The Technical &Economical Impacts of the Upgraded Simple Cycle Gas Turbines Operating on LFO to Combined Cycle Mode Operating on Natural Gas (Rehab Power Plant Upgrading)

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Abstract--**During the first decade of 21st century the electricity demand in Jordan has rapidly increased, the demand growth forced National Electric Power Company NEPCO which represent the system and the market operator of Jordanian power system to make new decisions related to adding new combined cycle power plants CCPP,s and upgrading the existing Rehab gas turbines power plant operated in simple cycle mode on light fuel oil LFO to be operated in combined cycle mode and burning natural gas NG as primary fuel and light fuel oil LFO as secondary back up fuel with additional extra 97 MW capacity.**

After the successful upgrading of Rehab power plant, two combined cycle power plants of 1000 MW capacity (Samra I, Samra II and Amman East CCPP,s) were added during the last four years, and another two CCPP,s of 600 MW capacities (Qatrana IPP, and Samra III CCPP,s) will be added during the next 2 years.

The upgraded Rehab gas turbines power plant (2*30 Mw simple cycle gas turbines and 297 MW combined cycle unit fully operated on natural gas) changed the operational philosophy of the Jordanian power system, such successful economical and reliable operation helped the decision makers in energy sector to increase the electrical capacity produced from combined cycle plants due to their high efficiency, low production cost and low CO_2 and NOx emissions.

The main objective of this paper is to explain and discuss the technical (Plant efficiency), economical (production cost) impacts of the successful upgrading of Rehab gas turbine power plant, and its role in changing hour by hour plans to achieve the most economical and reliable operational scenario of Jordanian electrical power system.

Keywords; combined cycle mode; simple cycle mode;plant effeciency;fuel heat rate

I. INTRODUCTION

The four-gas-turbine units Rehab Power Plant is located in the northern region of Jordan closed to central load area.GT10 (30 MW Unit), GT11 (30 MW Unit), GT12 (100 MW Unit), GT13 (100 MW Unit) were put into commercial operation in 1994, 1995, 1996, 2002 respectively to cover the continuous demand growth. All these gas turbines were operating as peaking units in simple cycle mode burning light fuel oil LFO to generate electricity during morning and evening peak hours or in emergency conditions. In the fact the Transmission System Operator TSO normally avoided to operate these gas turbine units due to their high operational costs and low efficiencies, but in some cases such as tripping of generator or main transmission line, or in case of shortage of power supplied from interconnection systems (Egypt or Syria), the TSO was forced to put them into operation for required duration of time until the system comes back to its steady state condition.

However, because of the need for more capacity, better availability and to reduce CO_2 emissions of Rehab power plant, Central Electricity Generation Company (the power plant owner) decided to upgrade the plant by conversion GT12 and GT13 gas turbine units to operate in combined cycle mode. Such upgrading of the plant included the installation of two heat recovery steam generators HRSG,s, new steam turbine and new electric generator with rated capacity 97 MW, in addition new control and burner management systems were installed to be operated in both types of fuel natural gas (NG) as primary fuel and light fuel oil (LFO) as secondary back up fuel (dual firing).

The major factor for such decision was the provision of natural gas to Jordan from Egypt through the Arab Gas Pipe Line. Since the date of the commissioning time of the second section of the Arab Gas Pipe Line from Aqaba to Rehab (390 km) in March-2005, Rehab GT12 and GT13 together with the new steam turbine started new mode of combined cycle operation on natural gas. This upgrading leaded to change the philosophy of unit commitment and economic dispatch procedures of Jordanian power system. Upgraded Rehab power plant invariably increased the efficiency and reliability of Jordanian power system.

The upgraded Rehab power plant 357 MW represents 10% of the 2650 Mw total installed generation capacity of the Jordanian Power System, which operates totally on natural gas as primary fuel, and it plays important role in the security of 132 kV transmission grid by keeping transmission lines loading in central area within acceptable operating limits taking into consideration (N-1) criteria to ovoid the cascade tripping of 132 kV transmission lines. Also such upgrading gives the TSO high flexibility in operational policy of Hussein Thermal steam units which are operating in expensive heavy fuel oil (HFO).

II. REHAB SIMPLE CYCLE POWER PLANT

In a gas turbine, large volumes of air are compressed to high pressure in a multistage compressor for distribution to combustion chamber. Product gases from chamber power an axial turbine that drives the compressor and the generator before exhausting to atmosphere. The latest gas turbine designs use turbine inlet temperatures of 1500 ºc and compression ratios as high as 30:1 giving thermal efficiencies of 35% for simple cycle gas turbine [4].

Figure (1) illustrates the simple cycle power plant (open cycle) which present the principle of operation for GT10 and GT11 and for GT12 and GT13 before the upgrading.

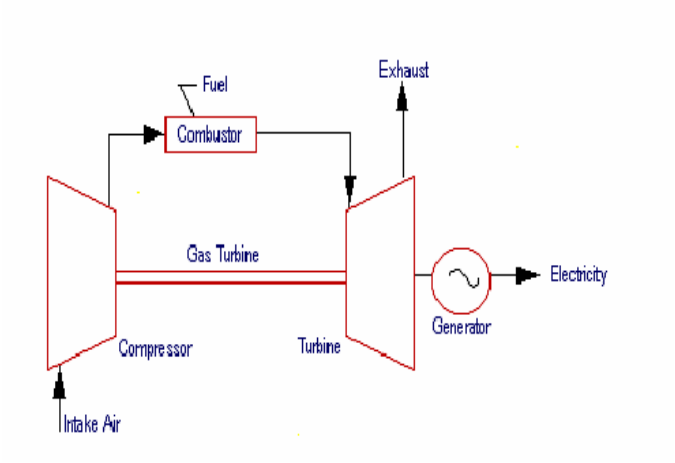

Figure (1)

The four simple cycle gas turbines (GT10, GT11, GT12, and GT13) and all other gas turbines in Jordanian power system were operated as peaking units on light fuel oil (LFO) to cover the load demand during the peak hours. The average efficiencies of these simple cycle gas turbines were: (28.23%, 28.53%, 27.92, 28,11) respectively in 2003 [3].Figure (2) illustrates the daily load curve of Jordanian Power System for typical summer day of year 2002, where it is clearly shown that gas turbines of Rehab power plant shared in covering only the peak loads for few hours (morning and evening peaks) in order to avoid as much as possible the non-economic dispatch of the system [2].

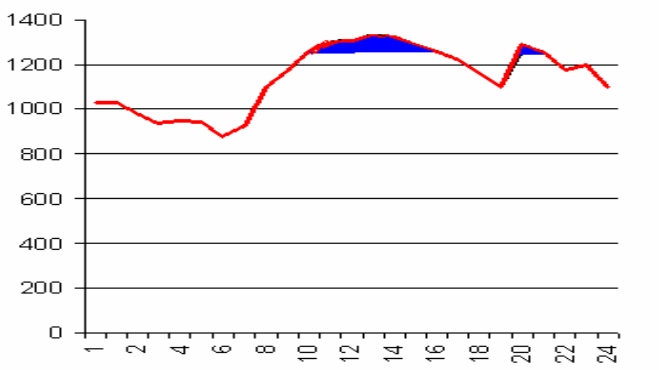

Figure (2) daily load curve 14-08-2002

The average gas turbines heat rates when burned (LFO) were: (14,800 KJ/kWh, 14,724 KJ/kWh, 14,080 KJ/kWh 14,122 KJ/kWh) respectively [3], where after plant upgrading to burn natural gas these average values became (13,028 KJ/kWh, 13,076 KJ/kWh, 13,026 KJ/kWh, and 13,101 KJ/kWh) respectively [3] which means that the plant performance, production cost and plant efficiency have been improved. The average gas turbines production costs when operating on LFO were:(44 Fils/ KWh, 43 Fils/ KWh, 40 Fils/ KWh, 39 Fils/ KWh) respectively referring to the average local LFO prices in 2002 while these average gas turbines production costs have been decreased after upgrading and became (27.3 Fils/KWh, 27.23 Fils/KWh, 28.1 Fils/KWh 28.05 Fils/KWh) respectively referring to the natural gas prices as in the Gas Purchase Agreement [1].

III. REHAB COMBINED CYCLE POWER PLANT

The combined cycle system includes single-shaft and multi-shaft configurations. The single-shaft system consists of one gas turbine, one steam turbine, one generator and one heat recovery steam generator, with the gas turbine and steam turbine coupled to the single generator on a single shaft. Multi-shaft systems have one or more gas turbine-generators and HRSG,s. In terms of overall investment a multi-shaft system is about 5% higher in cost [4].

Rehab combined cycle unit (GT12+GT13+ST) with multi-shaft configuration combines the Rankin (steam turbine) and Brayton (gas turbine) thermodynamic cycles by using the energy stored in the exhaust gases of the two gas turbines (GT12,GT12) for steam generation in the heat recovery steam generators HRSG,s to supply the steam turbine. The heat is produced by burning fossil fuel Natural gas as primary fuel and diesel oil as secondary fuel to produce (297) MW electricity. Figure (3) illustrates the combined cycle power unit which presents the principle of operation for GT12, GT13 and ST turbines in Rehab power plant.

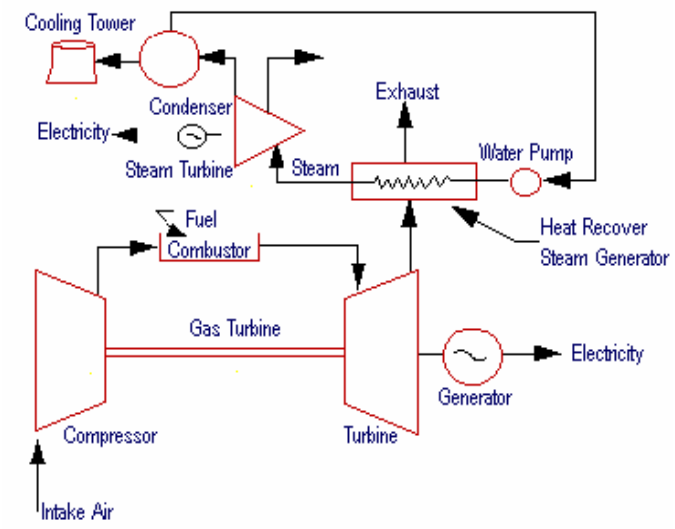

Figure (3)

After the commercial operation in 2005, Rehab combined cycle (GT12+GT13+ST) unit together with two small simple cycle gas turbines GT10 and GT11 started new mode of operation on natural gas purchased from Egypt through Arab Gas Pipe line. Since that time the operational policy of Rehab power plant completely changed, where the new combined cycle unit occupied the first order in economic dispatch program, and became the most economic generation unit operating at base load. The main concept in power system operation is the availability of generated power to ensure continuous electric power supply to the consumers taking into consideration the secure and economic supply. The upgrading of Rehab power plant to be operated in combined cycle mode added new advantages to the Jordanian power system:

- High flexibility in scheduling the maintenance program of the generating units of Jordanian power system due to the additional extra power 97 MW produced from steam part of the combined cycle.

- High flexibility in commitment of Hussein thermal steam units which burn an expensive heavy fuel oil (HFO) with average production cost 120 Fils/KWh referring to the present fuel prices. Before this upgrading TSO was forced to commit one or more of these units even during non-heavy loading days (spring and autumn seasons), where such operational policy leaded to increase the average generation cost of the whole power system.

- The total transmission system losses have been decreased due to the location of Rehab power plant near of the central load area instead of transmit the electrical power from far southern area (Aqaba steam power plant and Egypt) over long 400 kV transmission lines. It was defined by simulation that 100 MW generated from Rehab power plant is equivalent to 102 Mw purchased from Egypt, which means 2 MW reduction in the electrical losses.

- The probability of cascade tripping of 132 kV transmission lines in central area after the tripping of Rehab-Zarqa 132 circuit has been sufficiently decreased, which improved the capability of the power system to avoid voltage collapse phenomenon. Before Rehab power plant upgrading and due to the high cost of generated power from gas turbines operating on LFO and from Hussein thermal steam units operating on HFO, the double circuit 132 kV transmission line connected both power plants were in overload condition in case of tripping one of both circuits.

- The maintenance time duration has been decreased and maintenance management has been improved, which leaded to minimize the total maintenance cost and increase the Rehab power plant availability, where the availability performance indicators for GT10, GT11, GT12, GT13, and for combined cycle unit were 98.44, 98.56, 74.85, 99.48 and 86.98 respectively in 2008 [3].

- The spinning reserve has been increased which improved the power frequency characteristic and frequency regulation of the Jordanian power system in steady state conditions and after disturbances.

The capital cost for constructing combined cycle power plant is lower than of constructing steam thermal power plant with the same capacity. The start up time, shut down time, start up fuel are lower for combined cycle comparing with steam thermal power plants. Also the use of renewable sources (wind farms or solar energy) is very expensive at the present time. In the term of capital cost it is better to go to the combined cycle option.

The total natural gas quantities required for the operation of Rehab combined cycle unit on base load (297 MW) is equal 58800 MMBTU (57 MMSCF) which is equivalent to 8.16 MBTU/MWh, the merit order of the combined cycle plant occupied the first order after this upgrading in 2005, figure (4) shows the daily load curve for typical summer day 16-08-2005 where the Rehab combined cycle contribution in economic dispatch program is shown. At the present time and after the commercial operation of Samra I and Samra II combined cycle power plant of 600 MW and Amman East combined cycle plant of 370 MW Rehab combined cycle unit occupied the third order in economic dispatch schedules.

Table (1) shows the comparison between the economic dispatches of the generating units in Jordanian power system during the morning peak hour of the summer day 16-08-2005,

where the peak hour profit due to the upgrading reached around 13000 JD.

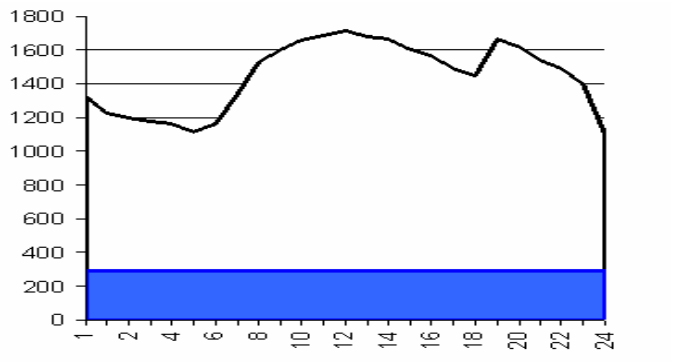

Figure (4) daily load curve 16-08-2005

Table (1)

STATION	RISHA	REHAB CC	REHAB GT DEISEL	ATPS	HTPS 66 MW
MW	50	297	0	650	260
MW	50	0	260	650	260
	HTPS33 MW	EGYPT	GTS	SYS LOAD	ADD COST
	85	300	68	1710	JD/H
	85	300	105	1710	13068

After upgrading the efficiency of Rehab combined cycle unit (GT12+GT13+ST) improved and reached in average 44%, the average heat rate also improved and reached in average (9500) KJ/KWh or 8.16 MBTU/KWh, and the average production cost is decreased to 18 Fils/KWh.

Rehab combined cycle can operate in different transitions; full combined cycle mode, half combined cycle mode and simple cycle mode. These possibilities gave the Transmission System Operator TSO high flexibility to be matching with system requirements such as emergency maintenance for Rehab thermal units or in case of natural gas quantities limitation or during the load limitations on other units in the power system.

The two simple cycle gas turbines GT10 and GT12 are operating on natural gas as primary fuel since 2005, the average production cost has been decreased (from 44 Fils/KWh to 27 Fils/KWh) in year 2005 for GT10 and GT11 respectively and (from 39 Fils/kWh to 28 Fils/KWh for GT12 and GT13 referring to the LFO prices in 2004, but if we take into consideration the current LFO prices in year 2010 the production average cost will decreased (from 130 Fils/KWh to 28 Fils/KWh) [2].

IV. CONCLUSIONS

The upgrading of Rehab simple cycle gas turbines GT12 and GT13 from the simple cycle mode burning an expensive light fuel oil LFO to combined cycle mode burning natural gas NG as primary fuel and LFO as secondary back up fuel (dual firing system) increased the total efficiency of Rehab power plant and minimized the average production cost for Rehab power plant individually and for an overall production cost of Jordanian power system, which leaded to change the daily dispatch and unit commitment procedures applied by TSO, and decreased the emission of gases (CO_2 and NO_x) in the atmosphere. This successful upgrading leaded to encourage the decision makers to increase the power plants operated in combined cycle mode and burning natural gas up to 48% of the total installed generation capacity until 2009, and this contribution shall increase in the next years. At the present time the international fuel prices are so high and it is strongly recommended to use natural gas instead of fuel oil for power generation, and upgrade the existing simple cycle gas turbines to be operated in combined cycle mode.

REFERENCES

[1] "Natural Gas daily Quantities Report" National Electric Power Company 2005-2010.

[2] "Generation production daily report" Central Electricity Generation Company 1996-2010.

[3] "Central Electricity Generation Company annual report" 2008.

[4] "A Course in Electrical Power" SONI. GUPTA and BHATNAGAR.