have established a limited partnership under the company name Brown, Boveri & Cie., Baden. The nature of the business: Fabrication of electrical machines'.* The two founders complemented each other perfectly: Brown was the technical wizard and Boveri, the dynamic businessman, Figure 2-7.

Figure 2-7 *The pioneers Charles E. L. Brown (1863–1924), J. Walter D. Boveri (1865–1924) in 1891, the year of BBC's foundation © ABB*

The colourful personal history of both pioneers and their families over the years found technically competent biographers on the occasion of various milestone anniversaries.[7] [8]

Charles Eugen Lancelot **Brown** was born in Winterthur, CH in 1863, the son of Eugénie Pfau and Charles Brown sr. His mother was the daughter of a tiled-stove builder, and his father was a steam engine designer who had come to Switzerland from Uxbridge, today the north-western end station of London's underground Piccadilly Line. Brown sr. played a major part in building up the Winterthur operations of the SLM Schweizerischen Lokomotiv- und Maschinenfabrik (1871) and years later was involved in setting up the Electrical Engineering Department at the Oerlikon[9] Machinery Works (MFO). In 1885, Brown sr.[10] handed over this MFO-post to his 22-year-old son. It soon became apparent

7 See Lang, Brown and Boveri

8 See Dietler and Lang, Tradition and Innovation

9 Oerlikon, a district in the north of Zurich since 1934; MFO Maschinenfabrik Oerlikon, founded 1876, became part of BBC in 1967, and today is where ABB is headquartered. The Oerlikon 20mm-AA-gun came from the Oerlikon-Buehrle trust company WO Werkzeugmaschinenfabrik Oerlikon, an MFO spin-off since 1906.

10 Actually Brown sr. had decisive influence on the early success of the coming power generation company: dealing with high-speed steam engines brought him in contact with Charles A. Parsons, the inventor of the multi-stage axial-flow steam turbine, a proven concept also for the future gas turbine. Brown senior's many

that Charles Brown jr. had inherited not only a position from his father, but also extraordinary gifts as well. Prior to his debut in Oerlikon, Brown studied mechanical engineering at the Technikum Winterthur. It was at MFO that Brown met his subsequent partner, Walter Boveri, who soon recognised the talents of the mechanical engineer two years his senior and promoted Brown to head of the MFO 'Assembly Division'. Finally in 1891, after the short joint MFO intermezzo, the two BBC founders moved to their own company in Baden. Soon thereafter, when BBC was transformed from a limited partnership to a joint stock company of the same name in 1900, Brown was named chairman of the board. As is typical for his profession, the creative and impulsive engineer became unhappy with this management post and the changes due between 1909–1911, including the adoption of mass production. Consequently, he withdrew into private life as a disappointed man. In his 20 years of designing, Brown had dozens of inventions patented; technology was his world, but he cared little for the commercial aspects of BBC. In this respect the end of the 'over-engineered company' BBC (with an anti-bookkeeping mentality) sounded like a last echo of the spirit of its original founder. Along the same lines, the match with Walter Boveri was a stroke of good fortune.

Walter **Boveri** was born in the provincial town of Bamberg in northern Bavaria in 1865[11]. His father Theodor Boveri sr. was a physician, and his mother Antonie ('Toni') Elssner was the daughter of a lawyer. Walter Boveri attended the Royal School of Mechanical Engineering in Nuremberg, where he completed his studies within three years. He was just 26 years old when BBC was founded. Company visitors, asking him to direct them to the 'boss' or 'your father' he replied unshaken *"The father, that's me"*. Apart from his technical qualifications, Boveri was a tough and smart businessman. When Brown had left the company, Walter Boveri stepped in as chairman of the board; his son Walter E. Boveri (1894–1972) held the same position from 1938 until 1966 and was the last family member to lead the company. Aside from the founders, key company positions were also held by a brother of Charles jr., Sidney William Brown, who was technical manager from 1891 to 1900 and thereafter the board's delegate in upper management. One of Walter Boveri's cousins, Fritz Funk, headed up the administrative staff from the outset. Funk also served as board chairman for ten years, following Boveri's early death after a car accident in Belgium in 1924. Walter Boveri's brother Robert Boveri (1873–1934) was one of the directors of BBC Mannheim from the

years of correspondence with Parsons led to a license agreement in 1900 that enabled BBC to build the first steam turbine on the 'continent', Figure 2-9. In combination with Charles Brown's AC generator this resulted in a successful head start into the new century.

11 Boveri's family originally came from Savoy [it. 'i poveri' – poor people] and settled near Iphofen, lower Franconia at the beginning of the 17th century. They moved to Bamberg in 1835. Besides Walter, *1865, who was the 3rd of four brothers, the 2nd eldest, Theodor Heinrich Boveri (1862–1915), became a renowned German cell biologist, whose ideas are still followed today [see Neumann, Theodor Boveri]. He reasoned as early as 1902 that a cancerous tumour begins with a single cell in which the make-up of its chromosomes becomes scrambled, causing the cells to divide uncontrollably. He proposed the existence of cell cycle check points, tumour suppressor genes, and that uncontrollable growth might be caused by radiation, physical or chemical insults or by microscopic pathogens. It was only later that researchers demonstrated that Th. Boveri was correct with these predictions. He was married to the American biologist Marcella O'Grady (1863–1950), who was the first woman to graduate from the MIT Massachusetts Institute of Technology. Their daughter Margret Boveri (1900–1975) became one of the best-known post-war German journalists. Actually, Margret's accounts somewhat surprisingly also give insight into the early commercial BBC history. After Theodor Heinrich Boveri's death the family decided to split and sell the joint family property at Hoefen/Stegaurach near Bamberg, which Margret and her mother tried to keep together, but *'this hindered uncle Walter, in whose company BBC all our money was invested'*, so that they were only able to buy the still marvellously maintained 'Seehaus' ('Boveri-Schlösschen').

foundation of the German company in 1900 until his death in 1934; Robert's son Dipl.-Ing. William Boveri was the director at Mannheim until the 1970s.

The decision to locate the firm in Baden was made only after a very careful assessment of all the alternatives. Once made, everything proceeded very rapidly: Five months after the company was founded, 124 BBC employees moved into the offices and factory halls 200 m north of the Baden train station. Baden ultimately won out due to the Limmat River hydroelectric power station being planned there and other advantages. The power station meant a reliable supply of electricity and more importantly the first major order. In the months after its foundation, the generators and switchgear for the Kappelerhof hydroelectric power station filled the factory buildings. Brown and Boveri were pursuing a strategy that has since become a guiding principle: Manufacture products in the markets in which you sell them.

Charles Brown and Walter Boveri recognised electricity as the key form of energy for a new age. Their insight was shared by few at the time, making it difficult for Brown and Boveri to procure money. After a long search, Walter Boveri finally found a willing investor for the required seed capital of 500,000 Swiss Francs (SFr)[12] in late 1890: Conrad Baumann, a silk magnate from Zurich, who would later also become his father-in-law.

Switzerland offered the BBC founders what they needed to get off to an excellent start, for the Alps had huge, as yet untapped, resources for hydroelectric power. The orders of the young company included equipment for power stations and subsequently electric railroads. The Jungfraubahn, a railroad electrified by BBC, carried its first tourists to the base of the Eiger Glacier in 1898 and by 1912 had been extended all the way up to the Jungfraujoch, 3454 m above sea level. The locomotives were considered technological wonders of the world at the time.

In addition to supplying the flourishing domestic market, BBC was export-oriented even in its first years of business. But high tariffs in other countries were an obstacle to expansive exportation. With the aim to penetrate new markets and avoid long-distance shipping, the company had to grant licenses or even establish local subsidiaries. The transformation into a joint stock company in 1900 was both an occasion for and a consequence of the internationalisation already underway and helped to procure capital for the cost-intensive manufacture of steam turbines. By the outbreak of the 1st World War, BBC had established a foothold in the key industrialised countries of Europe. After 1945, it proceeded to do the same on the American continent. Despite a number of setbacks and sell-offs, the BBC Group grew steadily, as already illustrated in reference to Figure 2-2.

Only one year after its foundation, BBC nominated their engineer Jean Jacques Heilmann to become the company's representative in France. The inventor of the Heilmann locomotive[13] was in close contact with Weyher & Richmond, steam engine manufacturers at

12 See Lang, Brown and Boveri

13 The Heilmann locomotives were the first steam-electric designs, using a reciprocating steam engine to drive DC generators, which in turn powered electric motors mounted directly on the axles. The initiative to improve the Heilmann locomotive brought Charles Brown sr. in contact with Charles A. Parsons (1854–1931), the inventor of the multi-stage axial-flow steam turbine. It was Brown sr. who saw the ideal qualification of the compact, high-speed steam turbine as a power generation drive. After corresponding over several years, a license agreement was finally signed in 1900; it permitted the young Swiss enterprise to prosper by building Parsons steam turbines in combination with its own high-speed generator exclusively for the European continent and several

Pantin near Paris. This enterprise laid the ground for C.E.M. Compagnie Électro-Mécanique to build and operate electric power plants as early as 1885, Figure 2-1. Since 1894 C.E.M. via Heilmann took the right to produce and distribute BBC engines in France and became BBC's full subsidiary BBC France in 1901.

The internationalisation of BBC was essentially shaped by one outstanding product:

In 1900 the company made the courageous and momentous decision to include steam turbines in its range of products, Figure 2-8. Watt's steam piston engines had triggered the first industrial revolution in the early 19th century; a hundred years later steam turbines coupled with generators were to play a role of similar importance. Rotating turbo-engines subject to constant impingement by jets of steam replaced the venerable piston steam engine.

Consequently, the production of turbine generators soon became a major line of business at BBC.[14] The fast-rotating, alternating current generator, a stroke of genius on the part of Charles Brown, led to the breakthrough of turbine generators at the turn of the century and to an influx of orders for BBC from around the world. By 1902, BBC had delivered 17 steam turbines, one of them with an output of three MW. By 1905 the product was already accounting for half of the total company sales, Figure 2-9.

Figure 2-8 *Steam turbine assembly, Baden ca. 1902* © *ABB*

In retrospect, the early years must not be viewed solely as a time of technical innovation and success; they were also rife with intense labour and social disputes. Shareholders for their part suffered major disappointments in the 1920s and 1930s; economic difficulties

other countries. See Lang, Brown and Boveri, p. 21. According to Traupel, Marksteine – first steam turbine tests as part of BBC's coming series production were carried out in 1901, but the first Parsons steam turbine on the European continent was ordered directly and built at C.A. Parsons and Co., Newcastle, UK in 1899/1900 for the public utility services of the city of Elberfeld, Germany.

14 A special company was founded, the 'AG für Dampfturbinen System Brown-Boveri-Parsons' (public stock company for steam turbines Brown-Boveri-Parsons) for the acquisition of additionally required capital to erect the necessary, separate manufacturing plant with corresponding machinery in 1900, Figure 2-8. The license agreement with Parsons ended in 1912.

have been as much a part of BBC's history as grand triumphs. From 1903 to 1914 the German AEG Allgemeine Elektricitäts-Gesellschaft held a large part of the BBC shares. After WW I, BBC entered into a licensing agreement with the British manufacturing firm Vickers Ltd. giving the British firm the right for to produce and sell BBC products throughout the British Empire and in some European areas. The agreement gave BBC the promise of considerable future annual revenues, especially at times when protectionist international policies inhibited further expansion. Nevertheless, the BBC Group had no choice but to join forces with the powerful British Vickers Ltd. for a short time. Paying out a dividend was out of the question from 1921 to 1924 and from 1931 to 1938, but – in parallel – the technical, innovative progress in the newly founded company appears to have continued nearly unaffected. In Switzerland and abroad many BBC employees lost their jobs in the crisis years, Figure 2-3. 1924 became the 'annus horribilis' in BBC's company history for another reason: Charles Brown, 61 and Walter Boveri, 59 died during that same year. Brown had become seriously ill over time, while Boveri lost his life in a car accident in the Netherlands. The death of these highly appreciated company founders finished the build-up phase.

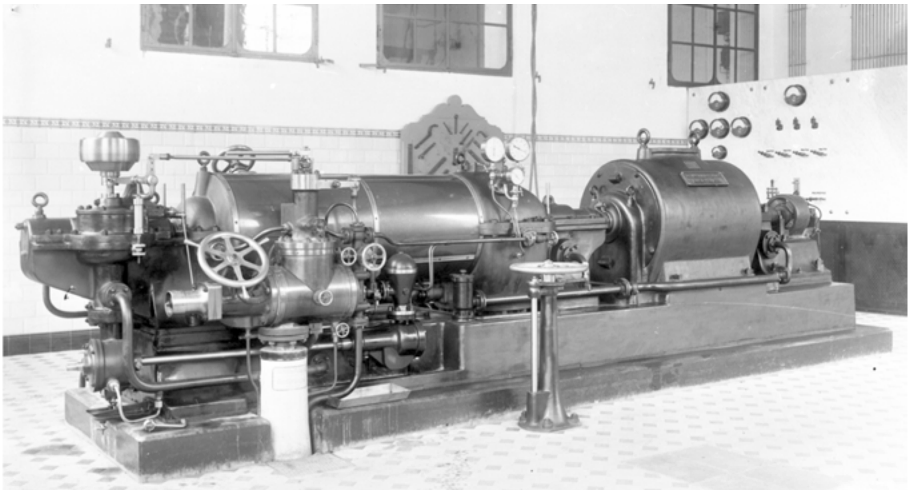

Figure 2-9 *First 'continental', serially produced steam turbine, BBC Baden 1902* © ABB

In the wake of WW I, Brown Boveri suffered heavy losses in its newly created network of successfully operating subsidiaries in Austria, France, Germany, Italy, Norway and the Balkans due to the devaluation of the French Franc and the German Mark. On top of this, the Swiss manufacturing costs in the domestic market grew considerably at the same time, while the domestic sales remained unchanged, causing further company losses. Consequently, BBC devalued its capital by 30 percent in 1924, and the promising license agreement with Vickers ran out and was not renewed in 1927. Serious economic problems prevailed until the early 1930s, even the turbine production in Baden was put into question and discussed in favour of a potential shift to Le Bourget or Mannheim. Finally, the supervisory board decided to proceed with the development centre in Baden and also to maintain a substantial development budget, otherwise *'we would lose our lifeblood'*.[15]

In view of popular business doctrines, the BBC development is a classical case study because it was one of only a few multinational corporations with subsidiaries that were larger than the parent company. So it is not too surprising that at times the Swiss central business unit ran into difficulties to maintain managerial control over some of its larger subsidiaries. For the next few decades especially, the relationship between BBC's Swiss headquarters in Baden and the expanding, increasingly mighty and independently operating German daughter company in Mannheim generated problems.

In 1934/1935 BBC had finally crossed the economic lowlands. BBC Switzerland saw a duplication of order intake out of the blue, though at marginal prices. In 1936 BBC share prices sky-rocketed, not the least thanks to the artificial German economic upturn based on straightforward war preparations; intermediately accumulated losses were completely recovered. During these years, BBC Mannheim surpassed the parent house considerably, Figure 2-10, and on the basis of a joint-stock capital of 12 Mio Reichsmark achieved actual revenues in the order of 112 Mio Reichsmark; consequently, the stock capital had to be duplicated to 24 Mio RM in 1938.[16] In reference to the starting values in 1933, the revenues had grown by 400 percent seven years later. Though BBC Mannheim was not directly involved in weapon production, its manufacturing of electric power generation equipment had of course considerable relevance in this respect. In the power regime BBC held the 3rd rank in Germany in 1939 with 17 percent market share, behind Siemens-Schuckert and AEG, both with 40 percent.[17] Soon the order intake exceeded the actual production capacities, so that e.g. customers for power plant equipment in Mannheim had to wait up to two years at the beginning of WW II. This gap between demand and actual production capability grew considerably during the war years, first throttled by Baden's opposition against further huge investments, after 1943 by significant destruction of the Mannheim manufacturing plants by allied bombing raids.

Since 1937, BBC Mannheim had become a dedicated 'marine plant', first by delivering steam turbine propulsion units up to 200,000 shp for several battleships, then as a prime source for German submarine electric drives. The other strong support out of Mannheim for the German Air Force since 1941 came from a dedicated department for aircraft turbo propulsion, in short TLUK; details on BBC's aero engine activities in Germany and Switzerland before and after WW II are planned to be described in a follow-on book project. A third fascinating area of 'dual-use technology' was wind tunnels for scientific research as well as for immediate military purposes. After the first installation of that kind, Ackeret's unique supersonic wind tunnel at ETH Zurich, 1932-1934, BBC was active in this field throughout Europe. While Baden specialised in these high-speed facilities for aerodynamic testing, Mannheim became practically single source for all kinds of high-altitude test facilities for piston and jet engines. Further details on these widely unknown areas of BBC's technology and product history have been collected in Section 4.2.4 as part of the early compressor development story.

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15 See Catrina, BBC, p. 54: quotation from VR (supervisory board) protocol, dated Oct. 26, 1934.

16 See Catrina, BBC, p.55

17 See Ruch, Geschäfte und Zwangsarbeit, p. 81

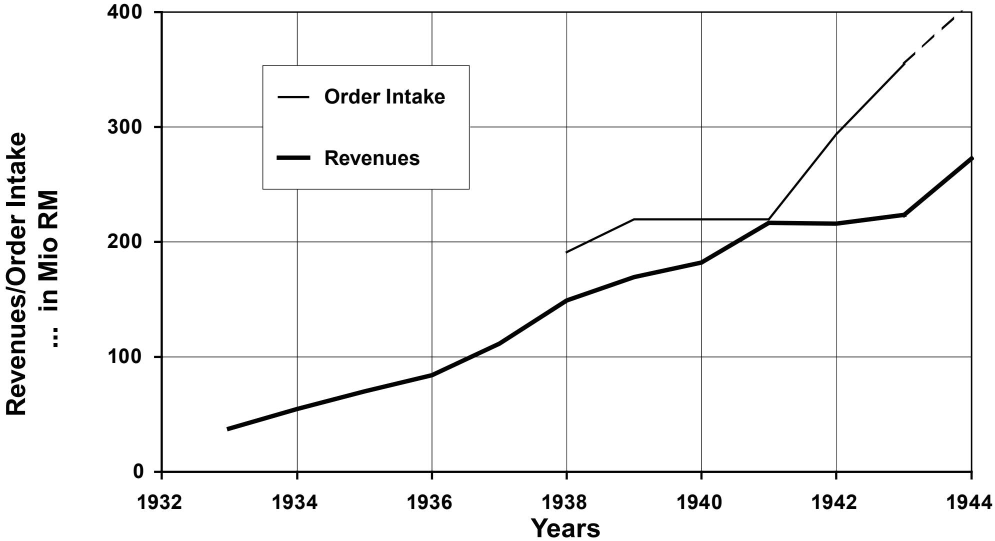


Figure 2-10 *BBC Mannheim, development of revenues and order intake 1933–1944*[18]

As an immediate consequence of the outbreak of WW II, in Switzerland 50 percent of the BBC personnel was mobilised to Swiss Army service, though over time the demand of the army decreased and some of BBC's employees were able return to the workbenches. The identification of the employees (and their families) with their Country and Company was extraordinary, Figure 2-11.

Currency exchange and strategic material problems hampered Swiss business activities during wartime, nevertheless BBC developed successfully and steadily as illustrated in Figure 2-3. BBC's workforce in Switzerland grew rapidly to 6,000 – with 1,500 'white collar' jobs in the offices.[19]

Beginning in 1939, the whole Swiss machining industry experienced a lasting war boom, both Germany and Italy as well as the Allies were treated as major customers. Since there are no suitable BBC data for this period, we refer here alternatively to Switzerland as a whole, assuming that these figures are also representative for the largest Swiss engineering company at that time. Figure 2-12 illustrates that the war parties dealt with the Swiss very differently. Dominating imports from Germany certainly also comprised war-related production orders, but to the same extent coal and iron/steel for Swiss needs and other exports[20]. German-Swiss trade agreements from July 1941 caused the British government to extend the sea blockade to Switzerland (with the exemption of food and feeding stuffs) while the USA continued to deliver to Switzerland, even after the outbreak of the German-American hostilities, thus also strengthening Switzerland's independent position towards Germany. The interests in the bilateral Swiss-German relationship were very balanced. The

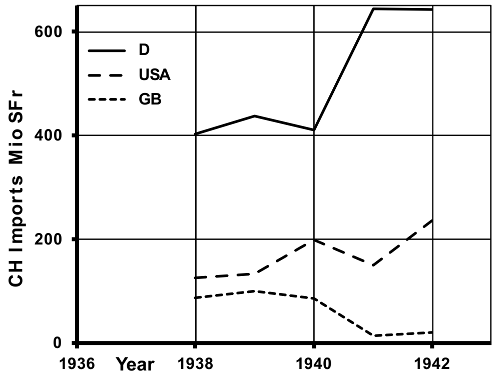
18 See Ruch, Geschäfte und Zwangsarbeit, p. 83 and 91
19 See Catrina, BBC, p. 63
20 See Eichholtz, Kriegswirtschaft, pp. 481–484

Figure 2-11 *'Proud To Be Swiss', BBC 'Halle 30'* [30]*, the public day at BBC's 50th anniversary in Oct.1941 saw 30,000 visitors, three times the population of Baden at that time © ABB*

Swiss Achilles' heel with respect to coal and steel imports was more than compensated by the dependence of South German industries on Swiss electricity deliveries and the need for unhindered Italian-German railway connections through Switzerland. The right-hand side of Figure 2-12 correspondingly quite clearly illustrates the trend to increased export figures for war-related goods from Switzerland to Germany up to 1942. It can be assumed that BBC covered a considerable share of the shown category 'Ironware'.[21] Though the Allies already started to produce a permanently updated 'company blacklist' of those 'trading with the enemy' early in the war, Brown Boveri was not listed. Obviously – and there will be some proof in this direction – BBC was too important for both sides to be denounced too severely. Strained capacities finally even led to the unique decision on the side of BBC to limit the order intake from the Soviet Union in 1940 to 20 Mio Swiss Francs, not to become too dependent just from one customer.[22]

21 The data from the German Statistics Office as reproduced by < Eichholtz, Kriegswirtschaft, p. 483 > had not been publicised during war-time. The focus on war-related goods is underlined by the fact that in the same observation period e.g. the Swiss export of cheese to Germany shrank from 4.1 (1938) to 0.3 Mio RM in 1943.

22 The sources are somewhat vague in this context. The 20 Mio SFr limit is a quote from < Catrina, BBC, p. 62 >. Internet sources make believe that the Baden deliveries towards the SU until the outbreak of the German-Russian war in June 1941 comprised amongst others at least one of the planned three 200,000 shp steam turbine drives for



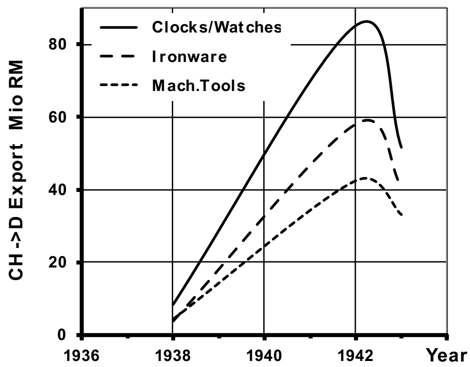


Figure 2-12 *Swiss imports from D, USA, GB (l) and exports to Germany (r)*[20]

The BBC Baden board started its post-war planning in time. The stock shares in most European subsidiaries had been wisely already written off to one SFr in March 1944; nevertheless, it was possible to invoice considerable license fees that had remained unchanged still then. End of 1945, a cash treasure of 47 Mio SFr and enormous material stocks put Baden in an excellent position for the upcoming, huge international reconstruction programmes. This capital stock was mostly used for the building of new fabrication plants between 1947–49, and for the improvement of production processes in general, Figure 2-4. By the end of the 1950s, a kind of series production had been established for key steam turbine parts, leading to a reported cost reduction of 25 percent. However, shortly thereafter, a certain ageing of the upper and middle management and of their style of handling businesses signalled negative consequences. The whole company accounting still only existed in rudimentary form.

One illustrative report in this direction came from Piero Hummel, who began in 1949, aged 26, and finished in 1988 as last CEO of the BBC group.[23] He started as mechanical designer in the steam turbine department, deliberately as he claimed and against the popular stream towards the more fashionable Gas Turbine department. When the renowned technical director Claude Seippel retired in 1965, Hummel became head of the Thermal Department. One of his first initiatives was 'vertical accounting' to assess the profitability of all major products in his eight sub-sections. This unveiled surprising results: BBC's total profit was smaller than that of the Thermal Department alone! Similarly, the turbochargers were identified as 'cash cows', while the electric departments – generating 70 percent of BBC's total revenues – contributed losses throughout. Thermal products and especially the highly profitable turbocharger business indirectly subsidised large sections of the group. Typically for the business organisation in the early 1950s, sales and production departments were not linked and consequently, without setting up a formal budget, decisive business figures were mutually unknown.[24] Strangely however, these revelations had no organisational consequences, yet.

the 75,000 ton battleships of the 'Sovetskiy Soyuz' class. It appears that also Mannheim produced heavily for Russian orders up until the very last moment. < Ruch, Geschäfte und Zwangsarbeit, p. 85 > quotes from BBC Mannheim supervisory board meetings that five altitude test facilities and 13 steam turbo sets had been ordered from Moscow; until June 1941 the (obviously unfinished) SU order backlog had grown there up to 23.3 Mio RM.

23 See Catrina, BBC, p. 82

24 See Wildi, Organisation und Innovation bei BBC, p. 19

Figure 2-13 *Proud of work and company, hydro generator delivery, Baden 1952* © *ABB*

The post-war upturn of BBC is reflected in the growing personnel numbers, Figure 2-3, that to a large extent were attracted from foreign countries. This also became visible in the surrounding, logistically well-positioned canton Aargau (AG), Figure 2-14. Except for the short recession in 1975 and 1976, the canton's population grew steadily due to immigration, largely attracted by BBC's workforce demands. Percentage-wise, the share of foreigners rose from three percent in 1941 to 18 percent in 1970 and surpassed the 100,000 mark (19 percent) in 1996. This then corresponded to 28 percent Italians (compared to 57 percent in 1974), 32 percent from the Former Yugoslavia and roughly 10 percent from Turkey. Most recently, the Alstom acquisition of the power generation business and the signing of bilateral agreements between Switzerland and the European Union has further boosted the share of the workforce from EU countries, especially from France and Germany.

By the mid-1970s, more than 50 percent of the gross income produced in Baden was generated by BBC in one way or another. Although this dominating influence has diminished markedly, ABB and Alstom are still the most important employers and economically of key importance in the Aargau region.

From a global perspective, there was a huge demand for high-quality goods such as power stations, switchgear and transmission lines. The bulk of business was in steam and gas turbine-driven turbogenerators. The outputs of power units leaving the BBC shops took on undreamt of proportions. In 1962 BBC won out over tough US competition to deliver a 550 MW steam turbine, which was claimed to be a 'world record' in the annals of the industry. However, merely ten years later Brown Boveri advanced into the gigawatt range, producing units with outputs of 1,300 MW.

Figure 2-14 *Social consequences: Tower buildings to accommodate the immigrants of the 1970s, Limmat Valley, shopping centre Spreitenbach*[25]*, AG, CH*

In 1970, BBC began a comprehensive reorganisation; the company's subsidiaries were split into five groups: Germany, France, Switzerland, the medium-sized production network with seven plants in Europe and Latin America and Brown Boveri International. Each of these groups in general had five product divisions: power generation, power distribution, railways, electronics and industrial equipment.

Throughout the 1970s, BBC struggled for access into the US market. E.g. the company discussed a joint venture with North American Rockwell to combine forces on Rockwell's 'sodium-cooled breeder' technology, but the companies could finally not agree on the financial terms.[26]

New lines of business, namely electronics and nuclear energy, were added to the traditional product portfolio in these years. BBC grew to become the largest electrical engineering company in Switzerland, and four out of the five Swiss nuclear power stations operate using steam turbine generators from BBC. But nuclear power failed to live up to the original expectations. Several of the advanced demonstration projects including the HTR high-temperature reactor in Germany had to be given up in the early 1980s, when it was realised that the technical readiness was not achievable according to original planning. Both Siemens and BBC had

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25 Source Wikimedia Commons http://de.wikipedia.org/wiki/Spreitenbach

26 See Catrina, BBC, p.110 ff., interesting, though today nearly unbelievable, the speculation on the planned delivery of 5×1,000 MW nuclear power stations to the US market – per year!

to write off research and development expenditures in the order of several billions of Deutsche Mark (DM).[27]

BBC entered the global recession following the 1973 oil crisis with full order books. The large-scale power plants on order ensured that company capacities would be fully utilised for years to come. At the same time, sales shifted to countries less affected by the cyclical downturn. In the mid-1970s, growing power demand in the Middle East distracted BBC from its push into North America. Riyadh 8 in Saudi Arabia, one of the largest crude oil-fired gas turbine power plants in the world, is a prime example of that trend. In 1982, BBC landed a relieving turnkey order to build this 800 MW project to supply energy for the country's capital. 'Turnkey' in this context means, that the main contractor takes care of all of the client's issues surrounding the project. For Riyadh 8, Figure 2-15, BBC handled planning and development, provided financing, supported local manufacturing, trained client personnel and set up effective service networks. Even the building of a water tower and a mosque for the power station had been contracted to BBC.

Figure 2-15 *Riyadh 8, 800 MW – Gas turbine power station in Saudi Arabia* © *ABB*

Changes in the global economic structures struck Brown Boveri with full force in the years around 1980. First problems had started in 1973, when the international system of fixed currency exchange rates had to be given up. The Swiss Franc subsequently gaining

27 Sometimes the Chernobyl disaster in 1986 is mentioned as major cause for the failure of the various nuclear projects. This may hold true for the public opinion, but e.g. the helium-cooled 300 MW 'Thorium High-Temperature Reactor' project with BBC participation at Hamm-Uentrop, Germany showed unforeseen technical problems with the pebble bed reactor ('Kugelhaufen') concept. After a lengthy construction period from 1970–1983 with costs overshooting excessively, the operation that had to be interrupted several times was finally terminated in 1989. The technical inheritance comprises 390 t of radioactive materials that can be dismantled earliest in 2027 when the critical radiation values will be diminished. [Wiki 'Kernkraftwerk THTR 300']

strength in combination with the ‘oil shock’[28] led to the most severe recession of all industrialised countries in Switzerland. In due course the attempt was made to compensate the reduced export revenues caused by the ‘cheap dollar’ of that time with extraordinary company acquisition activities in North America, Figure 2-2. After several years, the BBC corporate group of North America comprised no less than six operational business units with 20 companies and 50 sales offices spread across the country. The initial buy was the takeover of the gas turbine division of Turbodyne in St.Cloud, Minnesota in 1977, which later on was renamed to Brown Boveri Turbomachinery Inc. However, the presumed cheap acquisition showed no lasting benefit. Quality problems caused more damage and the planned technology transfer (e.g. to stabilise the US production quality) from Switzerland to Minnesota never materialised properly, Section 5.1.3. As an immediate consequence of the oil crises, the order volume for gas turbine power generation in particular shrank considerably, the sales flattened out and the company’s earnings declined. When the GT market cycle recovered in the US in the early 1980s, BBC had already given up and had decided to close the Turbodyne plant. Consequently, the logical idea of investing in an existing BBC licensee did not pay off. In many business areas orders fell off sharply due to the recessive trends in buyer countries. The all-important power station segment was hit particularly hard. Excess capacities in electricity production around the world created tough competition for the few available orders and narrow profit margins.

Besides these economic difficulties, the BBC management was additionally strained by the de-facto ‘compulsory purchase’[29] of BBC France (C.E.M.) in 1982. BBC owned 79 percent of this company, which traditionally produced two thirds of its output for the French power generation market. Indirectly this development had also been induced by a reorientation of the government-controlled French nuclear energy programme, replacing General Electric reactors with those from Westinghouse. For secondary equipment this meant that all further national activities should be focussed solely on Alsthom-Atlantique and Framatom, without exception for the established No.3 in France: C.E.M. In Section 4 the successful, long-term partnership between C.E.M. and BBC, Figure 2-1, will be honoured; it includes many excellent engineering contributions especially from Georges Darrieus, whose role for the emerging technical leadership of BBC in the 1930s cannot be rated highly enough.

In 1983 BBC Mannheim, which was responsible for nearly 50 percent of all power sales, recovered somewhat. Nevertheless, short labour weeks and layoffs were the consequences of this economic downward plunge from 1983 onwards. In spite of an increase in orders, the inherent cost structure kept earnings down. In desperation, BBC set itself ambitious goals to become more profitable and efficient. The group trimmed capacities and instituted certain reorganisation measures that indicated some positive effects. However, competitive price decreases, made more severe by unfavourable shifts in currency exchange rates, compensated the achieved gains by and large. Finally in 1986, the Swiss parent company acquired a significant block of shares in the German subsidiary, bringing its total stake up to 75 percent again.

In 1987, the BBC Group comprised 159 subsidiary companies on all five continents. BBC still had an innovative image, but with less and less cost-effectiveness, the products were

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28 Amongst others, the oil price rose by a factor of four as a consequence of the first energy crisis.

29 See Catrina, BBC, p. 173

correspondingly more expensive than those of the competition. On top of all this, the inherent rivalry between the Baden headquarters and the legally independent daughter company in Mannheim cast increasingly darker shadows over the relationship in general. Billions of DM investment in nuclear technology since the early 1970s had to be written off. Finally, on 31 December 1987 nearly 100 years of the technically impressive industrial history of Brown, Boveri & Cie. ended.

2.1.2 ABB Asea Brown Boveri Power Generation Ltd., 1988–2000

It was a great surprise when news agencies announced the merger of BBC Brown Boveri & Cie. and ASEA Allmänna Svenska Elektriska Aktiebolaget on 10 August 1987; on 1 January 1988 the two partner companies merged their many group companies to the newly founded ABB Asea Brown Boveri Ltd., the shares of which they held on a 50/50 basis. Two medium-sized international groups with strong national roots had been transformed into a single European technology group as the assumed answer to future world economic challenges. In sheer numbers BBC was larger than Asea – 25 percent in sales and 33 percent in personnel, but the Swedish trumped BBC in stock market value. In due course, BBC had to increase the share capital by 800 Mio SFr and to accept that several Asea affiliates remained outside the venture.

As a visible sign of the transformation the new ABB logo was unveiled in July 1988; in Baden it was prominently placed on the new engineering building Konnex, which was opened in 1995, a masterpiece[30] of architectural design and function by Theo Hotz, Zurich, Figure 2-16.

The initial phase following the merger was anything but easy for the new company. It even reported a loss in 1989. Only after ABB had concentrated once again on business areas with core competences and removed duplicate structures, was it able to return to sustainable profitability. This restructuring caused a considerable number of layoffs, but fortunately, this phase was short. Still in 1989, the volume of new orders had grown to such an extent that workers began to be rehired, with an inherent profound change. The personnel stock was tuned to highly qualified applicants in all areas, while less demanding shop activities were reduced. This implied a short-term change from labour-intensive, heavy machinery

30 Appreciation for advanced architecture and for adequate industrial design has a long tradition in Baden, see Affolter, Architekturfuehrer, and correspondingly in the power companies; best known example is the 'AEG-Turbinenhalle' of Peter Behrens (1868–1940) at Berlin-Moabit, 1909, an icon of modern industrial architecture which today belongs to the Siemens energy sector. Since its foundation in 1891, BBC had asked for iron structures for their production halls. One of these rare, remaining historic buildings is the 50 m long 'Alte Schmiede' (Old Forge) from the year 1906 at ABB Area West. BBC's largest 'Halle 30' was erected in 1927 by MAN on the site of the present Konnex building; it was 150 m long and 20 m high –, see Figures 2-16 and 4-2. For a long time this was the largest hall building in Switzerland, so that it was also used for the canton Aargau's direct-democratic assemblies, see also Figure 2-11. This hall became the measure for a total of 8 buildings designed and built by Roland Rohn according to his general plan from 1944, e.g. the 'Hochspannungslabor' (High Voltage Laboratory), in 1942, today the TRAFO corner building, the 'Zentrallabor' (Central Laboratory) in 1956, along Haselstrasse, and todays ABB Turbo Systems main building in 1947 to 1952, along Brugger Strasse. A further architectural landmark is the 'BBC Gemeinschaftshaus' built in 1952/1953, on Martinsberg, which saw the BBC management and workers united, not only for lunch, but also in the evenings, say, to attend a piano concert by Arthur Rubinstein.

production to a smart and flexible engineering enterprise with dominating research and development characteristics. In this respect, an astonishing number of 3,000 newly defined jobs were created on short notice, again to a considerable extent from in-house (Mannheim, Nuremberg) and external engineering sources in Germany.

Long overdue, one bid farewell to the old BBC practice of producing entire systems; the in-house production depth was in most cases cut in half – from original values above 80 percent. The vertical range of manufacture was reduced, while the proportion of purchased components was increased. An immediate consequence was that highly qualified purchasing departments had to be established. E.g. complex gas turbine blading travelled at times up to 8'000 km amongst highly specialised production centres, distributed all over the world. These new procurement processes demanded the newly established SCM supply chain management for both cost and time reasons. Rolling out a reliable quality and process control regime over the whole supplier network was of utmost importance. Continuous Cost Cutting, beating lead times and Concurrent Engineering[31] became the names of the game for the coming decade. As a result of sometimes painful adaptation processes, the produced power generation equipment was significantly more cost-effective and regained competitive positions. Overall systems even gained in value for the customers, since the purchase of parts and sub-systems from specialised suppliers could generate added value. The prudent use of 'could' in this context indicates that this process of production outsourcing was not automatically and by all means a success. Especially, high-temperature gas turbine parts represent an amount of production complexity, individual suppliers could not cope with alone. Therefore, the network capabilities had to be built up jointly – a cumbersome effort with drawbacks. This was an experience that sometimes was even new to the upper management, who had gained personal, practical experience in the field at 'another times'. Consequently, to 'manage the management' in some instances became an additional task for those fighting problems under pressure in all-new territories. On a broader scale this trend for specialisation was also implemented in the internal production factory network, where the new Swiss production site in Birr qualified as a 'rotor manufacturing plant' (gas and steam turbines, generators), whereas Mannheim took 'stator manufacturing' and assembly tasks.

In hindsight, the period of the power generation division with de-facto bankruptcy of BBC in 1987, then the successful recovery under the newly founded ABB regime followed by the Alstom takeover in 2000 appears like a dynamic outbreak of long-term stored management energies in comparison to the earlier, apparently somewhat complacent business developments in foregoing decades. A direct comparison of that period as expressed in the personnel development numbers of Figures 2-2 and 2-3 illustrates on the one hand the stunning performance in the early 'era Barnevik' from a global perspective, and on the other hand that during these transactions the Swiss share of the workforce in these companies could not maintain the volume achieved in the 1980s and is today – expressed in sheer numbers – back to a level of the mid-1950s.

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31 Concurrent Engineering stands for the parallel, collaborative execution of design, mechanical engineering and manufacturing development tasks for a certain design part instead of the traditional, sequential execution. This saves time and trades design demands against aspects of manufacturing feasibility and cost. In combination with an international supplier network, this demands a very flexible management of highly qualified and at the same time broadly trained engineering resources.

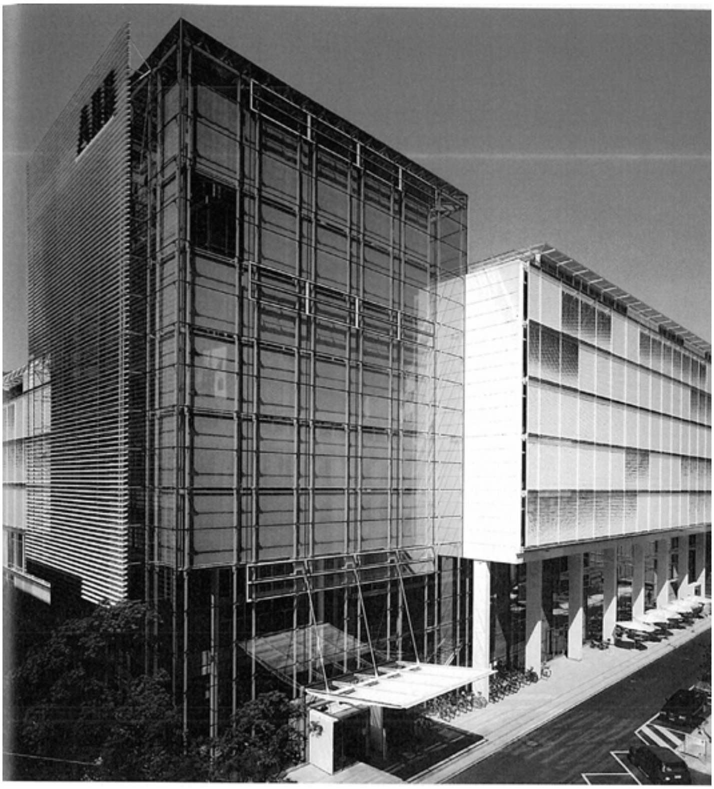

Figure 2-16 *ABB engineering building 'Konnex', 1995, designed by Theo Hotz, Zurich*

The turning point was in or shortly after 1995. The foregoing ABB years had been characterised by an unprecedented rush of activities. The main products of the ABB group were clearly power plants, mainly gas turbines, steam turbines and the combined cycles of both, locomotives, turbochargers and electric switchgear. All these areas were immediately driven to a comprehensive renovation and modernisation of the product portfolio and of the organisation – very often even in an internally competitive mode. Armin Meyer, President and CEO of the now independently managed ABB Power Generation Ltd. from 1992, states: "*Looking back, I remember three things from the fusion period: first aggressiveness, the dynamics of action and the unbelievable, sweeping spirit of heading to new horizons.*"[32] The field of gas turbines was critically reviewed to decide whether to either close it down or push it to the technological forefront. Of course, for enthusiastic engineers the latter was the chance of a lifetime, so it was done. '*Leap frog the competition*' was the rallying cry; over time a completely new family of gas turbines for the 50 and 60 Hz markets emerged, later

[32] See Catrina, ABB, p. 49. Armin Meyer, *1949, entered BBC as development engineer in 1976, Head of electrical drives R&D in 1980 and of the international business unit 'Electrical Generators' in 1984, General Manager of ABB Drives Ltd. in 1988, President and CEO of ABB Power Generation Ltd. from 1992, Executive VP of ABB Ltd. and member of the ABB Board between 1995–2000, Chairman of the Board and CEO of CIBA Ltd., 2001–2007, member of the Board of Zurich Insurances Company, since April 2010 non-executive Director of Amcor Ltd., PhD in Electrical Engineering from the Swiss Federal Institute of Technology (ETHZ), served 12 years as Professor for Electrical Engineering and Drives at ETHZ.

to be known as GT 24 and GT 26. Details of this development history will be outlined in Section 6. Prototypes of the new gas turbine were ready for operation in 1994, in 1998 approx. 300 Mio SFr had been spent on development improvements. For aero gas turbines, where the development costs are more transparent in multi-national consortia, it was and is established knowledge that each new, full development programme requires financial resources in the order of 2 BUSD. The ABB management became nervous, when the 300 Mio SFr development mark was recognised in the late 1990s. Questionable management and engineering decisions further hampered the problems with the new gas turbines. Some engineering problems came to light quite naturally over time and their extent could be considered rather normal, given the exposed uniqueness of the approach. The management counter-measures were not too rational in any case. But the resulting financial loads of several billions of Euros were in the long run shifted onto the shoulders of the new owners of the power generation division, the French Alstom Ltd. Gas turbine development was only one of several ABB problem zones at that time; the management dynamics of them all obviously got out of control and/or were beyond the capacity of those in charge at the turn of the millennium.

As clearly visible in Figure 2-2, company acquisitions on a grand scale continued to reign Barnevik's term. In the early 1990s, ABB purchased CE Combustion Engineering, a leading US firm in the development of conventional fossil fuel power and nuclear power supply systems, to conquer the North American market. Still not saturated, ABB purchased Elsag Bailey, a process automation group in 1997, which included established companies like Bailey Controls, Hartmann & Braun, and Fischer & Porter. This was the largest company transaction in ABB's history to date. While the acquisition wheel was still spinning, CE was confronted with huge asbestos liabilities from former workers. Unexpected GT development costs, accumulated acquisition debts and unforeseen liability claims, this negative trilogy nearly brought on the collapse of ABB. Barnevik left the ABB supervisory board in November 2001 with a 'golden handshake' of 148 Mio SFr, which at that time was considered a record sum and heavily criticised accordingly. In the meantime, after the excesses of global fortune makers in the past years, apparently a rather modest final compensation for the 'manager of the year'[2] several times over.

End of 1996, Göran Lindahl followed his Swedish fellow countryman Barnevik as ABB's CEO; his management style is still remembered for divesting large parts of the hardly consolidated company. Rail and transportation engineering went to a joint venture with Daimler Benz beginning 1996 – Adtranz ABB Daimler-Benz Transportation. In 1998 ABB retreated from this joint venture and sold the 50 percent share to Daimler-Benz. Similarly, ABB Power Generation Ltd. was transferred into a 50/50 joint venture with Alstom, becoming ABB Alstom Power Ltd. effective 30 June 1999. Following the well-known pattern, ABB retreated here after one year as well and sold all of power generation to Alstom.

In retrospect, these millennium years and their fragmentary leftovers in memory appear to be somewhat 'unreal'. Junior ABB strategists trying to explain what was going on declared the whole power generation business as part of 'old economy', while the presumed bright future of the 'New ABB' should comprise '*anything with the Internet*'. This short-sighted enterprise generation soon acclimatised to the familiar heavy machinery environment of Alstom, together with railways and shipbuilding Alstom's third product leg.

2.1.3 ALSTOM Power Ltd., since 2000

Alstom is a large French multinational industrial conglomerate with interests in the power generation/transmission, transport and renewable energies markets;[33] the headquarters are located at Levallois-Perret, a northwestern suburb of Paris, F, Figure 2-17.

Present Chairman and Chief Executive (Président-directeur général) is Patrick Kron (*1953), who managed Alstom's successful turn-around since 2003. Alstom's global business activities spread across 100 countries at present. The total number of employees is close to 92,000 (2012), recent annual global revenues (April 2011–March 2012) were € 19,934 billion with a profit margin of 7,1 percent.[34] At € 52 billion on 31 December 2012, the backlog represented 30 months of sales.

In Switzerland Alstom occupies a workforce of 6,000 in the business areas Power, Transport and Grid with annual revenues of 4,2 billion SFr (2011/2012), thus belonging to the biggest Swiss industrial enterprises. The corresponding German numbers are 9,000 employees at 24 sites with annual revenues of € 2,6 billion.

The global headquarter of Alstom's Power sector is at Baden (AG) – with the corresponding production site at Birr (AG). The Grid activities are located at Oberentfelden (AG), while the Swiss Transport branch is at Neuhausen am Rheinfall (SH), with a regional office at Lausanne (VD). Philippe Cochet (*1961) is President of Alstom's Thermal Power Sector and Executive Vice-President of Alstom since 2011, following Philippe Joubert (*1955), who kept this position since 2009. The new Alstom Thermal Power Sector has sales of over € 9 billion and 38,000 employees. It covers Gas, Steam and Nuclear power generation as well as the Service and Automation & Control activities.

Power activities comprise the design, manufacturing, services and supply of products and systems for power generation and industrial markets. The group covers all energy sources – gas, coal, nuclear, hydro and wind. Alstom supplies and maintains all components of a power plant and provides complete turnkey solutions. The company has a leading role in environmentally friendly power solutions based on advanced low emission combustion and special CO_2 reduction technologies. The Power sector in Switzerland is global lead centre for gas and steam turbine research and development – with special focus on combined cycle power plants and in addition, carries out the system planning for hydro power plants and is responsible for turbine and generator component manufacturing. The Service branch deals with global power plant maintenance (combined cycle, gas and steam turbine plants), with plant operation optimization, equipment refurbishment and maintenance/upgrade activities in Swiss nuclear power stations.

33 Alstom, the builder of the Queen Mary 2 cruising liner (gross tonnage 150,000 t, length 345 m, passengers 2'600) sold its unprofitable shipbuilding business to Åker Yards of Norway in early January 2006. Alstom's CEO Patrick Kron had it made clear since taking over in 2003 that he planned to quit shipbuilding to focus the company on its power and rail divisions. In 2010 Alstom re-acquired the electric power transmission division of Areva S.A. (previously sold in 2004), creating Transmission as Alstom's third main business area, called Alstom Grid. Finally in 2011, Alstom reshaped its operational activities into four sectors: Thermal Power, Renewable Power, Grid and Transport.

34 The successful management turn-around becomes evident in comparison to the 2002 numbers: then annual revenues of € 21,35 billion were accompanied by losses of € 1,35 billion.

In parts the company history reaches even further back than that of Brown Boveri & Cie., Figure 2-1. The name of the company was derived from the French region Alsace and the name of Elihu Thomson (1853–1937), who founded several electrical companies in the USA, Great Britain and France. Alstom with the original spelling 'Alsthom' in 1928 evolved from the merger of SACM Société Alsacienne de Constructions Mécanique, originally founded in 1879, and Thomson-Houston with its first and still existing factory in Belfort. The company developed into the leading railway and power generation equipment manufacturer in France, especially for nuclear power plants in the 1970s. In 1976 CGE Compagnie Générale d'Électricité took over the majority of shares and C.E.M. was integrated (see Section 2.1.1). In 1984 Alsthom acquired the Chantiers de l'Atlantique, a famous shipyard at St.Nazaire, figuring first as Alsthom Atlantique and later on solely under the name Alsthom. 1989 saw the formation of GEC Alsthom from the merger of the power and transport activities of CGE and the UK GEC. France's market was no longer sufficient, so the merger was to enable Alsthom to export into Europe. In 1998 GEC and CGE (Alcatel Alsthom since 1991) separated from GEC-Alsthom, sold off their stakes in the capital, and the company continued as Alsthom, before the name was simplified to Alstom in 1998.

Reacting to progressive concentration processes in the power generation business, Alstom and ABB decided to merge the corresponding units of both companies in 1999: first on a 50/50 basis to form ABB Alstom Power Ltd.; one year later Alstom acquired the remaining ABB shares. These and other acquisitions increased Alstom's debt level so that the company fell into financial difficulties when technical and contractual problems with the former ABB gas turbines, some stalled orders in cruising shipbuilding and a breakdown in the power generation market in the wake of the collapsing 'US bubble' superimposed. As a short-term remedy the industrial gas turbine business up to 50 MW power had to be sold to Siemens. Additional bank loans were secured by a generous debt guarantee of the French government. In 2006 the French industrial group Bouygues, diversified in construction, property and telecom/media, took the 21 percent share from the French government, which it sequentially increased to 30,07 percent until October 2007.

Figure 2-17 *Alstom headquarters at Levallois-Perret, a suburb of Paris, France – on the Seine river bank, ~3 km north-west of Arc de Triomphe*

Alstom also managed the technical turn-around for the ABB gas turbine heritage. In 2006, the GT 24 and GT 26 families combined achieved more than 1.5 Mio OH (Operating Hours). Major sales to countries such as Italy, Germany, Spain, Great Britain and Thailand demonstrate that technical teething troubles of this competitive, technologically advanced product have finally been overcome.

2.2 Gas Turbine Types

A ‘gas turbine’, also referred to as a ‘combustion turbine’, is a rotary machine that extracts energy from a flow of combustion gas. At the heart of the machine is a combustion chamber for heat addition (or, alternatively, a kind of heat exchanger). Upstream is the compressor, coupled downstream to a turbine component. A gas turbine is a heat engine which converts thermal energy into mechanical output. Energy is then extracted in the form of shaft power (like in power generation by means of a driven AC generator), compressed air or thrust to power aircraft, and any combination thereof.

The principle advantages of the gas turbine are:

1. the high power density; it is capable of producing large amounts of useful power based on its relatively small size and weight,
2. the GT’s long mechanical life and relatively low maintenance costs,
3. the relatively short start-up-time,
4. the wide fuel versatility,
5. atmospheric air as working fluid, without further coolant liquids etc.,
6. the relatively low costs for cheap and quick plant erection.

2.2.1 Stationary Power Generation Gas Turbines

The gas turbine in its simplest form has a single shaft configuration with one or more compressors, one or more combustors where – once the GT has been started – the energy-carrying fuel is mixed, ignited and burnt with part of the compressed air (while the remainder of the compressor air is used for cooling purposes in the combustor and turbine area as well as sealing) and a turbine group (again of one or several partial components) that drives the compressor group and provides the resulting net power to the output shaft.[35]

The gas turbine has found increasing service in the power industry over the past 40 years, both in utilities and merchant plants. Its fuel versatility is remarkable, also in view of future hydrocarbon fuel limitations; today there are gas turbines that run on natural gas, diesel fuel, naphtha, methane, low-BTU and biomass gases. The years since 1990 – partially influenced by global political changes with less emphasis on military-led developments – has seen a large growth in gas turbine technology. Higher compressor pressure ratios and turbine entry temperatures have increased the GT thermal efficiency beyond 40 percent. This increase is a consequence of the application of improved

[35] For this and the following basic description, see Boyce, Gas Turbine Engineering Handbook and, see Langston, Introduction to Gas Turbine.

computational fluid dynamics (CFD) for turbo-component design, equally supported by improved materials and manufacturing technologies, new temperature-resistant and wear-resistant coatings and more efficient cooling schemes. The economics of power generation depend on the fuel cost, running efficiencies, maintenance cost and first cost – generally in that order.

The gas turbine is classified broadly in five groups:

- Heavy-duty or frame type gas turbines in the upper power range until 400 MW,
- aero-derivative gas turbines, adapted to electrical generation industry by removing the bypass fan and adding a power turbine at exhaust, with a typical power range up to 60 MW,
- industrial type gas turbines, ranging up to 25 MW, mostly applied in petrochemical plants and for pipeline compressor drive trains,
- small gas turbines up to 2.5 MW find e.g. applications as APUs auxiliary power units,
- micro turbines, typically below 350 kW, with an impressive market upsurge due to the trend to distributed generation in the past 10 years.

In principle, approximately two thirds of the turbine power is used to drive the compressor, the remainder is used as output shaft power to turn an attached electrical generator (or e.g. a ship's propeller). As an example of a typical heavy-duty power generation gas turbine, Figure 2-18 illustrates the 'thermal block' of Alstom's most advanced gas turbine family. With the introduction of the GT24 (60 Hz) and GT26 (50 Hz) gas turbines between 1995–1997, a technology level was introduced to the power market that meets the requirements for extraordinarily low emissions, high total efficiency and unique operational flexibility. The GT cycle parameters, as indicated in Figure 2-21, illustrate the superior design principles of this GT family with (for the 50 Hz, 296 MW GT 26), an overall total pressure ratio of PR = 33.3, max. turbine inlet temperatures TIT > 1,700 K and a gross electrical efficiency of 39.6 percent.

Alstom's new gas turbines are characterised by a unique design feature, the sequential combustion, that distinguishes them from conventional machines. Downstream of the air intake, the 22-stage subsonic axial compressor pushes the design mass flow of 650 kg/s to a pressure level of nearly 35 times the inlet ambient pressure. This record level for power generation gas turbines is achieved on a single shaft with four rows of variable guide vanes. At full load, approximately half of the total amount of fuel is burnt in the first EV (EnVironmental) combustor. A first expansion occurs in the single stage HPT high-pressure turbine. The remaining fuel is introduced and burnt in the SEV (second EV) or 'reheat' combustor, followed by a second expansion in a four-stage LPT low-pressure turbine. At over 600 °C, the exhaust gas temperatures are ideal for combined gas/steam turbine cycle applications. The sequential combustion concept has a long tradition that dates back to the 1948 Beznau, CH engine from BBC, Section 5.1.5.2, with an interim revival in the unique air storage gas turbine in Huntorf, D, Section 5.5.3. During ABB's GT design relaunch in the 1990s it appeared to be an interesting vehicle to limit the challenges of high material temperature; in the meantime the operational versatility of this concept has become a clear marketing advantage in view of combined-cycle part-load performance and low emissions.

Besides the described 'open cycle' process of the constant-pressure gas turbine, there are also 'closed cycle' and 'semi-closed cycle' arrangements. The working fluid in a closed cycle GT facility can be air or other gas that is continuously recycled (back to the compressor entry) by cooling the exhaust air through a compressor pre-cooler. Because of the confined, fixed amount of gas, the closed cycle is not an internal combustion engine. Here, the normal combustor is replaced by a second heat exchanger. The heat is supplied by an external source such as a nuclear reactor, the fluidised bed of a coal combustion process or any other external e.g. crude oil combustor. The closed cycle gas turbine that is discussed in detail in Section 5.2.1, was invented by J. Ackeret and C. Keller in Switzerland; a first prototype of this gas turbine according to their AK process was built and presented by Escher Wyss Zurich in 1939. Inherent advantages can be listed as follows:

1. The turbo-components are relatively small, due to the low specific volume of the pre-cooled compressor air; a cycle pressure rise is used for a simple and cheap power level adaptation.
2. Very beneficial for the early developments was the fact, that there is no corrosion and blade contamination due to the external combustion; therefore, it is also possible to burn sulphuric crude oil and low-BTU fuels.
3. Plant efficiencies above 50 percent can be achieved e.g. by using an inert gas like Helium as the working medium. This allows the use of high-stress materials like Molybdenum alloys at elevated temperatures.

A related semi-closed gas turbine concept that tried to merge the advantages of open and closed cycles was proposed and demonstrated by Sulzer Winterthur, CH in the 1950s. A demonstration plant was built at Weinfelden, CH with an output of 20 MW, Section 5.2.2.

So far, abundance of cheap, clean fuels such as natural gas, the development problems of gas-cooled nuclear reactors as well as the general difficulty of realising a reliable and financially attractive fossil-fired gas heater with exhaust temperatures of 1,050–1,100 K have hampered the introduction of these configurations; this situation may change in the future.

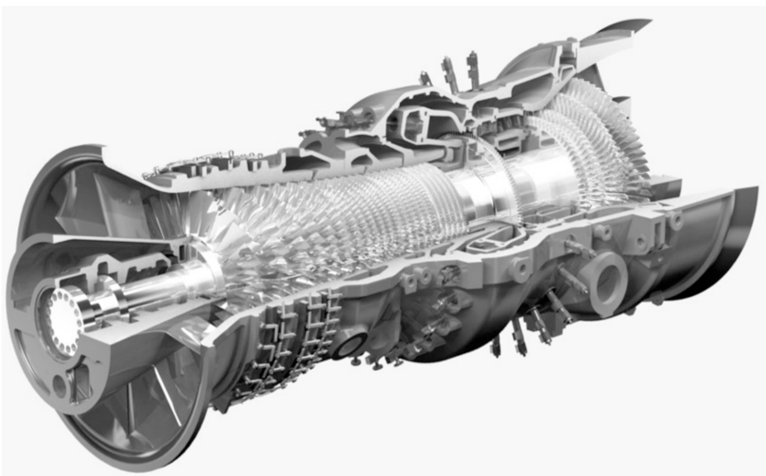

Figure 2-18 *Thermal block of the Alstom gas turbine GT24/GT26*

2.2.2 Gas/Steam Combined-Cycle Power Plants

A combined-cycle gas turbine power plant, here mostly identified by the abbreviation CCPP (combined-cycle power plant), is essentially an electrical power generation unit in which a gas turbine and a steam turbine are used in combination to achieve greater efficiency than would be possible independently, see Section 2.3.3. As illustrated in Figure 2-19, the classical Alstom arrangement is to place the generator between the GT 'cold end'/inlet and the steam turbine, so both can drive either generator side. The GT exhaust is then used to produce steam in a heat exchanger, called HRSG (heat recovery steam generator), to supply the steam turbine to generate additional electricity.

The historic tracking of the combined-cycle power plant leads without detour directly back to N.L. Sadi Carnot (1796–1832) and his ground breaking 1825 essay 'Reflections on the Motive Power of Heat', where he stated:

> *'... Air, then, would seem more suitable than steam to realise the motive power of falls of caloric from high temperatures. Perhaps in low temperatures steam may be more convenient. We might even conceive the possibility of making the same heat act successively upon air and vapour of water. It would only be necessary that the air have an elevated temperature after its use, and instead of throwing it out into the atmosphere immediately, to make it envelop a steam boiler, as if it were issued directly from a furnace.'*[36]

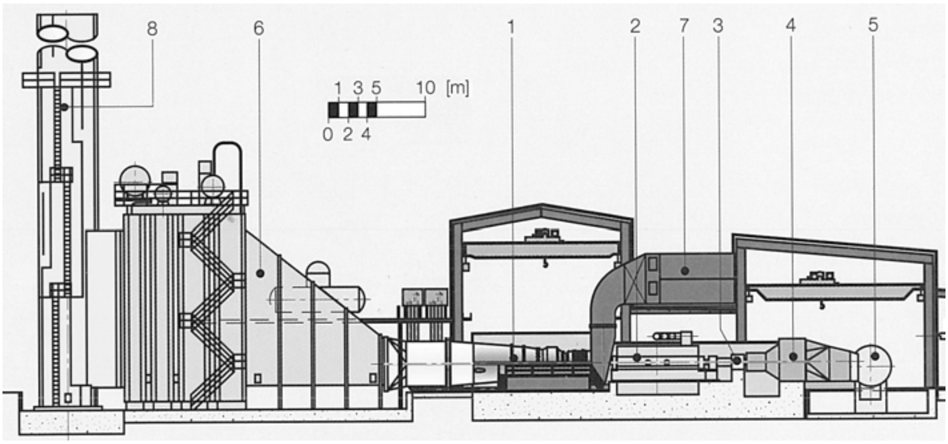

Figure 2-19 *Combined-cycle power plant KA26-1 with single shaft GT and a triple-pressure steam cycle: 1 – gas turbine, 2 – generator, 3 – clutch, 4 – steam turbine, 5 – condenser, 6 – HRSG, 7 – air intake, 8 – exhaust stack*

[36] See Carnot, Réflexions p. 61, where the quotation reads in the original: '*L'air semblerait donc plus propre que la vapeur à réaliser la puissance motrice des chutes du calorique dans les degrés élevés: peut-être, dans les degrés inférieurs, la vapeur d'eau est-elle plus convenable. On concevrait même la possibilité de faire agir la même chaleur successivement sur l'air et sur la vapeur d'eau. Il suffirait de laisser à l'air, après son emploi, une température élevée, et, au lieu de le rejeter immédiatement dans l'atmosphère, de lui faire envelopper une chaudière à vapeur, comme s'il sortait immédiatement d'un foyer.*'

As a result of the described technology-driven performance jump, the combined-cycle gas turbine to date is fast replacing the steam turbine as the base load provider of electrical power throughout the world. This is even true in Europe and the United States where the large steam turbines were the only type of fossil base load power for a long time.

Where appropriate, the realisation of CHP (combined heat and power plants), also known as cogeneration plants, would raise the thermal efficiency beyond 80 percent. CHP district heating e.g. uses the CCPP reject heat for large housing areas. Other forms of cogeneration comprise process steam export for industry, desalination plants, etc. Between 1954 and 2010 Alstom and the foregoing companies have successfully delivered more than 200 combined-cycle power plants for an installed power output of more than 90 GW, i.e. in reference to the present product portfolio the advanced versions KA26 and KA24 for the 50 Hz and 60 Hz markets respectively, as well as the KA13E2 (50 Hz) and the KA11N2 LBTU (50/60 Hz), especially for low calorific fuels.

2.2.3 Aero Propulsion Gas Turbines

In an aircraft gas turbine, the output of the turbine(s) is used to turn the compressor(s) that may also have an associated turbofan or turboprop(eller). The hot air flow leaving the turbine is accelerated into the atmosphere through an exhaust nozzle to provide thrust (propulsion power). Jet GT engines are differentiated as low and high BPR (bypass ratio) configurations. The BPR designates the ratio of air mass flow drawn in by the front fan but bypassing the core engine to that of the air burnt in the core engine. The low-bypass turbofan is more compact, but the high-bypass turbofan can produce much greater thrust, is more fuel efficient, and much quieter. Present commercial turbofans of the leading engine manufacturers General Electric, Pratt & Whitney and Rolls-Royce produce static TO (take-off) thrusts of up to 500 kN per engine. BPRs range from 6-11, the technology of HBPR (high bypass ratio) demonstrator 'ducted prop' configurations with BPR < 18 is under investigation in parallel to open rotor 'propfan' concepts.[37] These propfans with BPR < 30 have the potential for further considerable reductions in fuel consumption, but with critical, still unknown noise characteristics. Thrust is generated by both the cold bypass air as well as the hot core engine output. A turbojet has no bypass stream and generates all of its thrust from air that is burnt in the gas turbine engine. Turbojets have smaller frontal areas and generate peak thrusts at high speeds, making them most suitable for fighter aircraft.

In the context of this book it may be worthwhile selecting one of the first turbojets for illustration. Figure 2-20 shows an early version of the German BMW 003A turbojet, which together with the Jumo 004B was one of the two engines in series production during WW II. BBC (Mannheim) provided alternative compressors for this engine which would have increased the TO thrust to 9 (C version) and 11.5 (D) kN, i.e. by nearly 50 percent. The quality of military engine design is traditionally measured by the T/W (Thrust-to-Weight) ratio which was about 1.42 [kgf/kg] to start with. Progress in engine design and technology over the following decades is clearly marked by the T/W ~ 10 achieved in the meantime.

[37] See Geidel, Gearless CRISP and – see Eckardt, Future Engine Design Trade Offs

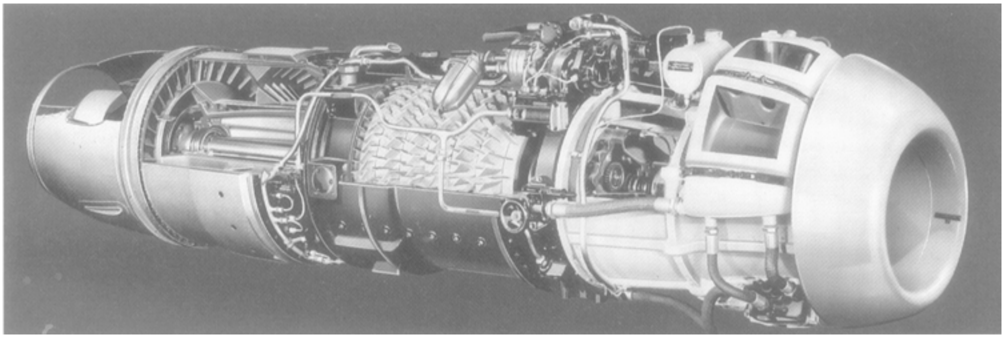

Figure 2-20 *BMW 109-003A German turbojet 1943: 7.8 kN TO thrust, length 3.53 m, diameter .69 m, planned –003 C/D versions with improved BBC 7- and 10-stage compressors* [38]

Over the first 50 years of gas turbine history, the aero GT engines (turbojets) were the leaders in most of the GT technology areas. The design criteria for these engines are high reliability, high performance with many starts and flexible operation throughout the flight envelope. Engine service lives of about 3,500 hours between major overhauls were considered good. Increases in engine thrust/weight ratios are achieved e.g. by higher turbo-component stage loading, by the development of high-aspect ratio blades[39] in the compressor as well as by optimising the pressure ratio and TIT (turbine inlet temperatures) for maximum work output per unit flow and the introduction of lightweight materials (composites, TiAl titanium-aluminide cast blading) in general.

2.3 Technical Basics

2.3.1 Gas Turbine Thermodynamics

Every thermodynamic system exists in a particular thermodynamic state. When a system is taken through a series of different states and finally returned to its initial state, a thermodynamic cycle is said to have occurred. In the process of going through this cycle, the system may perform work on its surroundings, thereby acting as a heat engine. A system undergoing a Carnot cycle is called a Carnot heat engine, although such a 'perfect' engine is only theoretical and cannot be built in practice.

The Carnot cycle was proposed by the aforementioned Nicolas Léonard Sadi Carnot[40] in 1824, see Section 2.2.2, and expanded by Benoît Paul Émile Clapeyron in the 1830s and 40s. It is the most efficient existing cycle capable of converting a given amount of thermal energy into work. The Carnot cycle when acting as a heat engine consists of the following steps:

– isentropic work input (compression),
– isothermal heat addition (at hot temperature T_H),

38 Picture source: Gersdorff, Flugmotoren und Strahltriebwerke, p. C XI
39 Meaning a high ratio of blade height to blade chord length
40 See also Section 3, Footnote 14.

– isentropic work output (expansion),
– isothermal heat rejection (at cold temperature T_C)

This leads to the simplest form of the definition of efficiency:

$$\eta = W / q_H = 1 - T_C / T_H$$

i.e. the ratio of useful work (W) done by the system to the heat input q_H can be expressed by means of the temperature ratio between 'Hot' and 'Cold' conditions or in other words for fixed ambient conditions, the maximum heat engine efficiency is a direct function of the realistically achievable T_H level in the combustor. The ideal Carnot cycle serves mainly as basis for the comparison to assess real engine cycles, like the Joule cycle for gas turbines and the Rankine cycle, correspondingly, for steam turbines. In any case, Carnot's theorem applies: *No engine operating between two heat reservoirs can be more efficient than a Carnot engine operating between those same reservoirs.*

The GT simple-cycle Joule process, in the literature sometimes also named after the Boston engineer George Brayton (1839–1892) and shown in graphic form in Figure 2-21a as a *h – total enthalpy/T – total temperature vs. s – entropy* diagram, is a representation of the properties of a fixed amount of air as it passes through a gas turbine in operation. The compression work W_C (with losses) is followed by a constant pressure heat addition process; then the hot gas is expanded in a turbine (again with losses), generating the turbine work W_T. Finally, the cycle is closed by a constant pressure heat rejection process. In this respect the Joule/Brayton gas turbine cycle is very similar to the steam turbines' Rankine process, with the main difference being that the latter refers to a two-phase (liquid and gas) substance with phase changes occurring during the two constant pressure processes.[41] Since the turbine drives the compressor, $W_T - W_C$ represents the net power output. For an optimum design in view of a high power output **and** efficiency, the increase in turbine inlet temperature has to be accompanied by a higher compressor pressure ratio. To give an example for TIT = 1,750 K, optimum power requires a compressor PR ~ 20, while the best efficiency values can be expected at PR ~ 40. The final fixation somewhere in between is part of the design evaluation and optimisation process.[42]

The gas turbine belongs to the category of IC (internal combustion) engines employing a continuous combustion process. This differs from the intermittent combustion occurring in diesel and automotive IC engines, but also from that in an 'explosion gas turbine' according to the German engineer Holzwarth, Section 3.3. This 'constant (combustion) volume' engine concept was actively investigated by BBC before the path to the present 'constant pressure' concept was started in the early 1930s; especially valuable experiences in high intensity heat transfer could be applied to the following development of the present days' standard GT configuration.

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41 The naming of the corresponding cycles after Brayton and Rankine is somewhat disputed in the Anglo-Saxon literature – see e.g. Potter, The Gas Turbine Cycle and Haywood, Analysis of Engg. Cycles – with the basic arguments, that the elementary GT concept was already disclosed in the 1791 patent application of John Barber, while both the ideal and practical gas turbine cycles were revealed in the 1851 paper by James P. Joule (1818–1889), if one is willing to substitute turbomachinery for the reciprocating compressor and piston engine. The same applies for the ideal Joule cycle in correspondence to the ideal Rankine cycle – after William J.M. Rankine (1820–1872). Both Brayton and Rankine – it is said – never suggested their cycles explicitly.

42 See Simon, Entwicklungen für grosse Gasturbinen

Alstom's sequential combustion has been illustrated with the characteristic double peaked process in Figure 2-21b as the so-called 'GT reheat cycle'. Reheating occurs in the turbine zone and is a way to increase on a relative basis the turbine work (W_{HPT} + W_{LPT}) more than the compressor work (W_{LPC} + W_{HPC}), thus limiting the thermal load of the turbines. As already shown in the foregoing Section 2.2.1, a row of SEV combustors was inserted between the HPT high-pressure and LPT low-pressure turbine for reheat, where the extra heat q_{SEV} is added in addition to q_{EV}. As opposed to the simple cycle, the expansion reheat cycle runs at three pressure levels. This process staging increases the GT thermal efficiency in principle by one to three percent. A comparison of both cycles shows the reheat process less sensitive towards deviating component efficiencies, with the mentioned advantage. In addition, the reheat cycle has the general benefit of some 15 percent higher specific work. Summarising, the processes with intermediate reheat represent a few essential advantages in comparison to the simple Joule process[43]:

1. The reduced sensitivity towards component efficiencies is in general reflected in a slightly higher GT thermal efficiency (assuming the same component performance).
2. The double expansion raises the specific work considerably above that of the Joule process, which increases the relative power output for same mass flows.
3. For equal thermal efficiency, the GT exit temperature of the reheat configuration is principally higher than that of the simple cycle. This has significant benefits, especially for combined-cycle (part-load) operation.
4. The splitting of the fuel input into two combustors generates also a few control options that cannot only be exploited favourably in combined-cycle part load, but also in view of a limitation of the turbine entry temperature. The advantages in view of material demands have been already discussed; however, in view of increasing environmental demands, the following aspect has become more and more important.
5. By injecting fuel into two combustion systems in series, it is possible to increase the output and cycle efficiency without significantly increasing the emissions at full and part load as the firing temperature in the first combustor can be kept relatively low and the second combustor does not contribute substantially to the critical engine NOx emissions. In this respect, the recently adapted sequential combustion operation principle in favour of lower NOx values has shifted the temperature peaks of
6. Figure 2-21b by unloading the NOx-sensitive first row of EV burners towards the SEV burners, where the incoming hot gas has a considerably lower O_2 content and thus, less oxygen is available for NOx formation.

[43] See Lechner, Stationäre Gasturbinen, p. 44. In addition to the listed thermodynamic and control-related advantages, the sequential combustion of course also has a few disadvantages:
In general, there is a need for higher compression ratios to exploit the advantage of the better reheat process efficiencies, thus increasing the number of compressor and turbine stages.
The thermally highly loaded SEV combustor is another costly GT component.
The additional mechanical design effort for the sequential combustion concept is accompanied by increased complexity e.g. for fuel supply and GT controls.

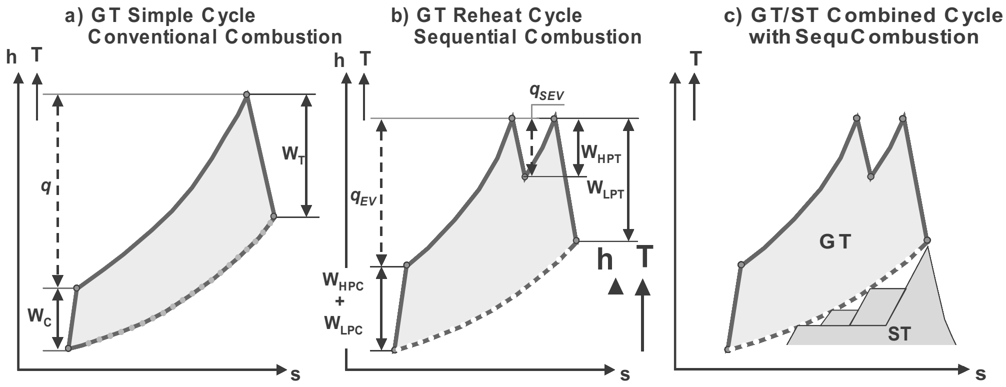

Figure 2-21 *GT simple, reheat and GT/ST combined cycles, h/T-s charts*

2.3.2 Gas Turbine Component Performance

The industrial gas turbine has always emphasised long life with – to give an example – MTBO (mean time between overhaul) values of 24,000 EOH[44] or longer; this rather conservative approach in the past has sometimes led to certain compromises against high performance and in favour of rugged operability. This has all changed in the past 15–20 years, either by direct competitive pressure from aero-derivative gas turbines or by a transfer of corresponding aero know-how to the heavy-duty GT configurations. Put in corresponding numbers, one could estimate the increase in the average engine pressure ratio from approx. 25 to more than 40, while the trend of turbine entry temperatures increased from a modest 1,250 K to impressive 1,750 to 1,800 K. Consequently, the former performance gap towards aero engines has been nearly closed, while the superiority in parts' life has increased even further.

The reason why the first gas turbine realisation efforts, like those of Stolze and Armengaud-Lemâle in the early 1900s, Section 3.2, did not prove to become a success can be seen in Figure 2-22 that shows GT thermal efficiency as a function of GT specific work – both for an early design standard of 1920/30 and for present state-of-the-art. With a turbine inlet temperature TIT[45] of about 830 K upfront of turbine vane 1 achieved by injecting water into the combustion chamber, the turbine was just able to supply the mere power for compressing the air. The cause of this disappointing result must be sought in the great volume of compressed air required to reduce the combustion temperature of 2,200 to 2,270 K to the value admissible for the gas turbine blading.

As already shown, one of the major disadvantages of the gas turbine in the past was its lower efficiency and hence its correspondingly higher fuel consumption when compared to

44 EOH equivalent operating hours refer to the number of operation hours, supplemented by the equivalent life consuming effect of cyclic loads, differentiated by number of events and thermal gradient over time.

45 There are different TIT definitions, besides the principle difference between absolute temperatures in 'degree Kelvin' (K) and those in 'degree Celsius' (°C), T (K) = T (°C) + 273.1 (deg C). **Thg** refers to the 'hot gas temperature' at turbine vane 1 inlet, while **Tmix** represents a theoretical 'mixed-out state' of hot gas mixed with all added cooling and leakage air; the latter is approx. 100–200 K below Thg.

other IC engines and to steam turbine power plants, see also Figure 2-23. However, during the last 70 years, continuous engineering development work has pushed the thermal efficiency from 18 percent for the 1939 Neuchâtel gas turbine to present levels of about 40 percent for SC (simple-cycle) operation and 60+ percent for CCPP (combined-cycle power plants). Even more fuel-efficient gas turbines are in the preparatory stage, with predicted SC efficiencies of 42 percent and especially large CCPPs considerably beyond the 'magic' 60 percent mark; these values are significantly higher than those of any other prime mover, such as steam turbine power plants.

2.3.3 Gas/Steam Combined-Cycle Power Plant

The h/T, s diagram of the KA26, the 'Kombi-Anlage' (combined-cycle plant version) of Alstom's GT26 gas turbine has been sketched in Figure 2-21c; the net electrical output for the (1 on 1) single shaft version is > 500 MW with > 60 percent electrical efficiency and for the schematically shown triple pressure reheat steam cycle.

The key advantage of the single-shaft arrangement as already outlined in Figure 2-19 is its operating simplicity which raises reliability – as much as 1 percent above multi-shaft blocks. Operational flexibility comes from the fact that the steam turbine can be disconnected, using a self-synchronising clutch during start-up or for simple cycle GT operation.

The combined cycle efficiency η_{CC} can be derived fairly simply from the equation :

$$\eta_{CC} = \eta_{GT} + \eta_{ST} - \eta_{GT}\,\eta_{ST}$$

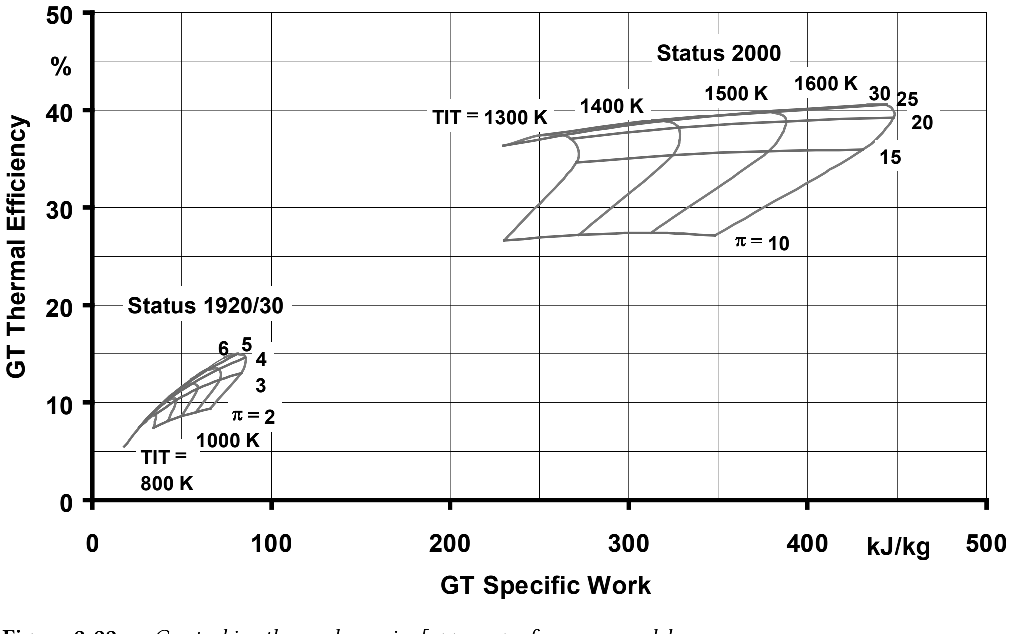

Figure 2-22 *Gas turbine thermodynamics [approx. performance model, TIT Turbine Inlet Temperature (Thg), π total pressure ratio [46]]*

[46] π – or mostly used PR – expresses the total pressure ratio between compressor discharge and compressor entry.