Predicting Turbine Efficiency Changes Using the Steam Turbine Redesign Evaluation (STRE©) Program

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Predicting Turbine Efficiency Changes using the Steam Turbine Redesign Evaluation (STRE[1]) Program

Abstract

The Steam Turbine Redesign Evaluation (STRE[1]) program was developed by Encotech, Inc. to allow steam turbine owners establish how a turbine will operate at off-design conditions.

STRE gives utility and engineering personnel a quick and efficient means of calculating changes in unit performance as a result of off-design conditions such as:

- lower inlet steam temperature and pressure as a result of geothermal resource losses,
- running with a row of blades missing while waiting for replacement parts, or
- plugging turbine extractions in order to repower using a heat recovery steam generator (HRSG)

This paper describes history and development of Encotech's STRE software, how STRE was used in each of the above cases, and how STRE can benefit the power generation industry.

The speaker is Shawn Whitecar, an Encotech engineer.

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Introduction to STRE

Encotech, Inc. initially developed the Steam Turbine Redesign Evaluation program for in-house use in evaluating the design of steam turbines for our customers. As a result of recent work for an electric utility that operates a large geothermal site, STRE has undergone additional development and is now available for sale to the power generation industry.

STRE is designed to assist steam turbine owners calculate the effect of operating at off-design conditions. Such off-design conditions may include:

- lower inlet steam temperature and pressure as a result of geothermal resource losses,
- running with a row of blades missing while waiting for replacement parts, or
- plugging turbine extractions in order to repower using a heat recovery steam generator (HRSG).

STRE Program Organization and Application

STRE is designed to give a detailed evaluation of the impact on performance of changes in steam turbine design. Figure 1 diagrammatically shows the organization of STRE.
The first step in using STRE is to create a base case. A base case is created by entering information such as turbine inlet conditions, exhaust conditions, shaft speeds, blade heights, root diameters, and nozzle exit areas. Based on the information entered, STRE predicts the turbine flow passing capability and performance. If actual flow and power output is known, the predicted performance and flow passing capability is adjusted to meet actual conditions.

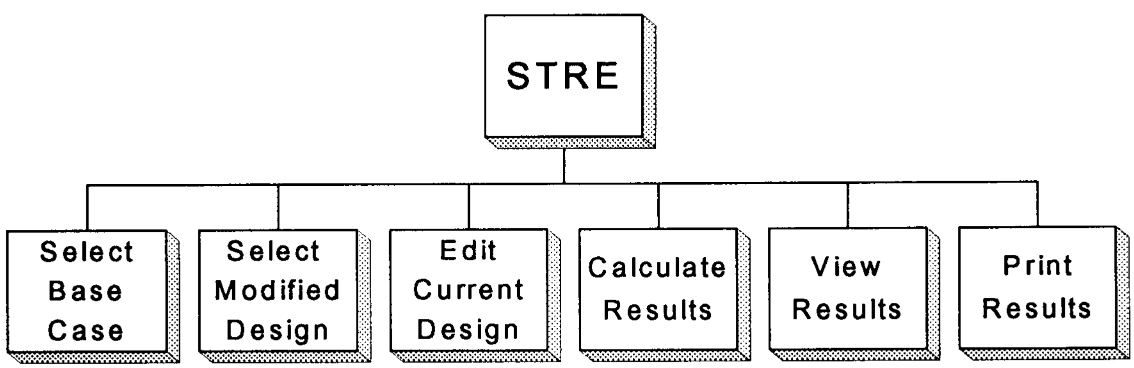

Figure 1. STRE organization.

Once a base case exists, a modified case can be created. A modified case is used to predict the impact of design changes on turbine performance. The user has the option of removing stages, changing nozzle area, plugging extractions, etc. The intent in making these modifications is to evaluate the specific impact on turbine performance. STRE is not a heat balance program. Heat balance programs such as PEPSE[2] or FCYCLE[3] can be used to complement the abilities of STRE by providing tools to evaluate changes in the cycle outside of the turbine.

Results are generated for each base and modified case by selecting the "Calculate Results" option. Results include items such as flow, stage moisture, stage efficiencies, and unit output. Figures 2 provides an example of STRE results for the overall turbine. Figure 3 provides an example of STRE stage-by-stage results.

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Encotech STPE - Redesign.........06/03/1994......................VIEW RESULTS
Fossil Unit 4                                                   Final Results


         Generator Output (KW)............................ 266693.59
         Expansion Line End Point (BTU/LBM)................. 1262.20
         Used Energy End Point (BTU/LBM).................... 1263.24
         Annulus Velocity (FT/SEC)........................... 311.04
         Shaft Output (KW)................................ 270930.66
         Mechanical Loss (KW)............................... 1018.52
         Generator Loss (KW)................................ 3218.55
         Gear Efficiency (%)................................. 100.00
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Figure 2. STRE overall results.

Case Studies

Three units were modeled for analyses and are presented in this paper:

- A 118 MW four flow geothermal unit,
- A 50 MW straight condensing unit to be utilized in a combined cycle repowering, and
- A 300 MW fossil unit missing an entire blade row while awaiting replacement parts.

Geothermal Unit

The geothermal unit modeled is a 118 MW four flow unit designed by Toshiba for steam inlet conditions of 100 psig and 355 F. As the pressure and temperature of the resource steam

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[2] Copyright, Halliburton NUS Corporation.

[3] Copyright, Power Software Associates.

begin to decline, there will be less available energy in the steam due to a lower starting enthalpy. STRE allows the user to quantify the expected decrease in output.

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Encotech STPE - Redesign.........06/03/1994.......................VIEW RESULTS
Fossil Unit 4                                                 Efficiency Results
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Ln	Stg No.	Avail. Energy (BTU/LBM)	Used Energy (BTU/LBM)	Stage Eff. (%)	Avg. Moist (%)	Corrected Stage Eff. (%)
1	0	0.00	0.00	0.00	0.00	0.00
2	1	20.27	16.82	82.97	0.00	82.97
3	2	17.21	14.92	86.70	0.00	86.70
4	3	16.93	14.76	87.18	0.00	87.18
5	4	18.54	16.13	86.99	0.00	86.99
6	5	17.40	15.25	87.65	0.00	87.65
7	6	19.40	16.97	87.46	0.00	87.46
8	7	16.18	14.22	87.86	0.00	87.86
9	8	19.39	17.07	88.01	0.00	88.01
10	9	16.85	14.79	87.75	0.00	87.75

Figure 3. STRE stage-by-stage results.

This allows forecasting changes in the unit output due to changes in the resource. Figure 4 shows a graph of the expected changes in output and unit steam rate versus changes in inlet pressure for saturated steam. This figure shows that output goes down as the inlet pressure declines as would be expected. A drop of 10 psi results in a decrease in output of 12,037 KW.

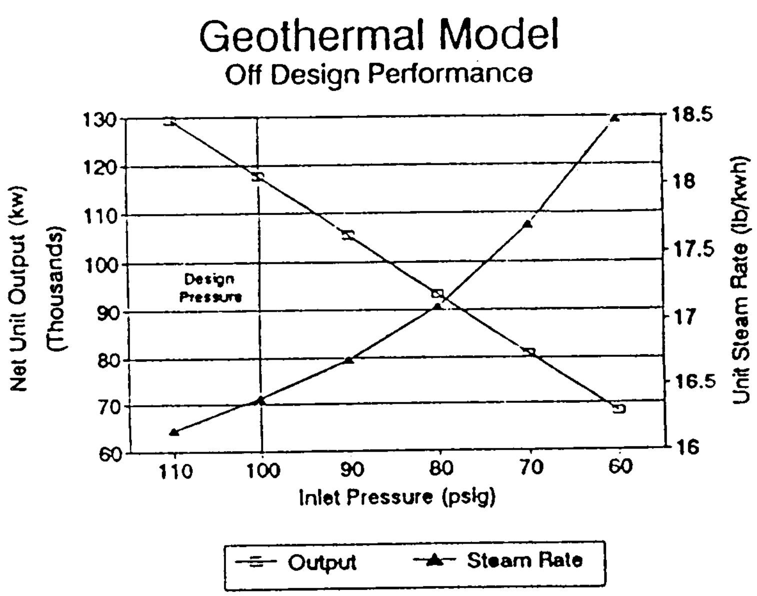

Figure 4. Geothermal unit performance.

STRE can also be utilized to determine if changes in the exhaust pressure, or modifications to the steam path, would help restore the loss in output. Modifications, such as removing a stage, could increase the steam flow through the turbine, resulting in a recovery of lost output. For example, if the first stage of the turbine is removed when the inlet pressure has dropped to from 100 psig to 70 psig, the flow would increase, causing the net unit output to increase from 80,768 KW to 111,956 KW, restoring the loss caused by the initial drop in pressure. Removal of a stage will require additional steam flow, further increasing the unit steam rate.

Repowered Unit

The unit modeled for repowering is a 1940's era General Electric straight condensing unit. The unit is a 60 MW single flow unit with 6 heater extractions. Inlet steam conditions are 1200 psig and 800 F. The unit is to be utilized in the repowering of a power plant in a combined cycle configuration using a heat recovery steam generator (HRSG). The HRSG will supply steam to the turbine inlet at the same conditions as the design case. The feed water heaters will not be used with the HRSG, and the extractions will be plugged. Plugging of the extractions will result in a higher mass flow rate through the latter stages of the turbine, because all of the flow will be passed through to the condenser instead of being extracted for feedwater heating. STRE can be used to estimate the output of the unit due to the effects of the plugged extractions.

Note that STRE will not determine the structural ability of the turbine to pass extra flow in the latter stages without deformation or damage. A complete engineering assessment should be conducted prior to making any changes to the turbine geometry.

The original design of the unit had a calculated output of 59,762 KW on a throttle flow of 1,050,885 lb/hr and an exhaust flow of 800,221 lb/hr. Plugging of the steam extractions results in a calculated output of 67,980 KW on a steam flow of 1,045,088 lb/hr, which is an increase in output of 13.75%.

Fossil Unit

The fossil unit model is based on a 270 MW non-reheat Westinghouse unit. The unit consists of a combined HP-IP casing, with a single flow LP. Inlet steam conditions are 2400 psig and 1320 F.

STRE was used to assess the loss in output of running the unit without the first row of rotating blades. This scenario could be the result of a significant blade failure. Without the availability of replacement blades a decision on whether to run the unit without the row and reopen it when the replacement parts are available will need to be made. STRE allows the owner to forecast the output of the damaged unit, giving the owner the information needed to make an economic evaluation of the different repair options available.

The design unit had a calculated output of 267,657 KW, while the unit missing the first blade row had a calculated output of 255,362 KW for similar throttle flows. This loss is a 4.5% drop in the total output of the unit. By applying operating costs, capacity factors, replacement lead time, and unit opening and closing costs, planners can make repair decisions based on the economic evaluation of the options.

Conclusion

STRE provides turbine owners and utility personnel with a quick and effective way to evaluate changes in turbine performance as a result of off-design conditions. STRE can be used to evaluate the impact of diminishing geothermal fields and help to the assess different ways of recovering lost output including increasing stage areas and removing stages. STRE can be used to estimate the change in output caused by plugging one or more extractions. STRE can be used to help evaluate repair options including the loss of a row of blades.

About Encotech

Encotech, Inc. is located in Schenectady, NY. Encotech, Inc. maintains a core staff of licensed professional engineers supported by design, technical, financial, and secretarial services. This staff provides services in software design and development for the power generation industry. Software products sold by Encotech include: The STPE[1] family of programs for evaluating the performance of steam turbines, the Cogeneration and Energy Planning Program (CEPP[1]), the Steam Cycle Diagnostic Program (SCDP[1]), and the Turbine Generator Maintenance Optimization Program (TGMO[1]).

Encotech, Inc.'s sister company Encotech Engineering, P.C. provides engineering consulting services. Some of Encotech Engineering, P.C.'s services include: rotating machinery design and analysis, failure analysis, forensic engineering, finite element analysis, and vibration monitoring.