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Improving Generation Efficiency of Power Plants in Arab Countries

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Abstract. The Arab countries have experienced rapid economic growth in the recent years. Economic growth causes increase in energy demand. As growth continues, the question of energy conservation is very actual. Many developments can lead to energy conservation. The following broad developments towards electrical energy conservation can be distinguished: (i) choice of appropriate power generation on technical and economic grounds; (ii) interconnections between countries; (iii) development of renewable technologies; (iv) energy efficiency on the transmission, distribution and user side. In the present paper, the first aspect in the above list is looked into in more detail: choice of appropriate power generation technology. Past achievements of many countries in the region towards significant efficiency improvement are illustrated. Insights on thermal power plant selection, from technical and economic point of view, are given as explanation to the trends seen in the different examples. The second aspect (Interconnection between countries) is also illustrated through a summary of a study performed by Tractebel Engineering on the benefits of interconnection of the GCC countries.

1 Introduction

The Arab countries have experienced rapid economic growth in the recent years. Economic growth causes increase in energy demand. As growth continues, the question of energy conservation is very actual.

Many developments can lead to energy conservation. The following broad developments towards electrical energy conservation can be distinguished:

- Choice of appropriate power generation technology: technological choice, optimal economic choice;
- Interconnections between countries. Several interconnected blocks already exist among the Arab countries, but without doubt many further opportunities exist to intensify the benefits of such interconnections;
- Development of renewable technologies. It is known, and obvious, that the Arab world has vast potential of Renewable Energies, both wind and solar (photovoltaic, concentrated solar power);
- Energy efficiency on the transmission, distribution and user side.

In the present paper, the first aspect in the above list is looked into in more detail: choice of appropriate power generation technology. Past achievements of many countries in the region towards significant efficiency improvement are illustrated. Insights on thermal power plant selection, from technical and economic point of view, are given as explanation to the trends seen in the different examples.

The second aspect (Interconnection between countries) is also illustrated through a summary of a study performed by Tractebel Engineering on the benefits of interconnection of the GCC countries.

2 Choosing thermal power plant technology

In this section, a high level overview of thermal power generation technologies is provided, before discussing trends in the Arab countries, shown in Section 3 below.

Thermal power plants represent of the order of 95% of installed power generation capacity in the Arab countries at this moment.

The overview in the present paper is limited to such thermal power plants. Hence we do not include in the illustrations of the present paper any analysis of:

- renewable energies, despite their fast technological evolution and significant potential for energy economies;
- hydro power, despite an installed capacity in the Arab countries of approximately 10GW (or of the order of 5% of the cumulated installed capacity), with contributions from Egypt, Iraq, Morocco, Sudan, Syria and minor shares from Algeria, Lebanon and Tunisia;
- cogeneration plants, despite the significant potential for combined power and desalination in the Arab countries. Selection of optimal cogeneration plant technology and configuration requires detailed analysis dedicated to the specifics of the power and/versus heat demand;
- nuclear power plants.

2.1 Thermal Power Plant Technologies

Considerations in the present paper are limited to power plants fuelled by liquid fuels (heavy fuel oil, light fuel oil), natural gas or coal. These plants are referred to as 'thermal power plants'.

When referring to thermal power plants, one distinguishes between :

- steam plants based on steam generating boiler and steam turbine;
- plants based on gas turbine in simple cycle (also referred to as open cycle gas turbine, OCGT);
- plants based on gas turbine in combined cycle (combined cycle gas turbine, CCGT);
- plants based on internal combustion reciprocating engines, either in open cycle or in combined cycle.

No significant share of power plants based on reciprocating engines appears in the portfolios of Arab countries (with exception of Djibouti and sub-saharan country Mauritania). Reciprocating internal combustion engines represent a competitive technology with gas-turbine based plants, for certain applications (size of plant, operating profile). Nevertheless, the high level considerations below do apply to reciprocating engines as well, hence such engine plants are not explicitly distinguished from gas-turbine based plants for the purpose of this paper.

2.1.1 Steam Plant

A steam plant is a power plant in which fuel is combusted in a boiler to produce steam. The greatest variation in the design of thermal power stations is due to the different fossil fuel resources used. Steam power plants can burn coal, fuel oil, or natural gas. Such power plants are also referred to as conventional power plants.

The energy efficiency of a conventional thermal power station is in the range of 35% to 45%. The higher efficiencies can be attained by increasing the temperature of the steam.

The figure below shows a simplified block diagram of a steam cycle in its most simplified form.

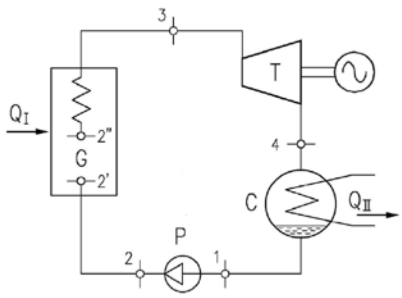


Figure : Simplified steam cycle

The block diagram represents the cycle 1-2-3-4-1. Water is pumped (pump P) from saturated liquid in state 1, to high pressure state 2. Steam is produced in the boiler G, through addition of heat quantity Q_I. The superheated steam is expanded in turbine T, which drives the generator producing electrical energy. At the exhaust of the turbine, the saturated steam at low pressure is condensed in condenser C, to saturated liquid in state 1, closing the cycle.

In order to improve the efficiency of the cycle, thermodynamic refinements are applied which render actual schemes significantly more complex, as shown in the example scheme below.

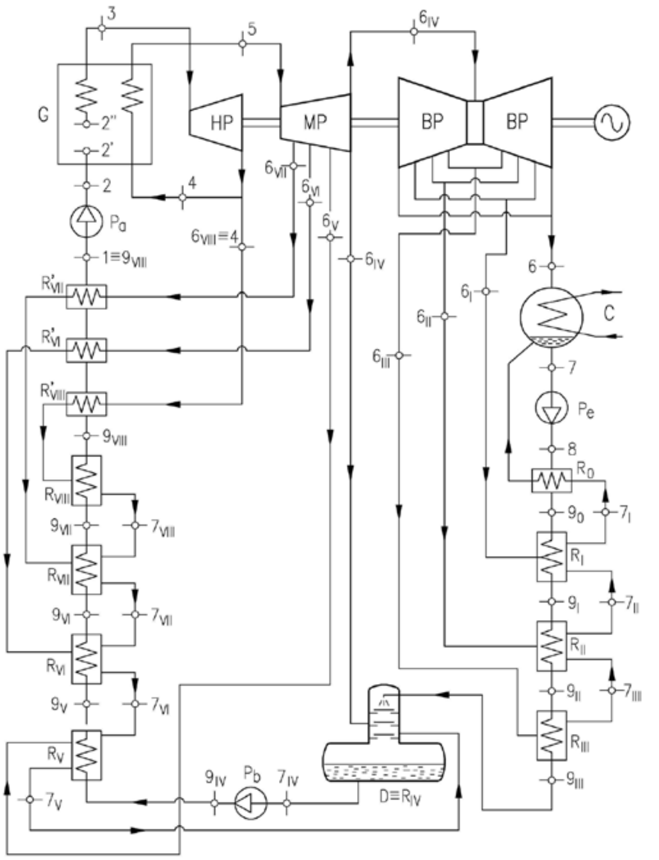


Figure : Steam plant cycle with thermodynamic optimisation

2.1.2 Open Cycle Gas Turbine Based Plant

A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor, a combustion chamber and a downstream turbine. Atmospheric air flows through a compressor that brings it to higher pressure. Combustion takes place in the combustion chamber, generating a high-temperature high-pressure gas flow which expands in the turbine section. The gas turbine drives an electric generator. Gas turbines are also used to power aircraft, trains, ships, …

The figure below shows a block diagram of a Gas Turbine.

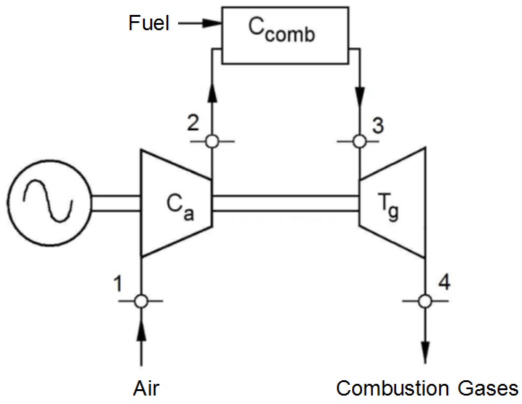


Figure : Gas Turbine Cycle

Air is compressed in Compressor Ca. Compressed air enters the combustion chamber Ccomb where the fuel (liquid fuel or gaz) is injected. The combustion generates combustion gases at high temperature, which expand in the turbine Tg section of the machine. The turbine drives the compressor; the power obtained in the turbine being superior to the power required for compression, the remaining power constitutes the power which can be converted to electrical energy.

2.1.3 Combined Cycle Gas Turbine Based Plant

The exhaust of the gas turbine still contains a significant amount of heat content, which can be used to generate steam in a heat recovery steam generator (HRSG). The steam thus generated drives a steam turbine. This occurs in a combined cycle power plant. Combining two or more thermodynamic cycles results in improved overall efficiency, reducing fuel costs.

Since single cycle (gas turbine only) power plants are less efficient than combined cycle plants, they are usually used as peaking power plants, which operate anywhere from several hours per day to a few dozen hours per year—depending on the electricity demand and the generating capacity of the region. In areas with a shortage of base-load and load following power plant capacity or with low fuel costs, a gas turbine power plant may regularly operate most hours of the day.

Gas turbines burn mainly natural gas and light oil. Crude oil, residual, and some distillates contain corrosive components and as such require fuel treatment equipment. Combined cycle plants are usually powered by natural gas, although fuel oil, synthesis gas or other fuels can be used.

The figure below shows a block diagram of a Combined Cycle Gas Turbine plant.

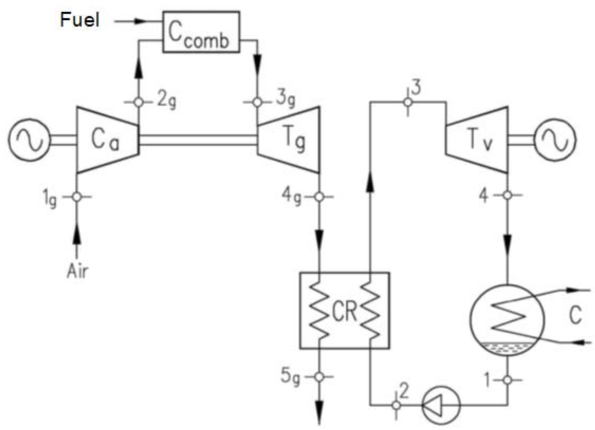


Figure : Combined Cycle Gas Turbine Scheme

The energy in the exhaust gases of the gas turbine is recovered in a heat recovery steam generator (CR), making steam for the steam cycle as shown in the schematic.

Similarly to the steam cycle as shown above, the steam cycle part of the CCGT in reality is more complex, in order to optimise thermodynamic efficiency. An example scheme of a steam cycle at three pressure levels is shown below.

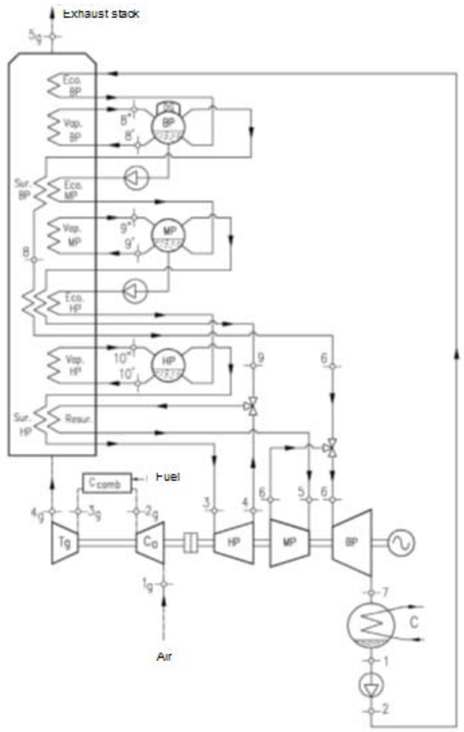


Figure : Combined Cycle Gas Turbine Scheme with thermodynamic optimisation

The design of the steam cycle (being essentially the number of pressure levels) is performed on a project per project basis, and is a result of an economic optimisation between investment cost and fuel economies (more pressure levels is thermodynamically more efficient, and hence increases thermal efficiency).

2.1.4 Combustion Engines

Reciprocating internal combustion engines represent a competitive technology with gas-turbine based plants, for certain applications (size of plant, operating profile). Nevertheless, the considerations in the present paper do apply to reciprocating engines as well, hence such engine plants are not explicitly distinguished from gas-turbine based plants, for the purpose of this paper.

2.2 Power Plant Technology Evolution

In this section, some technological developments are highlighted which have enabled the evolution of the fuel efficiency of the thermal power plants of the past decade(s).

2.2.1 Gas turbines

A parameter determining the thermodynamic efficiency of the gas turbine, is the temperature at the inlet of the turbine (Turbine inlet Temperature, of the combustion gases). As a result of the development of new materials, it has been possible to increase this temperature in the gas turbines with a direct effect on the power output and the efficiency.

The following shows typical parameters for successive generations of gas turbines. These 'generations' are commonly referred to as 'E-technology', 'F-technology', 'H technology'.

In the years 2000, the usual gas turbines were based on the E-technology and F-technology with the main following characteristics:

- E technology (performance indicated for 15°C ambient air temperature)
  - Turbine inlet temperature : 1100°C…1150°C
  - Power : 120 MW…160 MW
  - Efficiency : 33 % … 35 %
- F technology (performance indicated for 15°C ambient air temperature)
  - Turbine inlet temperature : approx. 1250 °C
  - Power : approx. 230 MW
  - Efficiency : 36% … 37.5%

Today, the E-technology machines are only installed in projects of limited size, or where the grid condition does not allow to install larger individual generators. The F-technology machines have improved and the H-technology is being implemented. The main characteristics of the recent gas turbines are as follows:

- F technology / 2014 (at 15°C)
  - Turbine inlet temperature : > 1350 °C
  - Power : 290 MW…300 MW
  - Efficiency : 38.5 % … 39 %
- H technology (at 15°C)
  - Turbine inlet temperature : > 1400°C
  - Power : 330MW…370 MW
  - Efficiency : 40.5 %

A second parameter which has a significant impact on the performance of the gas turbine is the ambient temperature (temperature of the air at the inlet of the compressor). The gas turbine performance figures are decreasing at high ambient air temperature.

By cooling the air at the inlet of the machine, it is possible to return to the performance corresponding to a lower ambient temperature. The air cooling is achieved by increasing its humidity content which, through evaporation, results in the temperature decrease of the inlet air.

The first large inlet air cooling systems have been implemented around the year 2000.

An example is given to illustrate effect of inlet air cooling. Inlet air conditions of 46°C and 42 % relative humidity are assumed, typical for conditions the Gulf countries. The chart below shows how, through inlet cooling, the point A (46°C, 42% relative humidity) moves to point E (35°C). A gas turbine having an efficiency of 37% without inlet air cooling, will have its efficiency increased to 38% as a result of inlet air cooling.

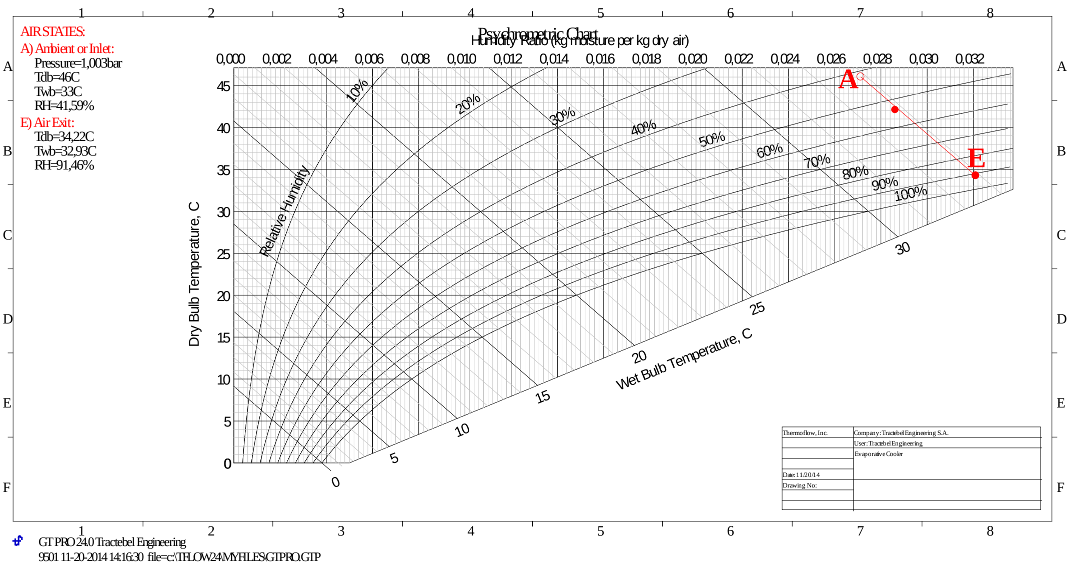


Figure : Gas Turbine inlet air cooling

2.2.2 Combined Cycle Power Plant

The Combined Cycle Power Plants obviously benefit from the evolution of the gas turbine technology.

In addition to the parameters mentioned for the gas turbine, the gas turbine flue gas temperature is also important for the combined cycle plant, as it determines the energy which can be recovered from it in the steam cycle.

The flue gas temperature is higher than 15 years ago (more than 600°C instead of 540 °C) so that it is possible to implement more performant water/steam cycles.

In addition, improvements in the steam turbine design have allowed to reach combined cycle plant net efficiency equal to 59%...60% (to be compared to 54%...55% 15 years ago).

It must be noted however that such values are given for reference environment conditions: 15 °C air temperature and cold water for the condenser (less than 15°C). In hot countries, it is more reasonable to consider 57%...58% for the highest achievable net efficiency of a CCGT plant.

2.2.3 Steam plants

For the steam plants, the major evolution lies in the development of technologies permitting the ever increasing level of steam pressure and temperature, with the aim of maximising the thermodynamic cycle efficiency.

The technology considerations are developed for coal fired plants, but remain valid for natural gas or oil fired plants.

The technological improvements are on:

- Evolution of materials;
- Optimisation of process (heat recovery, auxiliary power, etc);
- Optimisation of components (turbine blading, etc).

The following technology 'generations' are commonly referred to, for steam cycle plants:

- Subcritical cycles;
- Supercritical cycles;
- Ultra-supercritical cycles (USC).

The figure below illustrates the evolution of steam parameters and resulting plant net efficiency.

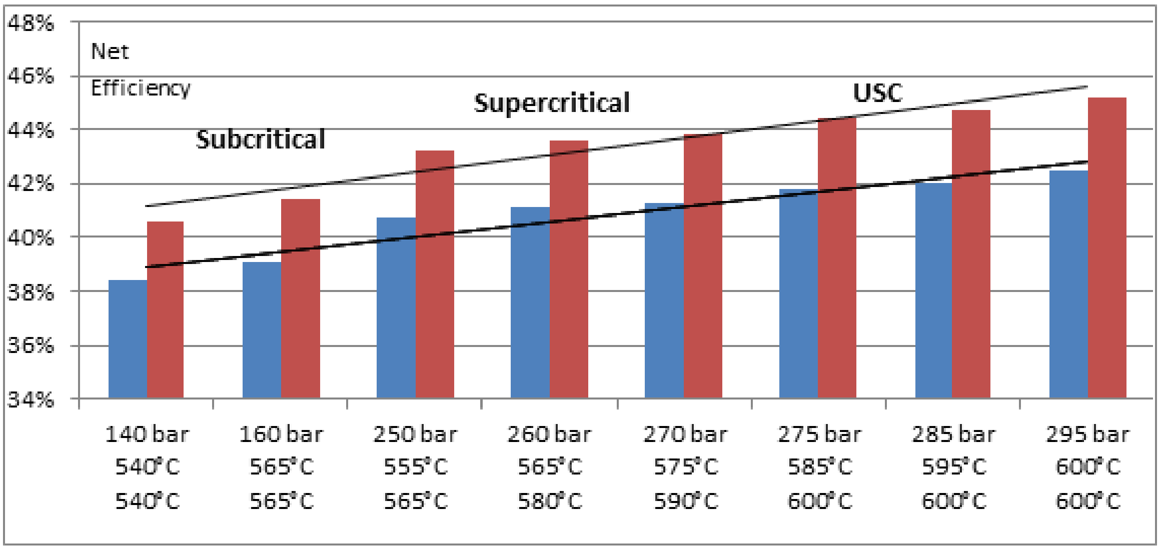


Figure : Steam Cycle parameters for Subcritical / Supercritical / Ultra super critical plants

In the above chart, two values are provided for net plant efficiency, represented as the red and the blue bars in the chart, for each set of steam parameters. The red value (highest efficiency value) assumes cold water is available for the condenser (typical of e.g. European conditions) while the blue value (lowest efficiency value) are calculated for a combination of ambient conditions representative of Arab countries. Hence it is seen that ambient conditions have a non-negligible impact on plant efficiency.

Even if the efficiency of the subcritical plants is lower than the one of the supercritical cycles, it has to be noted that it is in any case higher than 15 years ago thanks to the improvements brought in the steam turbines design (about +2%). This means that efficient subcritical units can be considered for smaller plants, plants which are too small for supercritical cycles (indeed the supercritical technology has been developed for large or very large units).

The choice of the steam cycle parameters for a specific project is performed on a project per project basis, and depends on plant size, manufacturer standards, Client preference for state-of-the-art technology or rather robust proven technology, …

2.2.4 Cogeneration plants

A way to improve the efficiency of a power plant is decreasing the loss in the condenser by using steam for an external process which requires heat or steam. This combination of power generation and providing heat is referred to as cogeneration. The electrical net efficiency is lower (since part of the energy is used for the external process) but, globally, the fuel utilization is more efficient than with a steam generation totally separated from the power plant.

Cogeneration obviously requires project-specific engineering of the plant configuration; in particular the steam turbine and steam extraction parameters have to be adequately selected.

In Europe, the extracted steam is generally used by an industrial process or in district heating.

In the Arab countries, cogeneration is (can be) applied to the following processes:

- Industrial process (petrochemical, …);
- Cooling systems (adsorption process/chillers using low pressure steam);
- Desalination through distillation (thermal process, using low pressure steam)(as opposed to desalination through Reverse Osmosis).

2.3 Thermal power plant efficiency range

As a summary, the following table provides a range of power generation efficiencies achievable through the different plant technologies.

Within the range per technology, the exact figure will be dependent upon plant size, thermodynamic parameters, technology generation.

For each individual project an optimum will be sought by putting in the balance the investment cost and the efficiency, as further explained in section 2.4 below.

Plant technology	Approximate efficiency range[1]
Steam plant	35 – 42%
Open cycle gas turbine OCGT[2]	33 – 38%
Combined cycle gas turbine CCGT	50 – 58%
Internal combustion reciprocating engines	42 – 45%

Table : efficiency range for different technologies of thermal power plants

[1] Estimated values at ambient conditions representative for Arab countries

[2] 'Heavy Duty' industrial gas turbines are assumed as opposed to aero-derivative gas turbines. Aero-derivative gas turbines have higher efficiency in open cycle, but are less relevant for the present paper, for the following reasons : (i) smaller size machines; (ii) less advantage to have such gas turbines in combined cycle configuration. Nevertheless, for specific applications (e.g. cogeneration, captive power plant dedicated to an industrial application, …), aero-derivative gas turbines can be studied.

2.4 Economic Optimisation Equations

Ideally, the technology of electricity generation to meet a certain layer[3] of power demand is chosen based on an equation involving marginal production cost and fixed cost. The marginal production cost is the element of cost which depends on the energy produced (MWh), and is composed of fuel cost and variable operation and maintenance cost. The fixed cost is independent of the energy produced, and consists of recovery of investment cost as well as the fixed component of operation and maintenance cost.

A choice of power plant technology means finding a compromise between marginal cost and fixed cost. Low marginal cost (e.g. through high efficiency plant) typically means high fixed cost (expensive plant), and vice versa. The compromise depends on the utilisation that is being made of the plant. For very high utilisation rates, one is prepared to spend a higher investment (fixed cost) in order to increase the efficiency (hence lowering the variable cost). For low utilisation rates, one will rather choose the somewhat lower efficiency (higher variable cost) by reducing the investment cost (fixed cost), since a high investment cost will not be economically recoverable during the economic life of the plant, given its lower utilisation rate.

Utilisation rate (also referred to as average of operating points) therefore is an important parameter in the optimal choice of power generation asset. The other very important parameter is the price of fuel. The selection of technology for a given project starts from an assumed fuel price.

2.4.1 Fuel Cost

The fuel cost of producing electricity depends on (i) fuel price per unit of energy, and (ii) the net power plant efficiency.

Fuel prices are subject to very significant fluctuations over time, as illustrated below.

A first illustration shows evolution of (i) US gas prices (Henry Hub); (ii) European gas prices (Amsterdam Power Exchange / European Energy Derivatives Exchange; (iii) brent oil price.

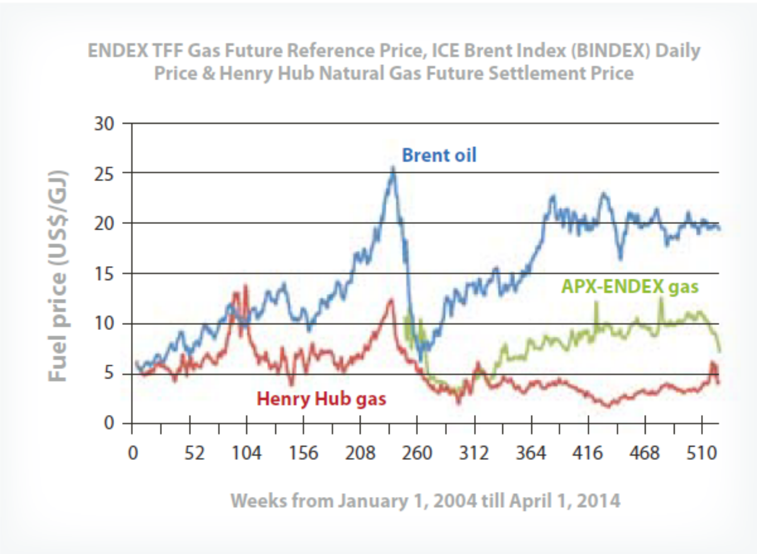


Figure : Gas and oil price evolution (world indices)

[3] A layer in the merit order.

Fuel prices differ upon the region. In North America, availability of shale gas has caused lowered gas prices since 2010. In Asia, the market depends on imported gas; gas price is high, at levels almost equal to oil per unit of energy. Gas prices are lower in Europe than in Asia. Coal resources are abundant in the world, and are a broad source of economic electricity generation.

A second illustration is the table below, providing liquid fuel (Heavy Fuel Oil, Light Fuel Oil) price levels in several Arab countries.

Fuel Oil		local currency / liter				USD / liter				USD/GJ			
Country		2000	2005	2010	2013	2000	2005	2010	2013	2000	2005	2010	2013
UAE		0,60	0,60	0,60	0,60	0,16	0,16	0,16	0,16	3,78	3,78	3,78	3,78
Bahrain						0,00	0,00	0,00	0,00				
Tunisia		210,33	210,33	210,33	210,33	0,11	0,11	0,11	0,11	2,65	2,65	2,65	2,65
Algeria	Light	5,50	5,50	5,50	5,50	0,06	0,06	0,06	0,06	1,49	1,49	1,49	1,49
	Heavy	10,00	10,00	10,00	10,00	0,12	0,12	0,12	0,12	2,70	2,70	2,70	2,70
S.Arabia		15,00	15,00	55,00	55,00	0,04	0,04	0,15	0,15	0,93	0,93	3,40	3,40

Source: OAPEC Statistical Report, various issues.

Gasoil	local currency / liter				USD / liter				USD/GJ			
Country	2000	2005	2010	2013	2000	2005	2010	2013	2000	2005	2010	2013
UAE	0,73	1,65	3,30	3,30	0,20	0,45	0,90	0,90	5,65	12,78	25,56	25,56
Bahrain	70,00	70,00	100,00	100,00	0,18	0,18	0,26	0,26	5,24	5,24	7,48	7,48
Tunisia	310,00	357,00	357,00	357,00	0,17	0,19	0,19	0,19	4,79	5,51	5,51	5,51
Algeria	13,70	13,70	13,70	13,70	0,16	0,16	0,16	0,16	4,55	4,55	4,55	4,55
S.Arabia	37,00	37,00	25,00	25,00	0,10	0,10	0,07	0,07	2,80	2,80	1,89	1,89

Source: OAPEC Statistical Report, various issues.

Figure : sample domestic liquid fuel prices

The raw data (local currency / liter) are (i) converted to USD at today's exchange rate; (ii) expressed per Gigajoule (GJ) of heat content, for ease of comparison to other fuels.

It is noted that the above prices of Fuel Oil are significantly lower than market prices for fuel oil seen on worldwide spot markets:

Fuel Oil Spot	USD/liter				USD/GJ			
Major Markets	2000	2005	2010	2013	2000	2005	2010	2013
US Gulf	0,131	0,229	0,443	0,585	3,024	5,302	10,257	13,547
Singapore	0,145	0,241	0,455	0,602	3,354	5,588	10,523	13,928
Rotterdam	0,129	0,218	0,444	0,591	2,980	5,036	10,271	13,669

Source: OPEC Annual Statistical Report, Various Issues.

Gas Oil Spot	USD/liter				USD/GJ			
Major Markets	2000	2005	2010	2013	2000	2005	2010	2013
US Gulf	0,214	0,445	0,563	0,766	6,085	12,641	16,008	21,765
Singapore	0,204	0,432	0,568	0,776	5,803	12,274	16,151	22,056
Rotterdam	0,212	0,446	0,571	0,779	6,035	12,676	16,232	22,144

Source: OPEC Annual Statistical Report, Various Issues.

Figure : world spot market prices for fuel oil

The price difference of fuel oil between Arab country domestic prices and world spot prices has a significant impact on the cost of electricity production, as shown in the next section.

2.4.2 Cost of Electricity Production

The cost of electricity production through various plant types is calculated as the sum of (i) capital cost, i.e. the cost component required to provide an adequate return on the investment cost, and (ii) the fuel cost. The O&M component in neglected in the present comparison. The cost of electricity production is expressed in USD per MWh. Comparisons depend on a number of main parameters such as fuel price and plant utilisation rate. The comparisons are simplified representations, but illustrative of the objective of optimum plant selection.

The following orders of magnitude are utilised for purpose of the comparison:

- OCGT : capital cost = 400USD/kW; plant net efficiency = 38%;
- CCGT : capital cost = 700USD/kW; plant net efficiency = 55%;
- Steam plant : capital cost = 1500USD/kW; plant net efficiency = 40%.

The graph below illustrates the electricity production cost for a varying utilisation rate, and adoption of the following fuel prices:

- Natural Gas price : 8 USD/GJ;
- Coal price : 4 USD/GJ;
- Fuel Oil price, low value assumed based on data of Arab countries : 5 USD/GJ;
- Fuel Oil price, high value based on world spot market values : 13 USD/GJ.

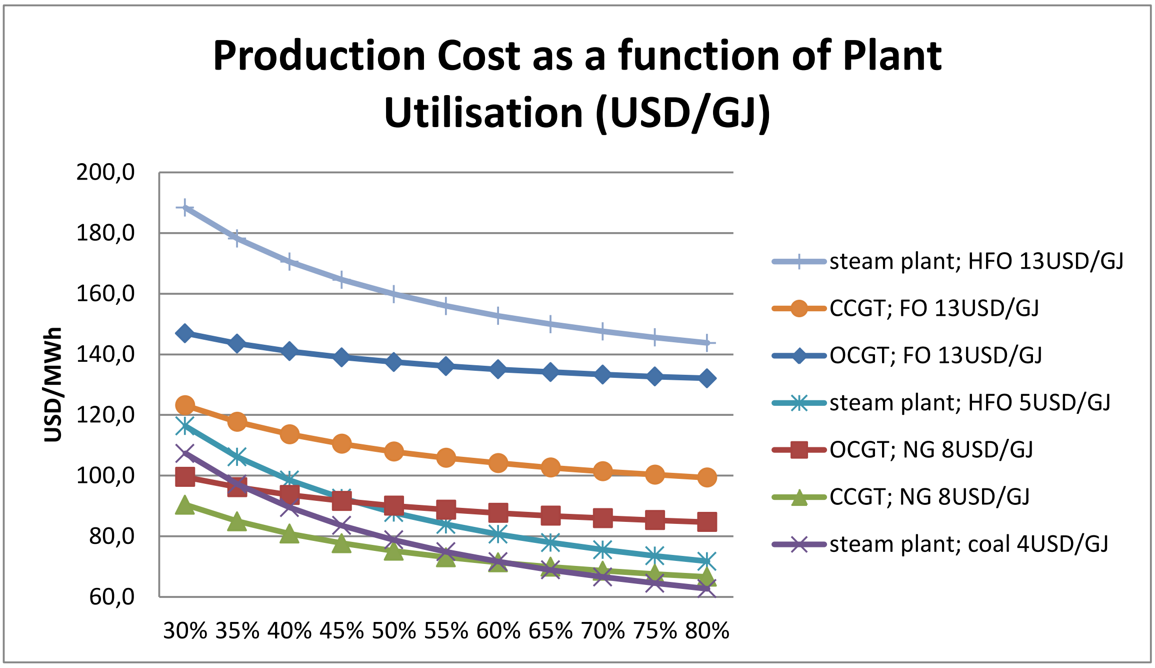


Figure : electricity production cost (capital recovery + fuel cost)

The figure illustrates the typical competition curve between technologies:

- Inclination of the curve is influenced by the ratio between the capital recovery cost component and the fuel cost component;
- The lowest production cost per MWh is achieved for the coal fired power plant (‘steam plant; coal 4USD/GJ’), at high utilisation factor;

- Below an annual utilisation factor of approximately 60%, the CCGT ('CCGT; NG 8USD/GJ') takes over as the lowest cost producer;
- At the very low end (peaking plant), the OCGT could take over from the CCGT as the cheapest producer.[4]

In the above figure, curves of electricity production cost using HFO are also shown, with the following assumptions:

- Fuel oil price of the order of 5USD/GJ, which keeps the electricity production cost in the ballpark of the other fuels;
- World spot prices of fuel oil (order of 13USD/GJ), rendering the electricity cost non-competitive with other fuels, independently of the plant technology applied.

This type of results is to be read together with the power generation portfolios in the Arab countries shown in Section 3, to understand the past trends as well as the possible opportunities for further improvement.

3 Arab Countries - regional and/or country specific energy features and trends

3.1 Some global figures

The electricity sector in the Arab countries is globally characterised by majority thermal power plant generation, and significant growth:

- total installed capacity of the order of 200 Gigawatt (GW);
- peak demand expected to grow from about 150GW in 2010 to about 280GW in 2020;
- thermal power plants represent of the order of 95% of installed power generation capacity;
- hydro capacity of approximately 10GW (with main contributions from Egypt, Iraq, Morocco, Soudan, Syria and minor contributions from Algeria, Lebanon and Tunisia);
- thermal power plant fuel is a mix of natural gas, heavy fuel oil, light fuel oil;
- fuel availability and distribution is very different from country to country in the region.

3.2 Country specific power generation mix

The generation mix varies by country in the region, depending to a large extent on each country's access to natural resources.

Example trends on power generation seen in various countries are:

- Historical dependence on oil for power generation. This dependence has often been reduced and replaced over time by gas-fired generation, being more economical and with reduced environmental impact.
- In several countries with significant gas resources, natural gas fired generation makes up the majority of the generation mix. Gas fired generation is based on low-efficiency simple-cycle gas turbines, or more efficient combined-cycle generation. The timing of combined cycles

[4] This crossing over is not shown in the graph; this is due to (i) not having considered the fixed O&M cost in the graph; (ii) fairly high gas price.

gaining market share has varied / is varying from country to country based on assumed gas prices, awareness about limits on gas resources, energy efficiency awareness, …

- Morocco, as an exception to other countries, relies to a large extent on imported coal in its generation mix.
- The Arab countries have a huge potential for wind and solar (both photovoltaic and Concentrated Solar Power) energy developments. Unlike oil and gas, wind and solar are more evenly spread across countries.

Different access to thermal fuel resources for different countries is given in the table below.

Algeria	- Major producer of crude oil and gas; exporter of energy; - Electricity generation portfolio almost entirely based on natural gas.
Bahrain	- Electricity generation portfolio entirely based on natural gas.
Egypt	- Significant available gas resources; - Power generation based mainly on natural gas, with smaller share part based on oil and hydro.
Iraq	- Significant available gas resources; - Electricity generation portfolio almost entirely based on oil.
Jordan	- Power generation based mainly on natural gas, with small part based on oil; - Limited existing gas and import contracts.
Kingdom of Saudi Arabia	- Power generation based mainly on oil, with smaller part based on natural gas; - Concern about gas availability.
Kuwait	- Power generation based mainly on oil, with small part based on natural gas; - Concern about gas availability.
Lebanon	- Electricity generation portfolio almost entirely based on oil, with small part of hydro.
Libya	- Significant available gas resources ; - Power generation based mainly on oil, with smaller part based on natural gas; - New generation capacity a mix of cogeneration, combined cycle and steam plants on natural gas.
Mauritania	- production based on Heavy Fuel Oil.
Morocco	- Net importer of energy; - mixed electricity generation portfolio based on coal, natural gas, oil, hydro; coal (imported) fired generation constitutes about half of its production parc; - Interconnection with Spain with a significant share of power imports.
Oman	- Electricity generation portfolio mainly based on natural gas, with smaller part based on oil.
Palestine	- Electricity generation portfolio entirely based on oil.
Qatar	- Electricity generation portfolio entirely based on natural gas.
Syria	- Power generation based mainly on oil, with smaller part based on natural gas; - Limited existing gas and import contracts.
Tunisia	- Producer of crude oil and gas; net exporter of energy; - Power generation based mainly on natural gas, with small part based on oil.
UAE	- Electricity generation portfolio almost entirely based on natural gas; - Concern about gas availability.

Table : main fuel (thermal power plants) availability per country

3.3 Historical Efficiency Improvement Achievements

In this section, historical evolution / achievement of a number of countries is looked into, by presenting data[5] on

- breakdown of the installed capacities, by technology of generation and fuel, over time;
- calculated average power generation efficiency for such installed capacities.

Statistics for a number of countries are provided, illustrating how the adoption of more efficient thermal generation technology has lead to very significant improvement of generation efficiency.

3.3.1 Bahrain

At the end of 2003, Bahrain had a total installed capacity of around 1200 MW, broken down as:

- 217.3 MW in steam turbines, having an average rated efficiency of around 27%
- 981.9 MW in (open cycle) gas turbines having an average efficiency of 29%

2 units, having an installed capacity of 246 MW were less than 5 years old. All other 21 units (total of 953MW) were more than 20 years old. The average generating efficiency in Bahrain was around 28% (very low).

From 2004 onward, only combined cycle power plants were added:

- Hidd 650MW combined cycle plant (2004)
- Al Ezzel 980 MW combined cycle plant (2007)
- Ad Dur 1234MW combined cycle plant (2011)

The generation mix changed to the following:

- Open cycle gas turbines : 981.9 MW (24%)
- Steam turbines : 217.3 MW (5%)
- Combined cycle : 2874 MW (71%)

As a result, the installed capacity is broken down as follows according to its year of commissioning:

Year Commissioned	Years in Service	MW installed	Percent
2008 – 2012	5 years or less	1234	30%
2003 – 2007	6 -10	1640	40%
1998 – 2002	11 -15	245.9	7%
1993 – 1997	16 -20	0	0%
1988 – 1992	21 – 25	0	0%
Before 1988	More than 25 years	953.3	23%

The following graphs illustrate the evolution of the power generation capacity, and its technology mix, over time.

[5] Illustrations are based on data assembled by the author; data are intended to be fit for illustration purpose; not a complete representation of sector nor country data

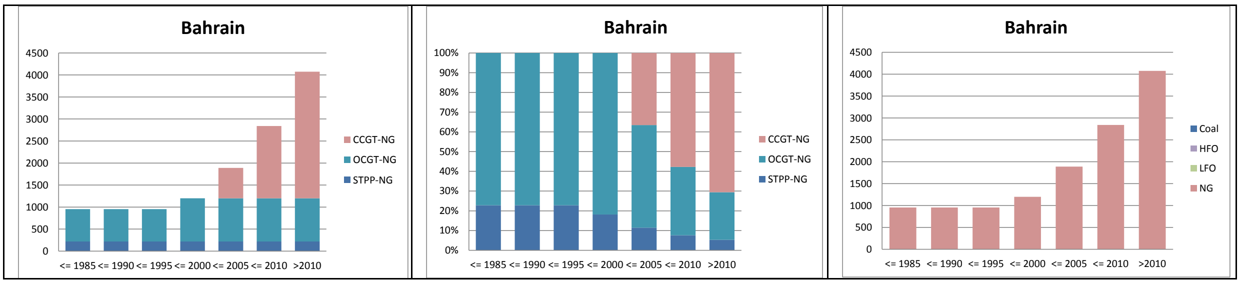


Figure : Bahrain installed capacity statistics

The addition of combined cycle power plants has raised the average efficiency of generation in Bahrain, during the period 2003 – 2013, from 28% to around 44%[6], as is illustrated in the following graph.

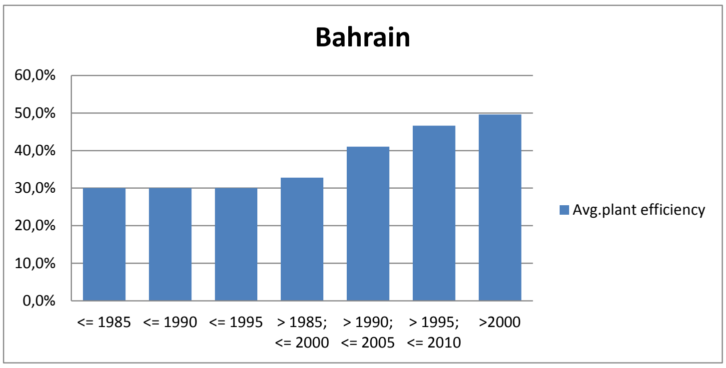


Figure : Bahrain progression of weighted average efficiency of the production portfolio.

The graph shows the clearly marked point of introduction of CCGT-s, as well as the extent to which efficiency can be improved.

3.3.2 Oman

Similar statistics are shown for Oman in the figures below.

All capacity is gas fired, although most of the plants have the ability to run on diesel as backup fuel.

From the moment of introduction of the CCGT technology, all further capacity addition has been under this form.

[6] When omitting some of the oldest capacity (decommissioned, or used with very low usage factor) from the average efficiency calculation, the average efficiency is even higher.

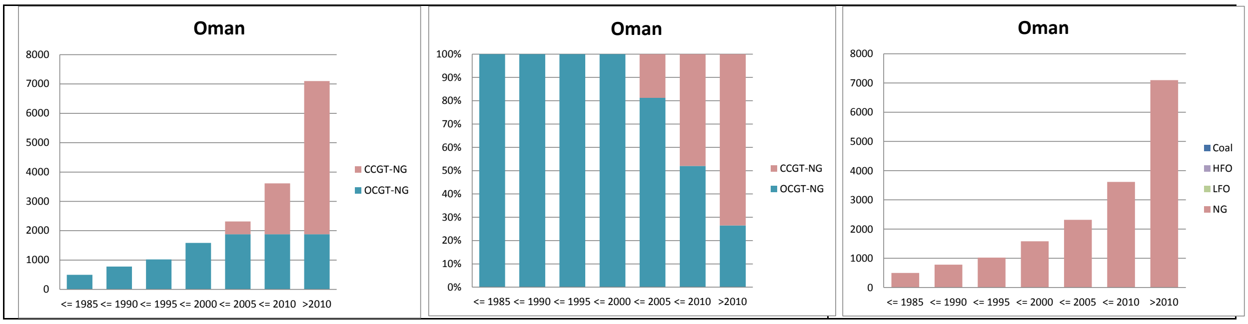


Figure : Oman installed capacity statistics : Installed Capacity (MW) - Installed Capacity by technology and fuel(%) - Installed capacity by fuel (MW)

A figure representing the weighted average efficiency of the electricity production portfolio is provided in the figure below.

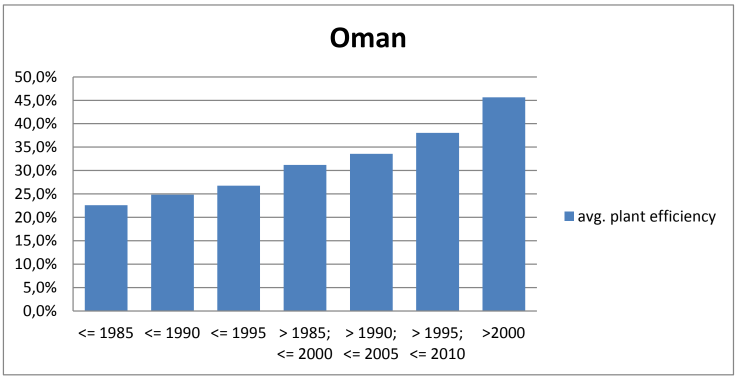


Figure : Oman progression of weighted average efficiency of the production portfolio

A marked trend of improvement of efficiency is shown. This is due to: (i) the share of CCGT in the production portfolio increases; (ii) most modern plant technology application[7].

3.3.3 Tunisia

A third country for which statistics are shown is Tunisia. As the previous two countries, the generation capacity in Tunisia is entirely based on gas.

These installed capacity statistics for Tunisia are shown in the figures below. All capacity is gas fired, although some of the steam plants have ability to run on Heavy Fuel Oil.

The graphs show an early introduction of combined cycle plant (Sousse B, 364MW, 1995). Nevertheless, the progression of combined cycle in the portfolio is less marked than in the case of the previous examples (Bahrain, Oman), as significant capacity additions also under the form of OCGT are seen.

[7] Trends should be looked at, rather than precise efficiency figures. As many projects are co-generation projects, precise thermal efficiency figures depend on how precisely cogeneration is accounted for in the efficiency calculations.

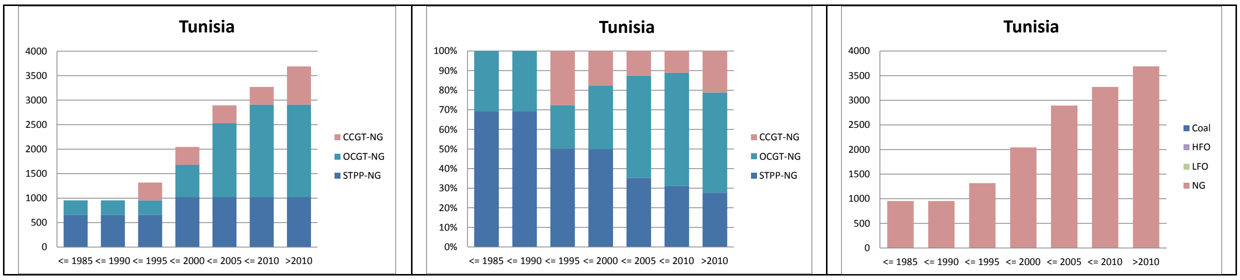


Figure : Tunisia installed capacity statistics

A figure representing the weighted average efficiency of the electricity production portfolio is provided in the figure below.

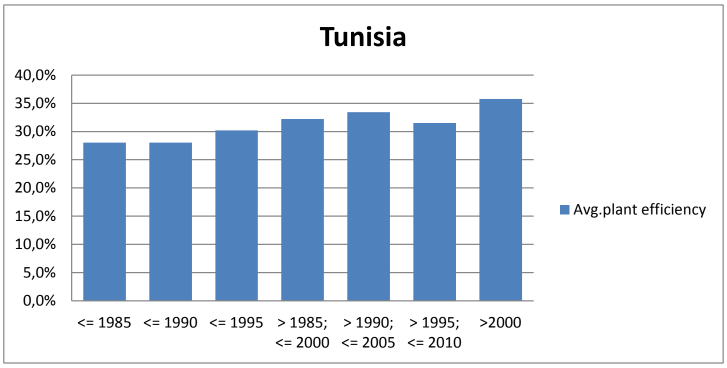


Figure : Tunisia progression of weighted average efficiency of the production portfolio.

An improvement of efficiency is shown corresponding to periods of percentage increase of CCGT in the portfolio. The trend is not continuous, and would be even clearer if a larger share of the capacity additions over the last decades had been under the form of CCGT.

Investigation of the reasons behind the technological choice of capacity additions (OCGT versus CCGT) should rely on the type of technical – economic analysis as illustrated in section 3 above.[8]

3.3.4 Jordan

Unlike the previous examples (Oman, Bahrain, Tunisia) which were entirely based on Natural Gas, Jordan has a mix of fuels.

Nevertheless, capacity additions over the last 2 decades have all been on Natural Gas.

Recent (last 15 years) capacity additions using Natural Gas have been mainly under the form of CCGT. A small capacity addition under the form of OCGT is seen. Capacity under the form of STPP burning NG is old, and economically outdated.

[8] One factor not taken into account in the calculation of the weighted average efficiency of the production parc is the utilisation factor of each of the assets. If for instance OCGT is introduced as a peaking plant, then the weight of its contribution to the average efficiency should be lower than the one of plants with higher utilisation factors (such as CCGT).

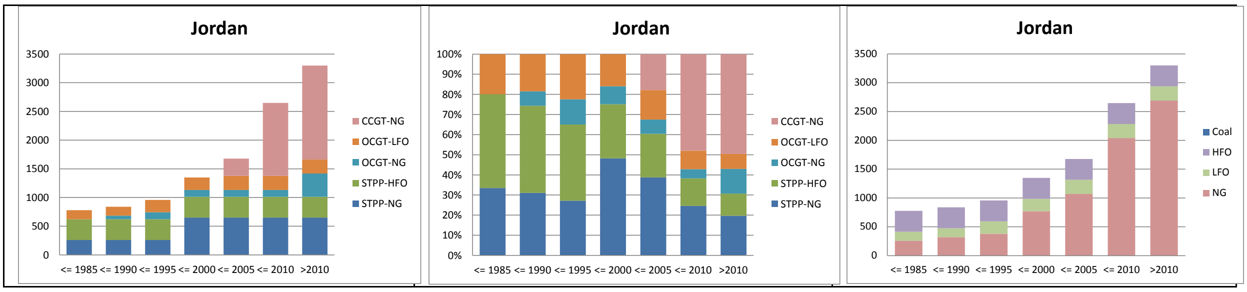


Figure : Jordan installed capacity statistics : Installed Capacity (MW) - Installed Capacity by technology and fuel(%) - Installed capacity by fuel (MW)

A figure representing the weighted average efficiency of the electricity production portfolio is provided in the figure below.

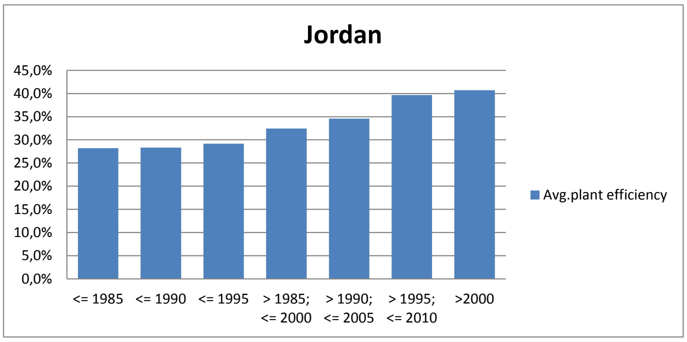


Figure : Jordan progression of weighted average efficiency of the production portfolio

A marked trend of improvement of efficiency is shown as the share of CCGT in the production portfolio increases.

3.3.5 Morocco

The installed capacity statistics for Morocco are shown in the figures below.

Diverse technologies and fuels are introduced over time, as represented in the graph:

- Earliest portfolio represented was already a mix of HFO (in steam plant), coal (in steam plant) and LFO (in OCGT plant);
- Main additions of capacity came under the form of coal (in steam plant), LFO (in OCGT) and NG (in CCGT). No further additions of HFO (in steam plant) were seen since 1990.

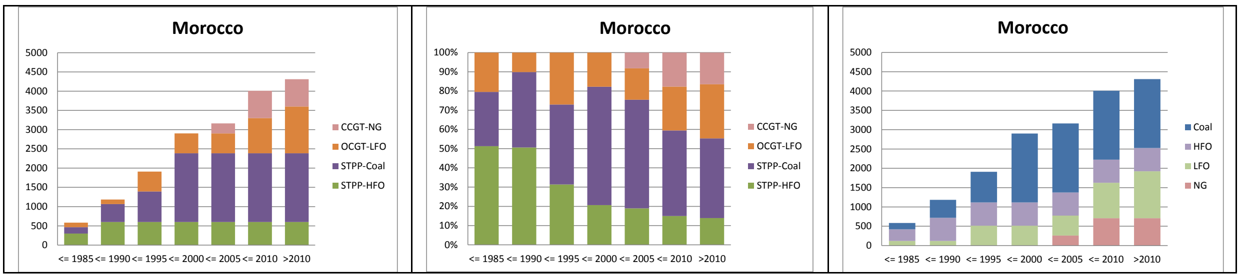


Figure : Morocco installed capacity statistics : Installed Capacity (MW) - Installed Capacity by technology and fuel(%) - Installed capacity by fuel (MW)

A figure representing the **capacity** weighted average efficiency of the electricity production portfolio is provided in the figure below.

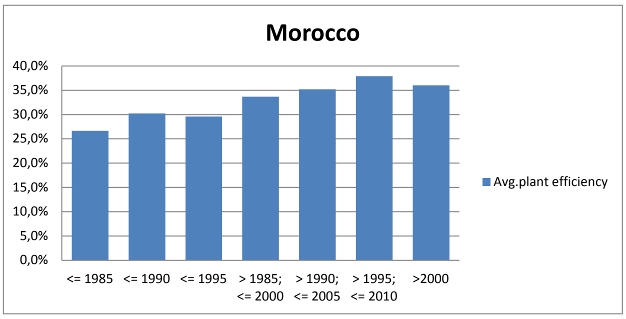


Figure : Morocco progression of weighted average efficiency of the production portfolio

In addition to efficiency improvement through evolution of the **mix** of plant types in the portfolio, a significant share of the improvement is likely to be allocated to the **evolution of technology** for each of the plant types (e.g. evolution of technology in steam plants on coal).

It must be noted that, for a portfolio as shown above, the calculation of weighted average efficiency based on **capacity** is not the best method. Rather, **energy** weighted average efficiency should be calculated. Indeed, different plant types will have different utilisation factors: coal plant will be used as base load (because of low marginal generation cost), whereas OCGT plant will be used rather in the peaking range (high marginal generation cost). However, such energy based weighting requires introduction of utilisation parameters in the comparison, and requires more detailed analysis.

3.4 Further Examples

No complete presentation of all Arab countries is intended to be provided. Rather, a few further examples of country power production portfolios (plant technology mix, plant fuel mix) are provided, together with the corresponding average efficiency. Such examples are intended to be illustrative of the potential for efficiency improvement / energy conservation.

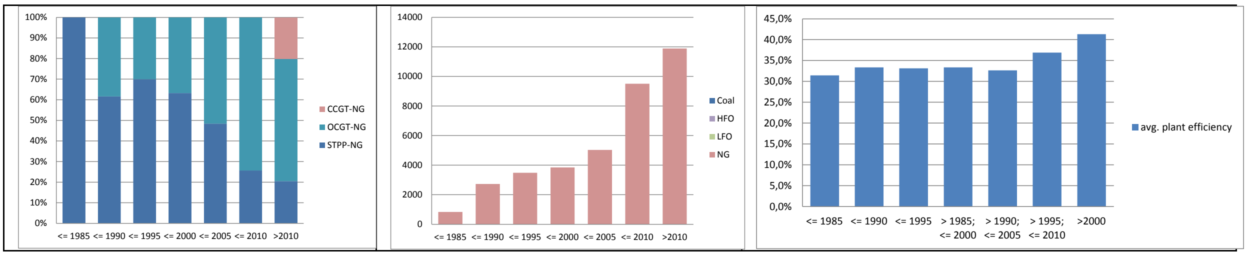


Figure : Additional example 1

One can notice:

- All capacity based on Natural Gas;

- Significant growth over time of installed capacity, mainly under the form of Open Cycle Gas Turbines (OCGT); introduction of over 2000MW on Combined Cycle Gas Turbines in the last period.

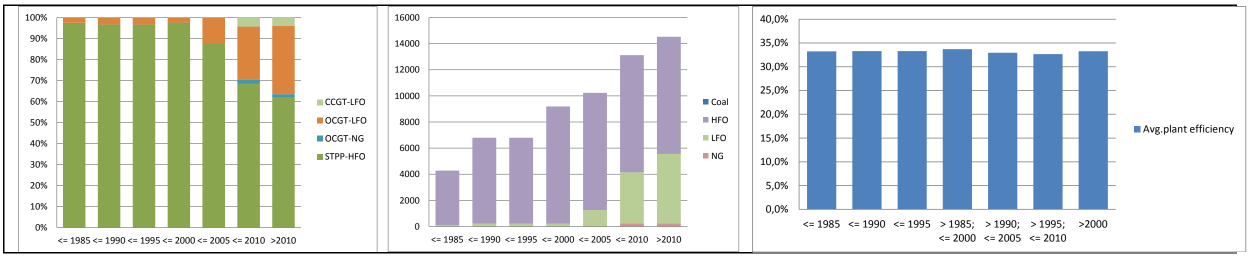


Figure : Additional example 2

One can notice:

- All capacity based on Heavy Fuel Oil (in steam plants) and Light Fuel Oil (introduction of Gas Turbine technology);
- Gas turbine technology mainly under the form of Open Cycle Gas Turbines (OCGT); small share under form of Combined Cycle Gas Turbines;
- Average efficiency essentially flat, indicating similar order of magnitude of efficiency between the steam plants and the OCGT plants.

4 Constraints

The choice of technology and fuel for power generation is obviously more complex than the mere comparison of electricity production cost for different power plant configurations.

Any exercise of choosing the optimum power generation asset must take into consideration a multitude of constraints which are specific to the Project, such as:

- fuel availability;
- fuel logistics;
- HV network configuration;
- requirement for cogeneration (desalination, heat and steam uses for various application);
- demand profile;
- ...

To take into consideration the complexity of all technology options as well as constraints, engineering studies are typically undertaken as a sequence of studies going from ‘global’ to ‘local’, from ‘strategy’ to ‘Project’ :

- At a strategy level, a Generation Plan or Generation Expansion Plan will be studied for a region, country, ... It aims at defining a global strategy of fuel supply and power generation taking into account a global picture of geography, current and forecast power demand, existing power generation, existing infrastructure, … The outcome of such study consists typically of high level mix of fuel type power supply; localisation of power plants; whether to transport the fuel or transport the electricity; fuel logistics; High Voltage network configuration; … The Generation Plan typically has a long forward looking time horizon.

- At the level of an individual project, the same equations hold, but the playing field is narrowed. Location, fuel, plant size, operating point … are fixed; the question at hand becomes a fine-tuning of project structuring and pencil-sharpening to minimize the electricity generation cost.

Uncertainty is a key challenge in all studies:

- A strategy study has to cope with multiple uncertainties, e.g. evolution of demand ; sizing thresholds being achieved which become triggers for implementing specific steps in the strategy (e.g. at which size/time does it become economical to install some infrastructure) ; … The outcome of the strategic study should allow arbitration on strategic choices that are robust to future evolutions, taking into account uncertainties on future demand, constraints on supply, … A certain number of decisions cannot be taken immediately, because of uncertainties. A strategy can be defined under the form of decision tree with pre-defined decision steps / thresholds.
- Project specific study still has some level of uncertainty – e.g. long term evolution of fuel price. Such uncertainty becomes a matter of risk allocation between stakeholders in the project (IPP; merchant versus PPA based; fuel purchase agreement)...

Hence the topic of 'Improving Generation Efficiency of Power Plants in Arab Countries' is vast and complex. The Arab Countries refers to a large number of countries, with widely varying size and features. Different countries have achieved different levels of maturity of optimising generation efficiency on their power systems.

A detailed analysis and reporting for each country is beyond the scope of this paper.

5 Opportunities

Opportunities are also offered by power systems which are beyond the mere optimisation of individual power plants.

Interconnection between countries represents a clear example of opportunity of power system efficiency optimisation.

The energy conservation benefit of interconnections lies in (i) sharing of reserve capacity, hence reducing the overall installed capacity; (ii) benefiting of non-coinciding peaks, hence reducing the overall peak demand; (iii) optimizing the use of generation technology and fuel on a wider basis; (iv) benefiting from Renewable Energies on a wider scale; …

Several interconnected blocks already exist among the Arab countries, but without doubt many further opportunities exist to intensify the benefits of such interconnections.

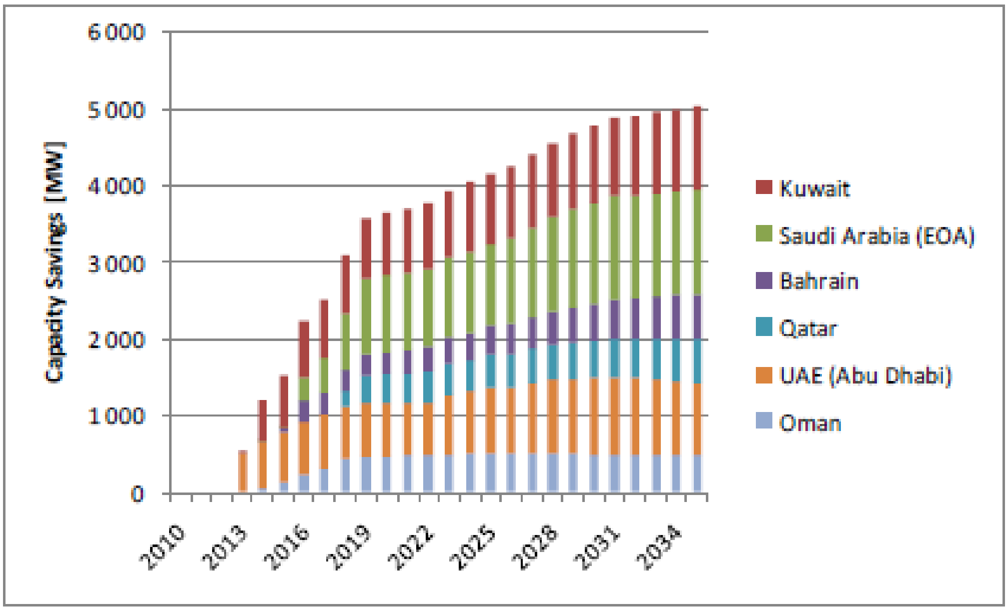
One example of an interconnection study is summarized below. The study was performed by Tractebel Engineering, and quantified benefits of interconnection of the GCC countries.[9]

Significant benefits can be realised due to the Interconnection that links the national power systems of the six Member States of GCC. Benefits are mainly classified into two types: reserve sharing and

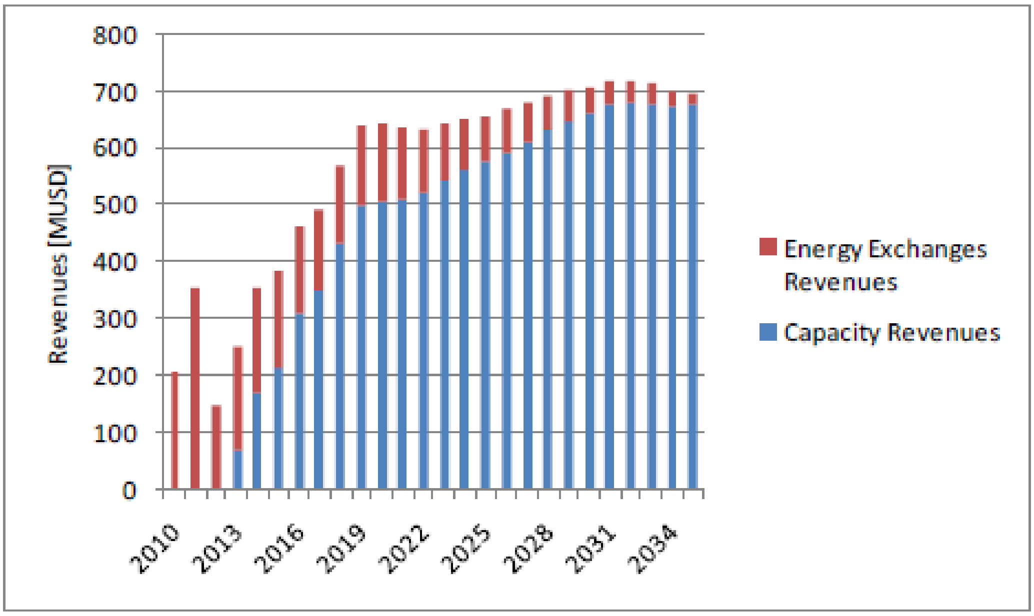
[9] Study results published in GCC Power 2011.

energy exchanges. The first type includes reduction in installed capacity requirements, reduction in spinning reserve requirements and other benefits such as emergency support and reliability benefits. The second type is related to benefits that can be achieved by energy and power exchanges.

Two graphs illustrate the interconnection benefits:



Reduction of Installed Capacity (Capacity Savings in MW) in each Member State due to GCC Interconnection



GCC System – Annual Revenues thanks to the GCC Interconnection

The top graph illustrates capacity savings. By comparing the optimum generation development plans meeting the target reliability level with and without the GCC Interconnection, capacity savings are obtained for each member state. The capacity savings due to the interconnection amount to 1.5, 4.1 and 5.0GW in 2015, 2025 and 2035 respectively. All member states can decrease the amount of installed capacity required while reaching the target reliability level due to the support coming through the GCC interconnection. The slow-down at the end of the study period is due to the fact that, at that time, the capacity reduction for several member states reaches the capacity limit of their link to the GCC grid.

The bottom graph illustrates the sum of the revenues associated with the installed capacity reduction and the revenues associated with the more efficient use of the generation system through energy exchanges. The drivers for the energy exchanges may be found in the differences in the types and fuels of generating units, in the limited installed capacity margin and in the non-synchronicity of the peak demands. The energy exchange is higher near the beginning of the study period and decreases as the share of future (assumed optimised) units in the generation system increases. The technical characteristics of the future units and the fuel costs are the same for each member state and there is therefore no driver for increased energy exchanges.

6 Conclusion

The main purpose of the paper has been to illustrate the past efforts of efficiency improvement over time of a good number of countries. The significant growth of electricity demand over the past decade(s) and hence the need for new installed capacity has provided the opportunity for such countries to adopt the right technological choices, as shown by the steep efficiency improvement trends.

Nevertheless, it is likely that some countries have margin to improve, as they may still bear the legacy of past investment decisions having been taken based typically on subsidized fuel prices. Also, the Arab world is practically the only region in the world that still relies on valuable oil products to generate a significant portion (40%) of its electricity.

The potential for energy conservation is too vast a topic for a paper. It’s the topic for a lot of interesting and challenging development along different axes, one of which is the technical-economic optimisation of fuel supply, power plant configuration and energy infrastructures.

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