Repowering Study Using PEPSE®

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ABSTRACT

The paper presents the use of PEPSE® by the Israel Electric Corporation (I.E.C.) for the investigation of repowering alternatives of aged fossil power plants.

Boiler and turbine models previously built for the existing power plant were used under Special Option 11.

Some of the computational difficulties and solutions found by I.E.C. are discussed in detail.

Results of the repowering study itself are partially presented too.

INTRODUCTION

The Israel Electric Corporation is the designer of its own electricity generating power plants. All of them are using fossil fuels (coal ; oil ; natural gas), most are of dual fuel design.

The Mechanical Engineering Department has been assigned the task of investigating in detail several repowering alternatives for some of the oldest plants. A team responsible for process modeling had to calculate the basic technical data for each alternative. A team responsible for boiler related problems had to check specific data (pollutants concentrations, metal temperatures, flame stability a.s.o).

The present paper refers mainly to the work of the process modeling team, using the PEPSE® computer program. The results have been calculated for a 75 MW, single reheat, oil and gas fueled unit.

INVESTIGATION GOALS AND STAGES

In order to select the best repowering alternative, a total cost-for-unit -lifetime had to be calculated (including : investments ; operating costs ; a.s.o.).
Two kinds of data had to be estimated : performance and equipment (modifications, new).

In order to reach these goals the following stages had to be completed :

1. Plant process optimization for NCR (normal continuous rate). This optimization had to end up with the highest attainable plant performance.

2. Partial load performance estimate. This step had to detect the operating changes (if) required for low loads.

3. Analysis of new operating conditions for the existing equipment.
   Some of the existing equipment will have new working conditions very much different from the original design (see : feed water heaters). The investigation had to outline prohibitive operating conditions.

4. Estimate design data of new equipment.
   Some alternatives require several new pieces of equipment (fans ; ductwork ; valves a.s.o.). A first estimate of their main design data had to be made at this stage.

Performance data obtained at the first two stages were fed into a computer program estimating the future electric power plant best (economically) loading distribution.

The equipment data resulting from stage 3 and 4 have been forwarded directly for pricing (including installation and maintenance works).

REPOWERING ALTERNATIVES

Three basic alternatives had to be investigated :

1. hot windbox
2. feed water heating
3. full cycle repowering

Although these solutions are well known [1], [2], we shall describe them shortly.

Alternative 1 : hot windbox repowering - fig. 1.

A gas turbine -new- (1) supplies high temperature and oxygen content flue gases to the furnace -existing- (2). The furnace is fueled with the same fuel as the gas turbine -existing- (3). The condensate and feed water flows are divided between the original heaters -existing- (4) and two new ones (5) having flue gas on the hot side. Depending on the gas turbine flue gas composition a supplementary air fan -new- (6) might be necessary.

Alternative 2 : feedwater heating repowering - fig. 2.

This alternative is very much like alt.1. However : no fuel is supplied to the furnace. The flue gases are used only for the feedwater and/or the condensate heating. Depending on the gas turbine flue gas flow a by-pass ductwork -new- (7) might be necessary.

Alternative 3 : full cycle repowering - fig. 3

A gas turbine -new- (1) supplies high temperature and oxygen content flue gases to a HRSG unit-new (2). This unit can have supplementary firing. The HRSG produces steam at two pressure levels and supplies it to the steam turbine -existing- (3). Pressures and temperatures at superheaters outlets are determined by turbine blading limitations. Some of the existing feedwater and condensate heaters (4) might be used. Depending on the gas turbine flue gas flow and composition a by-pass ductwork -new- (7) and/or a supplementary air fan -new- (6) might be necessary.

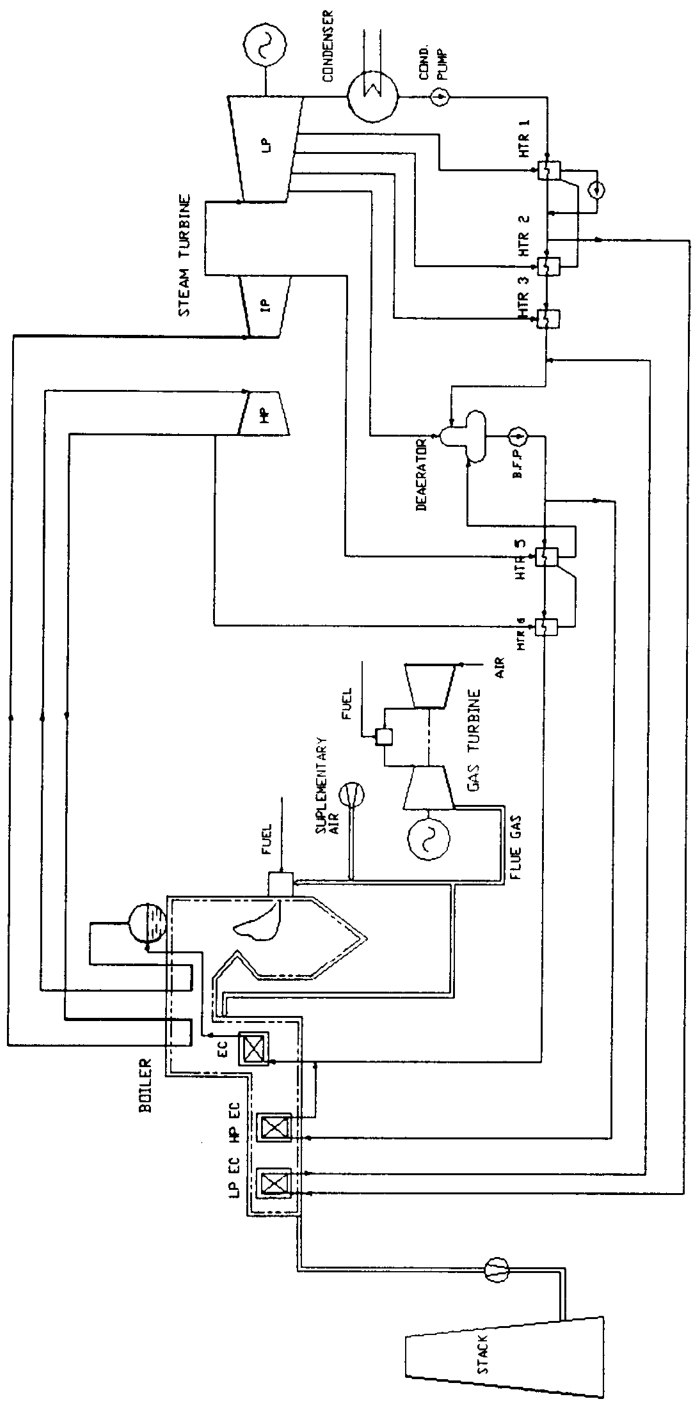

FIG. 1. BOILER WINDBOX REPOWERING

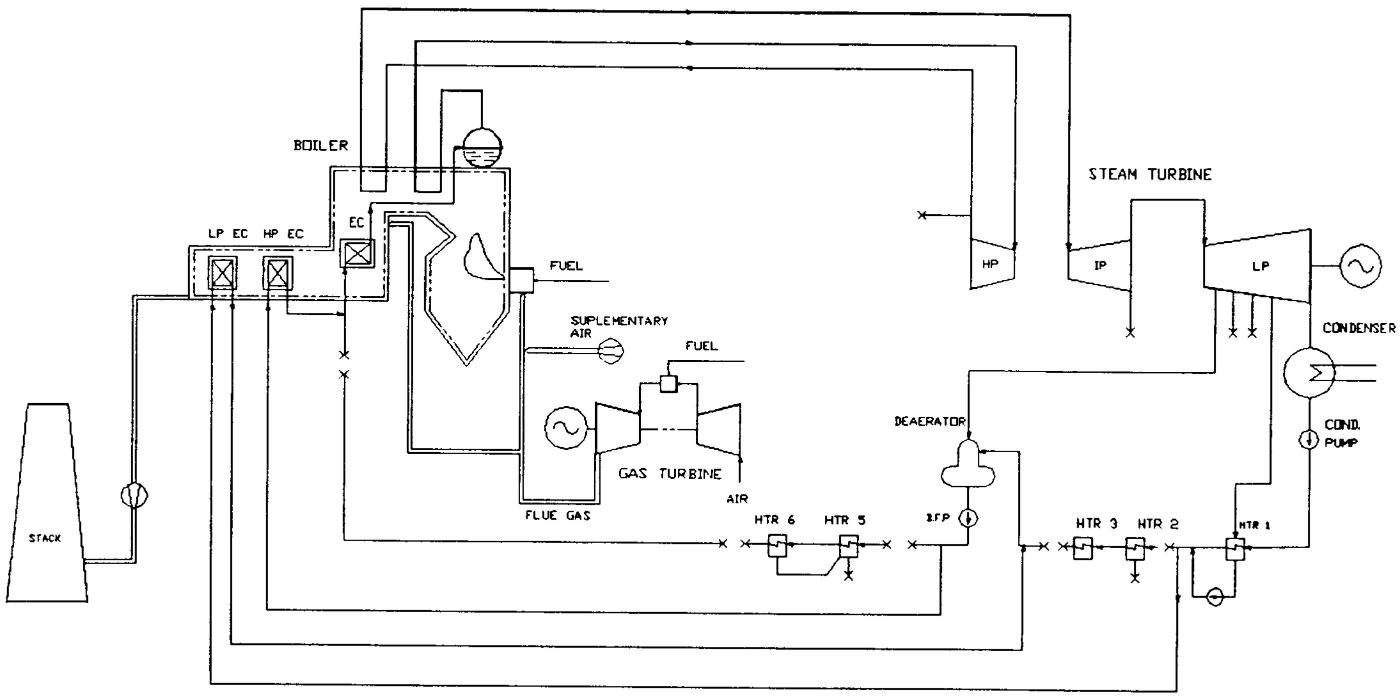

FIG. 2. FEEDWATER HEATING REPOWERING

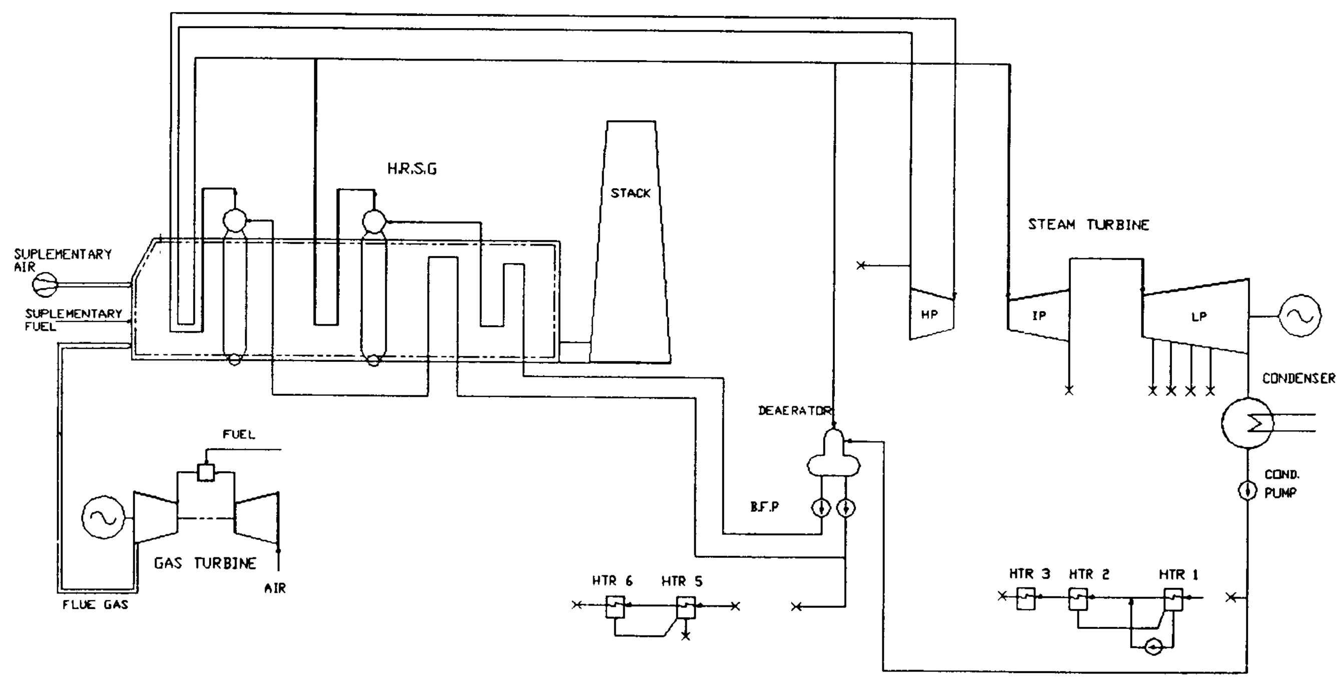

FIG. 3. HEAT RECOVERY REPOWERING

COMPUTATIONAL MEANS

1. The PEPSE-PC ver. 58.G program has been run on a PC-486 computer. Although version 60-H (for windows) has already been installed, we preferred to use the older version for three main reasons :

   a) Both the boiler and the turbine models were developed with the older version and required no modifications.

   b) Special Option 11 (SO11) which allows two models to be run together, is more user-friendly in the older version.

   c) The tight time-schedule for the repowering study did not allow for sufficient training with the new version.

2. The 75 Mw power plant units had already the boiler and the turbine models in operation. Both models have been built according to the vendors' data sheets for the main equipment and the existing ducts and piping.

   The components in the models were in "design" mode, or calculated their performance according to vendors' curves. For ducts and piping special operations were written for pressure loss calculation. The models have been run also under SO11.

   Most of the calculation have been made for a given steam turbine load (S03). The boiler model had the flue gas parameters input (from the gas turbine data sheet) and exchanged data with the steam turbine model. (see : spray flows, superheater and reheater outlet pressures and temperatures, a.s.o.)

The two new heaters (condensate/flue and feedwater/flue) were first designed (approximately) and then run in “design” mode. They are modeled as... economizers.

The heat transfer coefficients for the convective type heaters have been separately tuned for oil and for gas firing.

3. For alternate 3 an HRSG model (new) has been built. It is currently being run together with the turbine model (existing) under SO11. Because of its complexity the HRSG, its components could not be “added” to the turbine model.

COMPUTATIONAL ISSUES

The process modeling team has run into several computational difficulties. Some have been solved -nicer or uglier !- but some cannot be solved but through a tight cooperation with NUS. To our best knowledge none of the following issues has been eliminated in version 60-H [3].

All the next issues have their origin in the alternate 1 and 2 investigation.

1. Limited number of connections between two models (6).
   For several modeling cases the needed number of connections exceeded the PEPSE® allowed one.

   For example : alternate 1 has two sprays ; two water/flue heaters ; steam converter ; main steam ; hot reheat.

   Each of these items need one connection between the models. It did not seem reasonable to build a third model only for the steam converter alone, for example.

   For the work itself, we simply made some approximations and left the steam converter out.

2. Connections between models allow only water/steam.
   Since the connection points between the models do not allow any gases to flow through, we were forced to build the water/flue heaters into the boiler model. This situation complicated to some degree the water distribution optimization. It appears to us that this limitation can be easily overcome.

3. Automatic plant efficiency calculation.

   Special Option 11 allows for the run of several models together. It has a key role in power plant calculations including boiler and turbine models. We feel that an automatic plant efficiency calculation is strongly needed. Since all the data are available in the output of both models (after "NORMAL TERMINATION") they can be easily combined to give a "NET" and "GROSS' plant efficiency. This calculation could be triggered only for a two-model (boiler and turbine) situation.

4. Automatic stack-effect calculation.

   The stack-effect has been modeled using a set of Operations associated with a special stream and a fan component. It appears that a new component could simplify the modeling by providing the user with an automated calculation based on geometry, flue gas temperature, ambient temperature.

   The new component could offer a reasonable choice of liners, connections a.s.o.

5. Attemperator mixer "switch-off" and its convergence criteria.

   We made several attempts to use this component for the superheater and reheater spray flow calculations, however we run into the following difficulties :

   - For the cases where small spray flows were needed, the attemperator was "switched-off" (i.e. spray flow set to zero) during the iterative calculation and - remained so for all the next iterations.

   - In some cases the prescribed outlet temperature has not been reached with an acceptable precision, although "NORMAL TERMINATION" has been reached. It looked as if the attemperator internal controls have been "switched-off" again for some reason.

We did overcome these difficulties by using a simple mixer and a control for each spray. For the cases where the final solution did not require spray we manually forced the control to converge.

Although several control on-off switching methods have already been described [4] none of them are automatically available to the user's choice (in the "Menu"). As for the convergence criteria of the attemperator mixer, it might be helpful to the user to have direct access to it.

6. Furnace component ports.
Alternative 1 and 2 require the feeding of the furnace component with high oxygen content flue gases. Fuel has to be fed according to the boiler load. In some cases support air is required.

The inlet port (IA) allows only air into the furnace (see :0_2 ; N_2 ; H_20).

The inlet port (IX) allows any gas into the furnace but 0_2 and H_20 are not accounted for in the combustion equations [3-Vol 2, Engineering model description p15-4÷15-8].

We had to build a rather cumbersome operation set which separates 0_2; N_2 ; and H_20 from the flue gases. Theses elements, mixed with the support air were directed to port (IA). The other gases went to the (IX) port.

An extension of the combustion equations to include the 0_2 ; N_2 ; H_20 elements from the (IX) port could be a solution.

7. Pollutants calculations.

The combustion calculations of the furnace component do not include NO_x calculations or any other polluting components. Since the pollution control has become a major issue, an improvement of the combustion set of equations in this direction is becoming more and more necessary. At least two-three major pollutants should be calculated. Even it the precision is not high, a trend and a base for further calculations could be obtained.

This data, required by the repowering investigation, have been calculated by another computer program, specialized in boiler/furnace simulation.

8. Special Option 11 convergence control.

The extensive use of SO11 has revealed some specific convergence problems. Several cases showed an overall oscillation although each model converged separately.

The amplitude of the oscilations were diminished by tighter convergence criteria for the superheater and reheater spray controls. However, beyond a certain level no further improvement could by reached. The initial values of the spray flows appear to have an important influence too.

For alternative 1 and 2, gas fueled, the total spray flow (superheater - reheater) can reach very significant percentages of the feedwater how (≈18% for some cases). This can lead to important boiler load changes from one S011 iteration to the other. We could not find a systematic way of improving the decay of these oscillations and ensure the overall convergence.

REPOWERING STUDY RESULTS

We have selected some of the results obtained for alternative 1 in order to underline the key position of these calculations for further economic evaluations and operating decisions.

Several commercially available gas turbines were used as flue gas sources. Generated power ; fuel consumption ; flue gas temperature, flow and composition at different loads were known for these turbines and input in our models.

For each of them the condensate and feedwater distribution has been optimized both at NCR and at partial loads.

Some of the gas turbines had such high flue gas flows that it was possible to connect one of them to two steam generating units.

Table 1 presents some of the most significant data obtained for oil firing and for gas firing. Table 2 shows the requirements for the main equipment items.

Some interesting remarks can be made even at this early stage of the study :

- The high flue gas temperatures reached at the stack inlet when firing oil ask for either a high cost coating of the new stack or an upper load limit (less than the NCR shown in table 1).
- The configuration of the plant (one gas turbine with one or two steam units) cannot be decided at this stage, without economic evaluation.
- Much of the existing steam generating unit remains in operation.
- A detailed investigation of the effects of low loads operating for the feedwater and condensate heaters is necessary.

Table 1. Performance Data for Alternative 1

Case	Steam	Flue	Water Distrib.		Fuel Cons.		Add.Air	Flue Gas at Stack		Power Plant
Name	Units	by-	CD	FW	Boiler	Gas	(Tair=35 C)	(from two units)		Efficiency
	No	Pass				Turbine		Temp.	Flow	
		%	%		t/hr		Nm3/hr*10^3	C	Nm3/hr*10^3	%
OIL FIRING, 73 MW										
E1	2	NO	60	60	15.85	7.374	112.9	211	618.48	37.53
E2	1	NO	60	60	14.10	6.378	0	221	632.88	38.51
E3	1	NO	60	60	15.75	4.98	93.2	216	622.08	39.58
E4	2	NO	60	60	15.93	7.817	106	199	594.00	40.31
NATURAL GAS FIRING, 73 MW										
					Nm3/hr	t/hr				
E9	2	NO	60	50	17684	7.374	95.3	175	568.08	38.46
E10	1	10	60	50	15887	6.378	0	203	647.28	39.19
E7	1	NO	60	50	17080	4.980	71.9	181	575.28	40.49
E8	2	NO	60	50	17775	7.817	96.5	175	570.96	40.27
NATURAL GAS FIRING, 45 MW										
E13	2	NO	50	40	10790	7.374	30.4	200	---	---
E14	1	34	50	40	9712	6.378	0	240	---	---
E11	1	NO	50	40	10292	4.980	7.7	205	---	---
E12	2	NO	50	40	10829	7.817	31	199	---	---

Table 2. Equipment requirements for hot windbox repowering

Main Equipment	Requirements for repowering
Steam turbine	None
Main condenser	None
Boiler feed-pump	None
Feedwater heters	None
Condensate heaters	None
Boiler heat transfer surfaces	None
Burners	Changed
I.D. Fan	Changed
H.P. Economizer	New
L.P. Economizer	New
Stack	Changed
Boiler exhaust ductwork	Changed
Feed water piping	Changed
Plant load control	Changed

CONCLUSIONS

A repowering study needs a detailed simulation all the existing power plant elements. PEPSE® has proved to be a very useful and efficient tool in executing the basic calculations of this study. Some possible improvements of the program have been singled out too.

REFERENCES

[1] Repowering Reheat Units With Gas Turbines, EPRI AP-5216, Virginia Power, Richmond Virginia, May, 1987/

[2] Design Possibilities and Performance of Combined Cycle Operation of Converted Steam Power Plants, M.J.J. LINNEMEIJER, J.P. BAN BUIJTENEN, ASME paper 88-gt-178.

[3] PEPSE Manuals 1-4 for ver. 60-H NUS corporation, 1995.

[4] On-Off Switching of PEPSE® CONTROLS ; G.L. Minner, Performance Software User's Group Meeting Proceeding, June 21-24, 1994.