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The Gas Turbine Family GT13E and GT13E2 Provides Reliable Power for Asia

by

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ABSTRACT

Many Asian countries are experiencing economic growth which averages 5-10% per year. This environment has led to a privatization process in the power generation industry from typically state-run utilities to a system in which a federal agency oversees a market divided by private utilities and independent power producers (IPP) with the need for high efficiency, reliable power generation running on natural gas and diesel oil. In the 50 Hz market, modern, high efficient gas turbines of the type GT13E and GT13E2 have been chosen as prime movers in many combined cycle power plants in Asian countries. This paper includes a product description, and a general overview of GT13E and GT13E2 operating experience, well as an economic evaluation of a typical 500 MW combined cycle power plant.

INTRODUCTION

Making additional electrical capacity available in a short time is an important task for many Asian countries where economic growth averages 5-10% per year. This environment has led to a privatization process in the power generation industry from typically state-run utilities to a system in which a federal agency oversees a market divided by private utilities and independent power producers (IPP). This new and competitive situation has resulted in the need for high efficiency, reliable power generation running on natural gas and diesel oil. Gas turbine based combined cycle power plants not only meet these requirements, but in addition, they can be installed in a short time period, allowing for electrical capacity in less than 20 months from project closure.

In the 50 Hz market, modern, high efficient gas turbines of the type GT13E and GT13E2 have been chosen as prime movers in many combined cycle power plants in Asian countries including India, Malaysia, Indonesia and Vietnam. More than 20 units of the type GT13E rated at 147.9 MW and 40 units of the 165 MW gas turbine GT13E2 have been installed or put on order. This extensive fleet has accumulated more than 350'000 operating hours achieving combined cycle efficiencies of more than 54% and NOx emissions below 25 vppm (corr. 15% O_2), while showing

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excellent availability and reliability levels (figure 1).

CUSTOMER REQUIREMENTS

Today's customers are not only seeking the best value for their invested capital, they are looking for a partner capable of providing turnkey power plants, including innovative solutions for the financing of those large plants. A strong supplier like ABB has capabilities which include financial engineering and project development facilitating the realisation of such power projects (figure 2).

Additional project objectives focus on low capital and maintenance costs, and high plant power output and efficiency, while including a large degree of operational flexibility. All of these objectives are met by gas turbines of the type GT13E2, making it an ideal prime mover for combined cycle facilities with high profit potential. This paper will describe the GT13E2 gas turbine and its predecessor unit of the type GT13E, and present the latest status of operating experience in the different power plant applications.

GT13E2 Product Description

The first GT13E rated at 147.9 MW was sucessfully commissioned in the summer of 1987 in the Hemweg facility, owned and operated by UNA in the Netherlands. Subsequently, 28 units of this type were put into operation. Market requirements for gas turbines with higher thermal efficiencies and Dry-Low Nox emissions of less than 25 ppm (corr. 15% O_2) led to the development of the GT13E2 in 1991.

One of the main reasons that the GT13E2 has evolved as the leading gas turbine in the 165 MW power output class in the 50 Hz market, was the successful adaptation of the Low-NOx EV (EnVironmental) burner to an annular combustor. The design of the predecessor unit, the type GT13E utilized a single, top-mounted SILO combustor (figure 3), however, in regard to fundamental aerodynamic and mechanical design features, both units share many components. The upgrade to an annular combustor, as the main modification from the GT13E to the GT13E2, allowed for an increase in turbine inlet temperature from 1070°C to 1100°C (defined per ISO 2314) and increase in compressor ratio from 13.9:1 to 15.0:1.

Proven design features of the GT13E like a single, welded rotor, two bearing design, subsonic compressor and high efficiency turbine described in detail by Viereck et al. /1/,/2/ were utilized in the GT13E2 and resulted in a compact design (figure 4) with a high specific power output (fig. 5).

Other typical ABB gas turbine features such as 'axial exhaust' and 'cold end drive' are also part of the GT13E2 design features. The axial exhaust is defined by the exhaust gases from the gas turbine exiting in axial direction. Especially in a combined cycle plant with a heat recovery steam generator downstream of the gas turbine, such a design allows for a compact plant lay-out. Gas turbine designs with a side exhaust system require typically larger distances between center lines, as the exhaust stacks have to be located inbetween the units.

In addition, the axial exhaust of the GT13E2 puts the generator on the compressor side of the gas turbine. This design is called cold end drive and relates to the electrical generator and the gas turbine being connected on the compressor, and not on the hot turbine side. Thermal expansion associated with the hot turbine side does therefore not affect the generator position, making the cold end drive design more reliable.

The combustion system of the GT13E2 is based on a single annular combustor with 72 EV burners arranged in 4 rings around the turbine. The symmetrical arrangement of the burners results in an homogeneous temperature distribution at the inlet to the turbine, effectively lowering temperature variations typically associated with the SILO design and the can-annular combustors. In addition, the large, single-annular combustion chamber of the GT13E2 possess the inherent advantage of reliable ignition and very stable combustion, as it does not require cross-firing tubes and separate transition pieces which are necessary in the can-annular design /3/.

The GT13E2 combustor is designed for long lifetime and easy access which results in overall low maintenance cost. A manhole in the combustor allows maintenance personnel to carry out combustor inspections without dismantling the unit. The lean pre-mix EV burner system in the GT13E2 allows for NOx emissions below 25 vppm (corr. 15% O_2) on natural gas without water injection and 42 vppm (corr. 15% O_2) on diesel oil with water injection (figure 6).

Today's need for operational flexibility requires good part load efficiency and low emissions over a wide load range. The GT13E2 meets these requirements through its capability to reduce air by closing the variable guide vanes in the compressor, as well as by utilising a combustion concept based on "external piloting". This concept relies on operating some EV burners at a very lean equivalence ratio, while utilising adjacent EV burners at a self-stable equivalence ratio as a pilot or stabilising flames. High part load efficiency is a benefit in simple, as well as combined cycle operation (fig. 7).

The GT13E Family in Combined Cycle Power Plants

Most new applications of gas turbines in Asia require high thermal efficiencies. This can best be achieved by operating one or multiple units in a combined cycle power plant. Such a plant utilises the waste heat from the gas turbine exhaust to generate steam in a so-called waste heat recovery boiler (WHRB) or heat recovery steam generator (HRSG). This steam is then either used in a steam turbine for additional electricity generation and/or for steam usage in an industrial application.

Figure 8 shows a summary of combined cycle performance data in different arrangements /4/. For most power plants requiring approximately 250 MW's electrical output, the KA13E2-1 in a dual pressure arrangement is the first choice with an impressive 53.4% gross combined cycle efficiency. Only applications with very high fuel costs will justify going to the triple pressure system with combined cycle efficiencies above 54%.

The GT13E2 can be started up from stand-still to full load in 25 minutes by using a static starting device. However, in a combined cycle power plant, additional time is needed in order not to exceed certain temperature gradients in the steam turbine. Depending on cold, warm or hot start, full CC power output can be reached between 55 and 120 minutes. Figure 9 shows a typical start-up diagram for a KA13E2 combined cycle power plant.

GT13E Operating Experience in Asia

A total of 28 units of the type GT13E are in operation worldwide with over 300'000 fired hours operating experience. All units are either operating on natural gas or on diesel fuel oil. Three projects are located in Asia, the Malaysian project Connaught Bridge, the Indian project Gandhar and the Indonesian project Tanjung Priok.

Connaught Bridge Facility (Malaysia)

The customer Tenaga Nasional Berhad had ordered 4xGT13E for commercial operation in 1992/93 for simple cycle operation. The compact 520 MW Connaught Bridge facility provides a key contribution to Malaysia's fast emerging power, and was operational in less than 2 years of contract award on a previous jungle-and-swamp site. In addition to its typical base load operation, the GT13E offers 'power augmentation', a unique feature by which power output of the gas turbine can be increased through water injection into the large SILO combustor.

Tanjung Priok Power Plant (Indonesia)

The 1180 MW project Tanjung Priok consists of two blocks each comprising three GT13E gas turbines and one ABB steam turbine. The plant is located in the port of Jakarta, and is capable of delivering 1180 MW power output at a thermal efficiency of 50%.

The gas turbines are installed outdoors, while the steam turbines are indoors in a common building with the control room. The units have been operating on diesel fuel oil as primary fuel, but they are equipped for dual fuel operation with natural gas and diesel fuel oil. Special requirements aimed at a high operating flexibility, which included simple and combined cycle operation with both fuels.

Gandhar Power Plant (India)

The 650 MW combined cycle power plant Gandhar utilizes three GT13E gas turbines and one ABB steam turbine. The plant is located in the Indian state of Gujarat, 350 kilometres north of Bombay, where rapid economic development required fast delivery of electrical capacity. The plant was supplied by a consortium headed by Marubeni and included ABB Switzerland, ABB India and Kawasaki Heavy Industries from Japan.

The thermal efficiency of the plant at the high ambient temperature of 27°C is an excellent 47% and one which has not been achieved by any other plant in India today. The units have been in operation since the spring of 1994 and have accumulated more than 16'000 operating hours. NOx emissions on natural gas are less than 50 ppm, making this plant one of the cleanest in India.

GT13E2 Operating Experience in Asia

A total of 39 units of the type GT13E2 are in operation or on order, with 14 units having accumulated more than 50'000 fired hours to date (fig. 10).

KGRC Sodegaura Station, Japan

The first GT13E2 went operational in 1993 at the KGRC site in Japan. The plant is owned by Kawasaki, and delivers power to the Tokyo Electric Power Company (TEPCO) grid. The unit is operated on natural gas in a simple cycle arrangement. Local regulatory restrictions limit NOx emissions to 2.8 vppm (corr. 16% O_2) which is achieved by using a SCR catalyst system. A special operating permit restricts operation to 1'000 hours per year. The facility has operated 3'000 fired hours to date.

Kuala Langat Power Station (Malaysia)

The Kuala Langat Power Station is located within the confines of the Genting Sanyen Power paper mill complex, 70 kilometres south of Kuala Lumpur. The plant is based on a KA13E2-3, utilising three GT13E2 gas turbines and one steam turbine in a combined cycle. Power output of the power block with a dual pressure steam system is 667 MW and the combined cycle efficiency is 50.6% at an ambient temperature of 30°C. The units have been operational for one year and have accumulated a total of more than 20'000 operating hours.

Lumut Power Plant (Malaysia)

The 1'300 MW combined cycle Lumut power plant comprises two blocks of 650 MW with each block consisting of three GT13E2 gas turbines and one ABB steam turbine. The first units are in the commissioning phase and commercial operation is scheduled for summer 1996 (block I) and January of 1997 (block II). This plant was developed by Segari Energy Sdn Bhd, and the site is located on the western coast of Malaysia. The new plant will increase the country's power generation capacity by more than 10%.

Muara Tawar Plant (Indonesia)

The 1'100 MW power plant is owned by PLN of Indonesia and comprises two blocks of each three GT13E2 gas turbines. One block will be operated in open cycle and one block will utilize heat recovery steam generators for supplying steam for a 220 MW steam turbine. The project is in the commissioning phase, and will achieve commercial operation in 1997.

Meishi Power Plant (China)

This simple cycle power plant is located in the Guangdong province in China utilises a single GT13E2. The power will be supplied to the city of Shenzhen, where rapid expansion of industrial facilities is accompanied by increasing power requirements The plant burns diesel oil as primary fuel, delivering 166 MW at site conditions. The commissioning of the plant took place in the spring of 1995 and the plant has reached commercial operation as of the beginning of 1996. It is currently being converted to combined cycle operation.

Phu My 2 (Vietnam)

The Phu My 2 power plant will be located approximately 70 kilometres south of Ho Chi Minh City in the southern province of Ba Ria. The project is financed by the World Bank and Vietnamese financial institutions and will be executed as a fast track project with an expected operating date in the first quarter of 1997. The 287 MW plant will use two GT13E2 gas turbines in simple cycle operation.

Economic Considerations

When discussing customer requirements, it is apparent that financial considerations are among the main drivers for the realisation of new power generation facilities in Asia.

The necessary factors for a comparison need to include the following:

- capital cost (normalized)
- construction period
- operation & maintenance cost (including fuel cost)

It is assumed that other factors, i.e. debt financing, project reliability, completion risk will be comparable for the different alternatives.

Comparing a combined cycle power plant with other power generation alternatives, shows a cost advantage of more than 60% for the gas turbine based power plant. The combined cycle power plant is also advantageous when comparing the shorter construction time of such a plant with different alternatives, i.e. hydro power, coal boilers, nuclear power. The length of the construction period is directly connected to the additional cost for the plant owner, as longer financing periods together with a later start of revenue generating electricity production will have a negative economic impact.

Hydro power can be generated with the lowest operation and maintenance costs (O&M), as there is no fuel cost for operating the plant. However, geographic and ecological circumstances generally limit the utilization of hydro power, making combined cycle power plants one of the most competitive alternatives.

The decision which type of new power plant to build is in most cases made on the basis of an economic analysis. The factors influencing such evaluations typically include first cost of the plant, poiwer output and thermal efficiency, lifetime of the plant, fuel prices and the discount factor. These factors vary with region and other project specific variables. For a 500 MW combined cycle power plant based on two gas fired GT13E2 gas turbines, a typical economic evaluation over a 25 year project lifetime shows a pay-back period of only 5.2 years, making such a plant an attractive investment with an internal rate of return of over 20% (figure 11).

Conclusion

With its high economic growth rates, Asia has become the region with the highest electrical power requirements. With the ongoing privatization process, high efficiency gas turbine based power plants have already been the main source for additional electrical capacity. In order to facilitate financing and insurance of such power plants, high reliability based on solid operating experience of the gas turbines as prime movers has become an important asset.

The GT13E2 is such a proven product based on a leading gas turbine design which will meet future demands. With gas turbines of the type GT13E2 now installed or on order, and the solid operating experience of the predecessor unit GT13E, it is an excellent choice for natural gas and diesel-fired simple and combined cycle power plants with a need for a high efficiency and reliable power.

References

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/2/ Klohr, M., Rihak, P., Tschirren, S., Schmidtke J., 1994, "Test Results and Operating Experience of ABB's Gas Turbine GT13E2", 1995 Yokohama International Gas Turbine Congress

/3/ Tschirren, S.; Aigner, M.; "The Design of a Single Annular Combustor with EV Burners", CIMAC Conference 1993, London

/4/ Weicht, U., Viereck D., Rohrer, A., 1993, "Advanced Combined Cycle Power Plant Concepts with the Gas Turbine GT13E2"

Fig. 1: GT13E2 Proven Design for High Availability

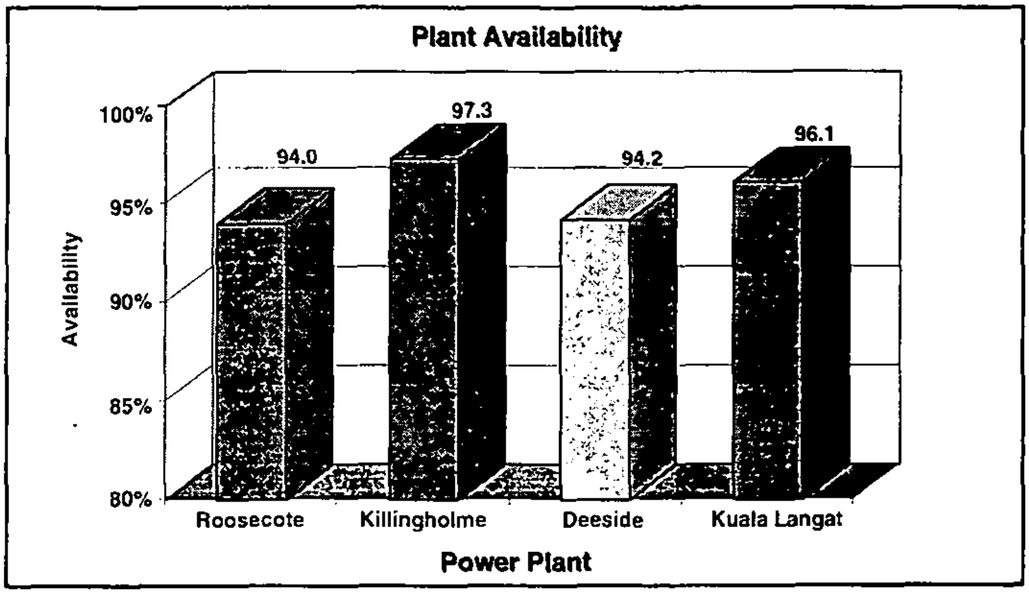

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Fig. 2: Scope of Products and Services (ABB)

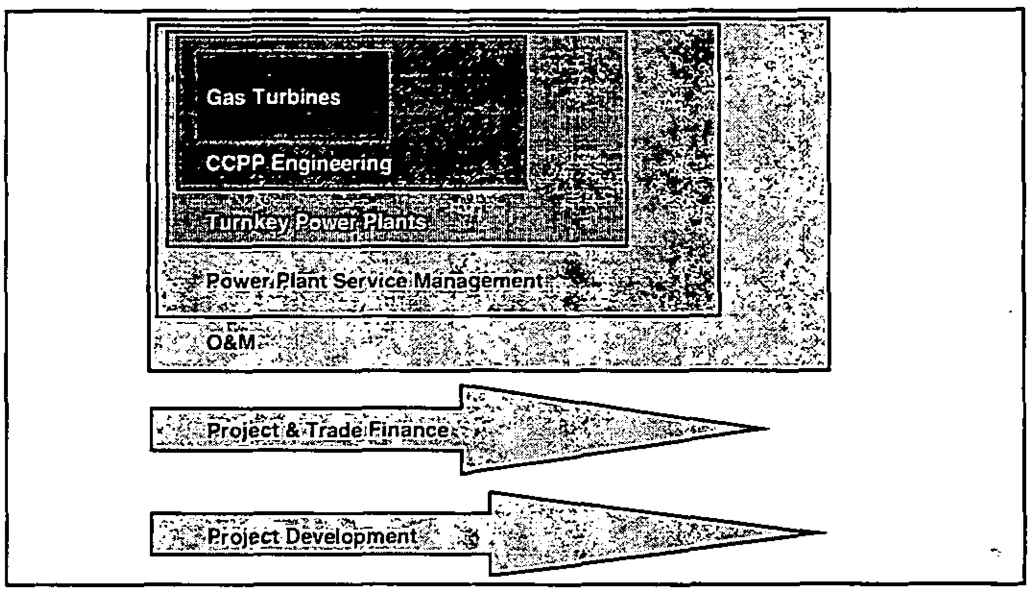

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Fig. 3: GT13E Gas Turbine

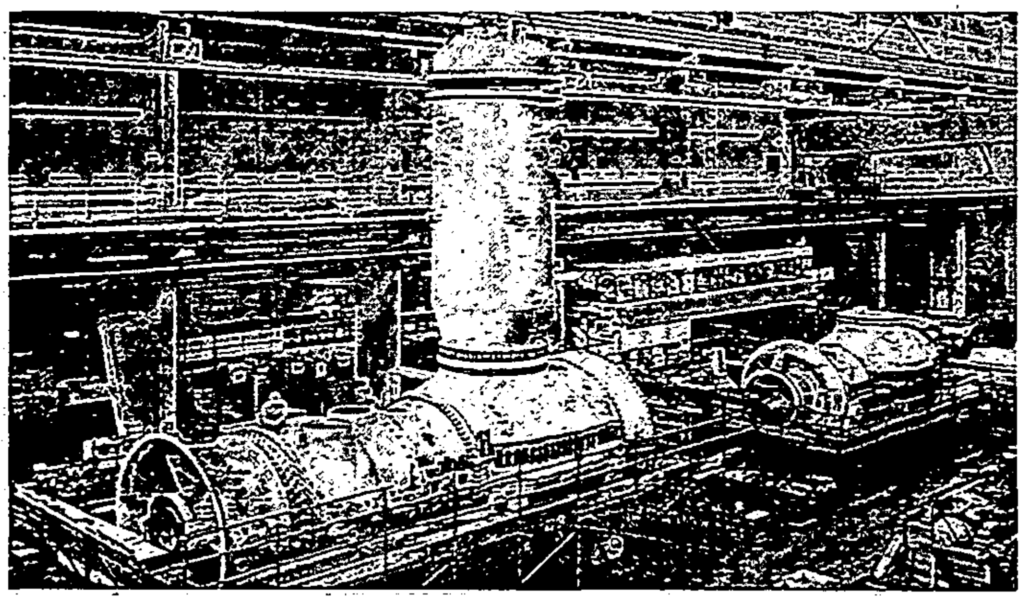

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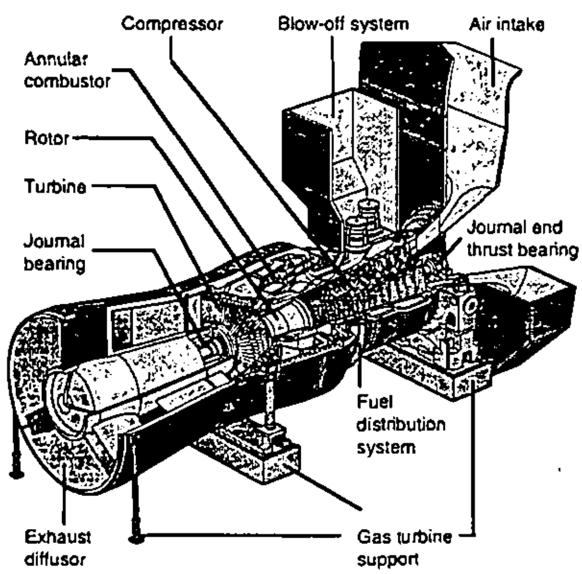
Fig. 4: GT13E2 Thermal Block



Features

- Highly efficient reliable subsonic compressor
- Latest annular combustion chamber technique (no cans)
- Highly efficient turbine
- Monolithic rotor using forged segments

Benefits

- Easy operation for start up and run down
- Maintenace free rotor with full reblading capability on site
- Easy and fast access to all thermal block components

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Fig. 5: GT13E2 Simple Cycle Performance

(ISO conditions)	
Electrical output (Nat. gas)	167.4 MW
Electrical efficiency (Nat. gas)	36.1 %
Heat rate	9,780 BTU / kWh
Exhaust mass flow	532 kg/s / 1,173 lb/s
Exhaust temperature	524 °C / 975 °F
NO_x emission with natural gas	25 vppm
NO_x emission with diesel oil	42 vppm*
	***** *with water injection*

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Fig. 6: EV Burner

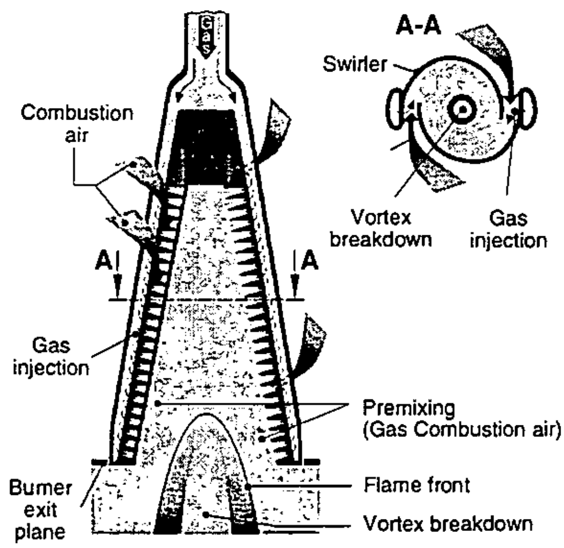

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Fig. 7: KA13E2-1 Rel. Efficiency vs Load

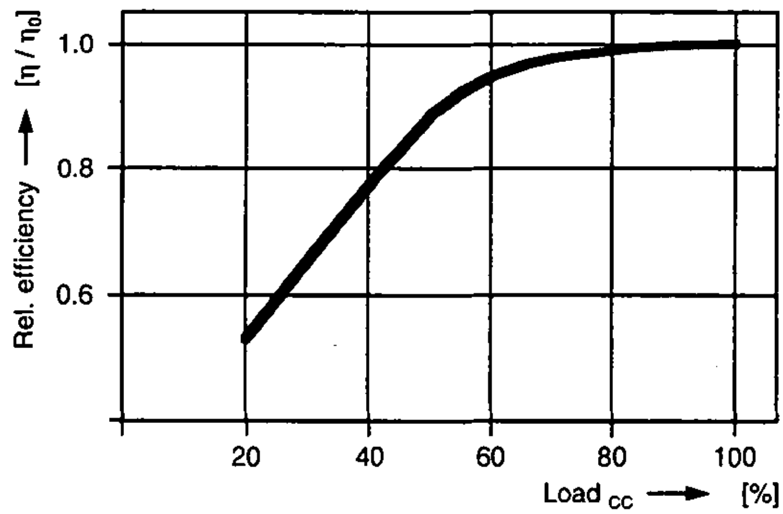

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Fig. 8: GT13E2 Combined Cycle Performance

At ISO 3977, Annex E		Gross output			Gross efficiency (ref. to LHV*)
Ambient air temperature	15 °C				
Ambient air pressure	1,013 bar	PGT	PST	PCC	
Relative air humidity	60 %				
ST condenser pressure	0,045 bar	MW	MW	MW	%
Single pressure cycle	KA13E2-1	167.6	73.9	241.6	48.6
Dual pressure cycle	KA13E2-1	159.3	82.3	241.6	53.4
Triple pressure cycle	KA13E2-1	159.1	85.1	244.2	53.9
Triple pressure cycle	KA13E2-2	318.2	172.6	490.8	54.2
Triple pressure cycle	KA13E2-3	477.3	260.0	737.3	54.3

* = LHV (Lower Heating Value) of fuel

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Fig. 9: KA13E2-1 Start-up Curve CC Plant

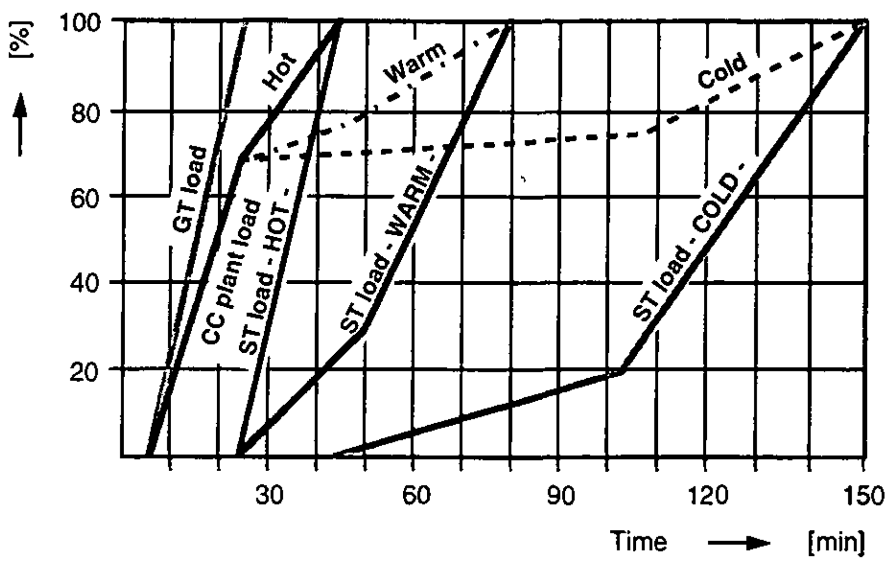

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Fig. 10: GT13E2 Operating Experience

Status: June 1996

No.	Plant	Customer	Ctry	Fuel	Utility	1st Ign.	Fired Hr.	Starts
1	KGRC	KHI	JP	NG	SC	20.08.93	2844	373
2	DEESIDE	National Power	GB	NG+No2	CC	02.06.94	8667	153
3	DEESIDE	National Power	GB	NG+No2	CC	22.06.94	10460	115
4	LAGE WEIDE 6	UNA	NL	NG	CC CoG	17.10.94	6667	180
5	DIEMEN 33	UNA	NL	NG	CC CoG	27.04.95	4204	81
6-7	BERLIN MITTE	BEWAG	GE	NG+No2	CC CoG	Mar-96		
8	RAS ABU FONTAS	MEW	QA	NG	CoG Des	21.06.95	3016	77
9	RAS ABU FONTAS	MEW	QA	NG	CoG Des	02.08.95	3123	40
10	RAS ABU FONTAS	MEW	QA	NG	CoG Des	Feb-96	50	10
11-12	RAS ABU FONTAS	MEW	QA	NG	CoG Des	Jun-96		
13	KUALA LANGAT	Gentin Sanjen	MY	NG+No2	CC	20.11.94	2572	92
14	KUALA LANGAT	Gentin Sanjen	MY	NG+No2	CC	20.12.94	3004	119
15	KUALA LANGAT	Gentin Sanjen	MY	NG+No2	CC	20.01.95	2889	108
16	LUMUT	SEV	MY	NG+No2	CC	31.01.96	70	14
17	LUMUT	SEV	MY	NG+No2	CC	05.02.96	65	13
18	LUMUT	SEV	MY	NG+No2	CC	09.02.96	68	13
19-21	LUMUT	SEV	MY	NG+No2	CC	Jun-96		
22	MEI SHI	Shenzen Neishi	CN	No2	SC	22.05.95	3180	209
23-24	RWE LU	RWE	GE	NG+No2	CC CoG	Jan-97		
25-30	MUARA TAWAR	PLN	IND	NG	SC/CC	Dec-96		
31-32	MARMARA	UNIMAR	TY	NG+No2	CC	May-97		
33-35	SOUTH HUMBER BANK	Humber Power	GB	NG	CC	Sep-96		
36	ALBA EXTENSION	Alba	BAH	NG	SC	Jan-97		
37-38	PHU MY	EVN	VN	NG+No2	SC	Dec-96		
39	FALCONARA	API	IT	SynG	SC			
Accumulated							50879	1 597

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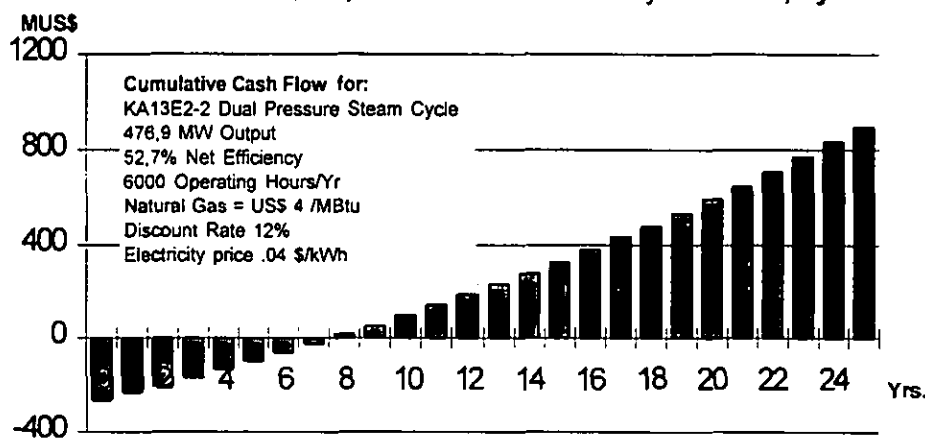
Fig. 11: ABB KA13E2-2 Combined Cycle

NPV = **MUS$ 45,8** IRR = **14.12 %** Pay Back = **7,5 yr.**



Evaluated over 25 yrs economical lifetime

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