Thermal Performance Indicators (TPI) Monitoring and Reporting Enhanced Using PEPSE

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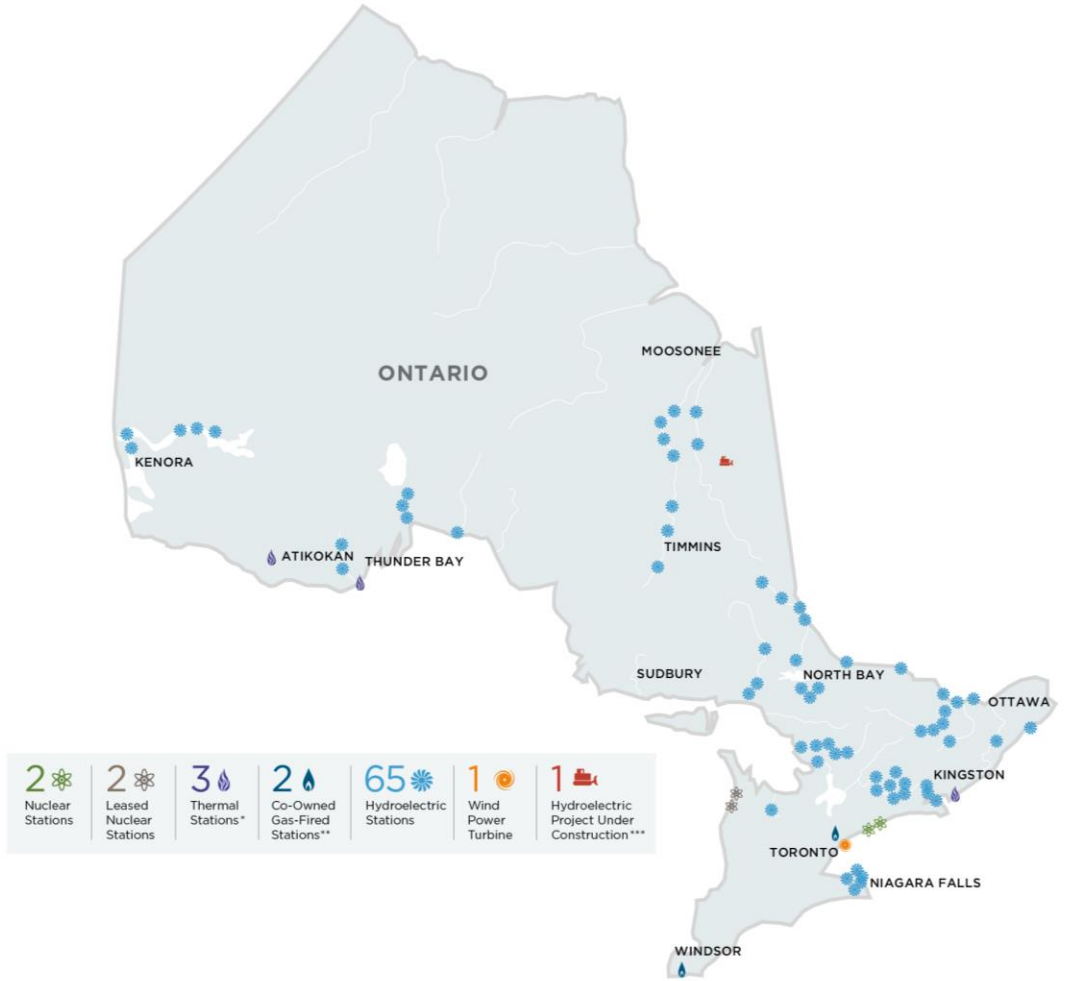
OPG - Who and Where We Are

- Ontario's clean power producer
- Approx. 17,000 MW generating capacity
  - 65 hydro, 3 thermal (including 2 biomass), 2 nuclear stations
  - 2 co-owned gas-fired stations
- 2 nuclear stations leased to a private generator
- Produce about 50 per cent of Ontario's electricity
- About 9,200 regular employees
- Over $44 billion in assets
- Moderate overall price of power



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Clean, Reliable, Low-Cost

- Province's clean energy provider – more than 99% free of smog and greenhouse gas emissions.
- Produce majority of power homes, hospitals, schools, businesses rely on every day.
- Provide consumers with lower cost power than other generators.
- Our profit goes back to the province.
- Investing hundreds of millions in clean and renewable power.
- Successful closure of our coal stations represents North America's largest single climate change initiative.
- Strive to ensure efficiency, value for money.

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The Company We are Today

- Our history includes more than 100 years of operation.
- Commitment to public, environmental and employee safety.
- Values set out in a Code of Conduct – safety, integrity, excellence, people and citizenship.
- Building long-term mutually beneficial relationships with Indigenous communities.
- Enjoy strong relations with site communities.
- Focused on continuous improvement and development in project management and operational excellence.
- Environmental Management System registered to ISO 14001 standard.

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Nuclear Operations - Darlington

- One of the top-performing nuclear stations in the world.
- Four-unit station with a total capacity of 3,512 MW.
- Serves about 20 per cent of Ontario's electricity needs – or a city of two million people.
- In 2015, OPG received a 10 year operating licence for Darlington from the CNSC– the longest ever granted to a Canadian nuclear power plant.
- OPG Nuclear is rate regulated through a transparent, public process.

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Nuclear Operations - Pickering

- Six operating CANDU reactors.
- Total output of 3,100 MW, enough to serve a city of 1.5 million people.
- Recognized across the industry for safety.
- In 2015, Pickering supplied about 14 per cent of Ontario's power while achieving its highest level of reliability.
- In 2013, Pickering's operating licence was renewed for five more years of operation.

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Introduction – TPI Program

- TPIs including Thermal Performance Indicator (TPI), Turbine Cycle Efficiency (TCX), the Condenser Vacuum Efficiency (CVE), Thermal Power Error (TPE), and Non-Productive Load (NPL) are monitored and reported routinely (three times a week).
- As a Scientific, Engineering and Safety Analysis (SESA) software for engineering support, it should be SESA certified. National standard CSA N286.7 and company procedures applies.
- Independent TPI calculations are executed to cross check the results.
- Two methods: Curve-method; PEPSE-method
- Performance analysis and MW accounting will be performance engineer's focuses.
- TPI Program Automation and historical performance database are required. All features including PEPSE OLE automation are integrated together using convenient Excel spreadsheet.

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Key TPI Calculations

- Thermal Performance Indicator (TPI)

$$\text{TPI} = \frac{\text{Actual overall unit efficiency}}{\text{Design overal unit efficiency}}$$

- Turbine Cycle Efficiency (TCX) and MWe Loss

$$\text{TCX} = \frac{\text{Actual turbine cycle efficiency}}{\text{Design turbine cycle efficiency}}$$

- Condenser Vacuum Efficiency (CVE) and MWe Loss

$$\text{CVE} = \frac{\text{Patm} - \text{Pcnd}}{\text{Patm} - \text{Pdesign}}$$

- Thermal Power Error (TPE) and MWe Loss

$$\text{TPE} = \frac{\text{Measured Reactor Power (by DCCs)} - \text{ActualReactor Power (Calorimetric Heat Balance)}}{\text{Actual Reactor Power (Calorimetric Heat Balance)}}$$

$$\text{MWe Loss} = (\text{TPE} \times \text{Reference Reactor Power}) \times \text{Reference Unit Overall Efficiency}/10000$$

- Non-Productive Load (NPL) and MWe Loss

$$\text{MWe Loss} = (\text{Actual NPL prorated to }100\% - \text{Reference NPL}) \times \text{ActualTurbine Cycle Efficiency}/100$$

Data Collection – DCC Data

- Calorimetric test
  - ✓ Controlled test (as steady as possible) performed three times a week
- DCC
  - ✓ Dependent on the Digital Control Computer (DCC) system to retrieve required data (around a hundred measurement points)
  - ✓ Data validation
- Interfaces
  - ✓ Input the Dates corresponding to the calorimetric test. DCC data will be updated for the time corresponding to the test.

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Data Collection – Manual Inputs

- Correction factors
  - ✓ The total feedwater flow
    - Deaerator Mass and Energy Balance (DAMEB) tests carried out every four years
    - Ultrasonic flow measurements annually
  - ✓ Feedwater temperatures, reheater drains flow and temperature
    - Precision measurements using calibrated instruments.
  - ✓ The above values are used in deriving the boiler thermal power, which is an input into the PEPSE model.
- Corrections applied to DCC measurements when suspect measurements cause the PEPSE models to non-converge

Curve Method – Thermal Performance Curves

- Generator Terminal Output (GTO) vs net boiler power
- GTO vs CCW inlet temperature at 100% FP
- GTO vs condenser pressure at 100% FP
- Condenser pressure vs CCW inlet temperature at 100% FP
- A general polynomial relationship to represent the curves
  - ✓ $Y = A7*X^7 + A6*X^6 + A5*X^5 + A4*X^4 + A3*X^3 + A2*X^2 + A1*X^1+A0$
    - Where Y = calculated result of the function
    - X = function variable

      A0 to A7 = coefficients

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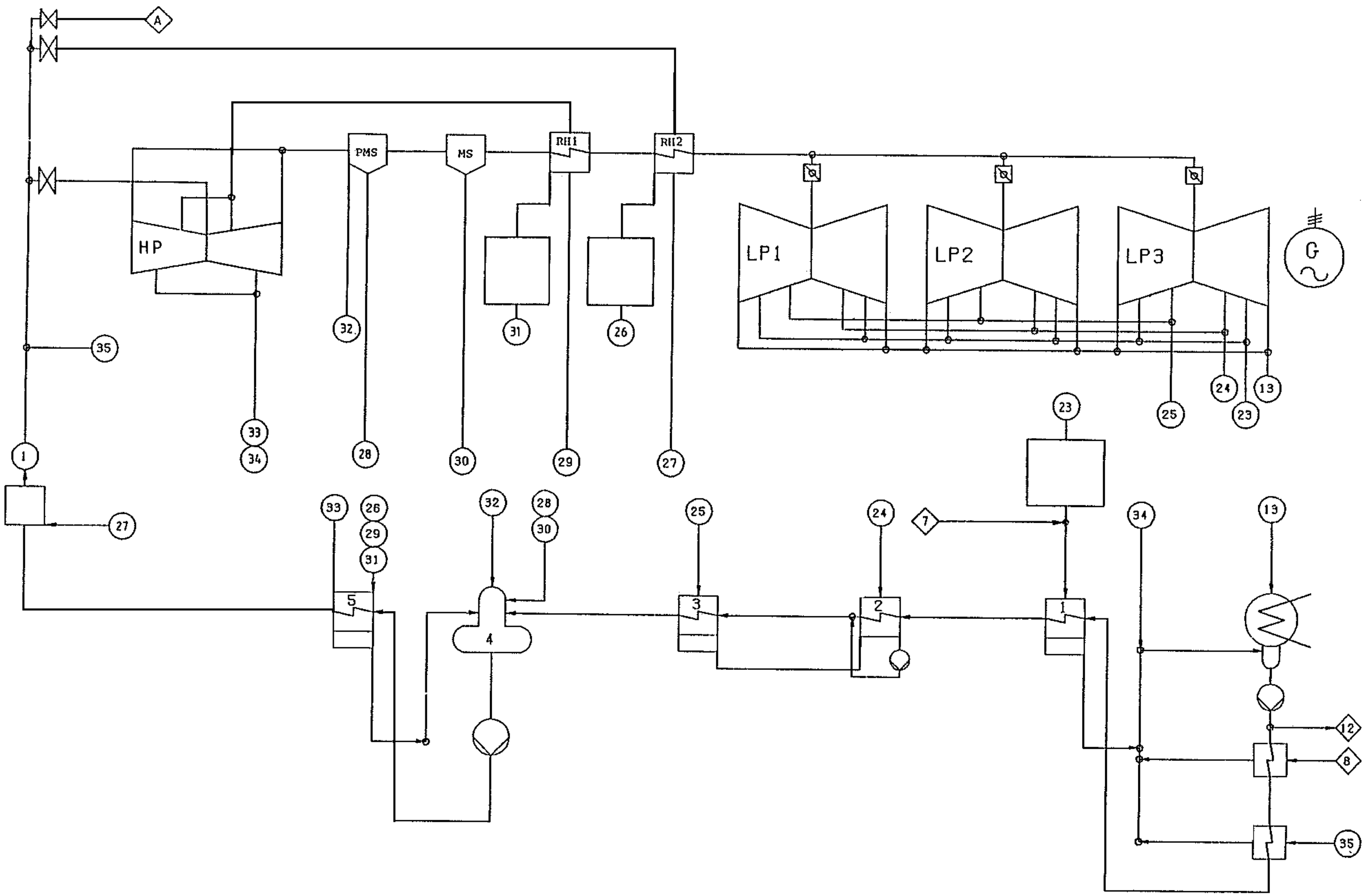
PEPSE Method – Simplified Turbine Cycle



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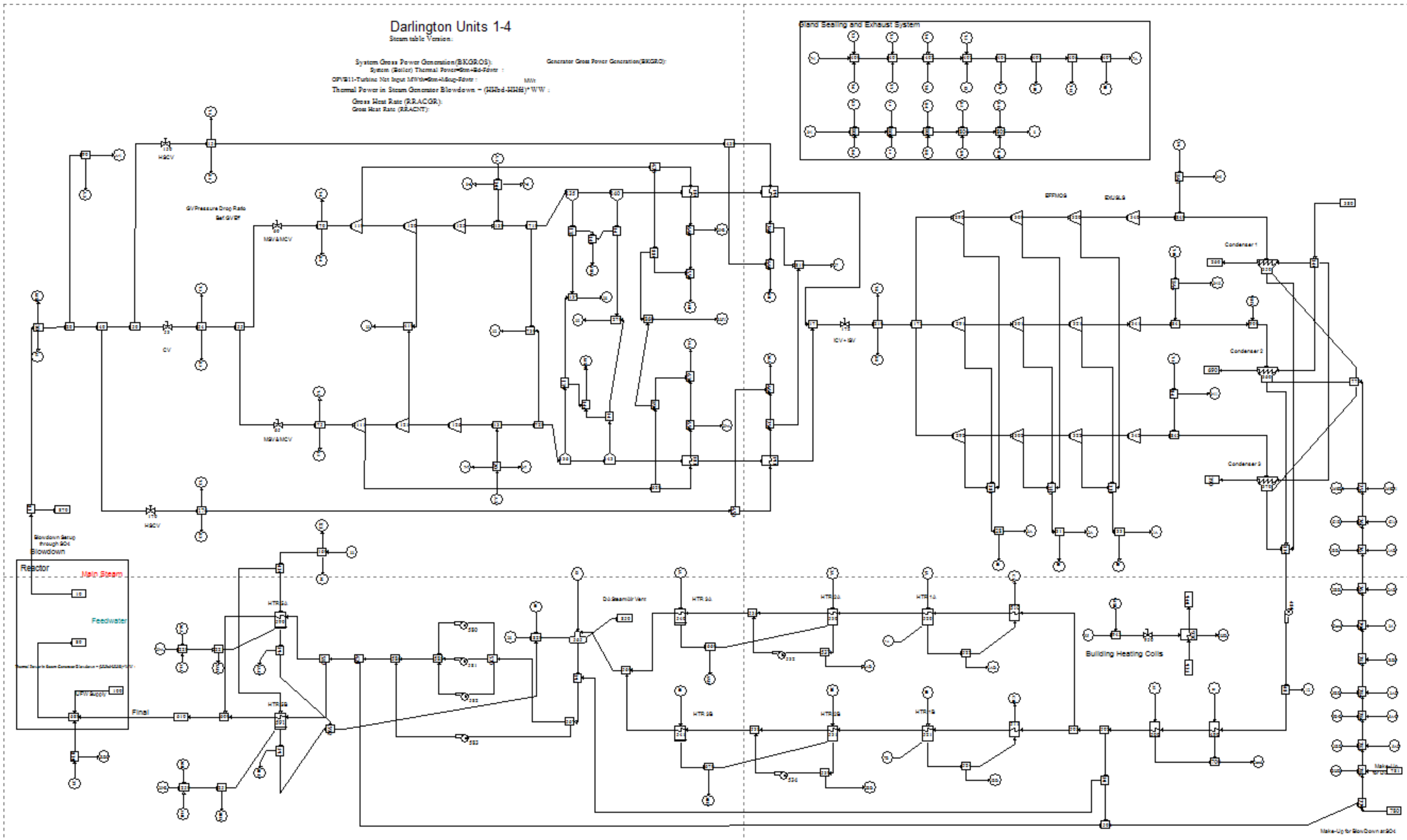
PEPSE Method – PEPSE Model



PEPSE Method – PEPSE Model Sets

- Five cases to simulate different plant conditions with different boundary conditions

Case #	Case Description	Purpose
1	Performance Mode	- Simulate the design turbine cycle using PEPSE Performance mode - Based on the design heat balance .
2	Design Mode	- Simulate the design turbine cycle using PEPSE Design mode.. - Tune unit performance to actual reference of output of 932.6 MWe, lake water temperature of 12 °C, condenser pressure of 5.04 kPa, reactor power at 100% FP
3	Design Mode (TCX)	- Simulate of the design turbine cycle using the Design Mode with the exception of the condensers, which is in the performance mode, at the defined station measured condenser pressure. - Use the simulated output in the TCX calculation
4	Design Mode (TPI)	- Simulate the design performance of the turbine cycle. - Use the simulated output in the TPI and CVE calculations
5	Performance	- Simulate actual performance of the major components at conditions including process steam consumption and equipment out of service through setting up a series of controls

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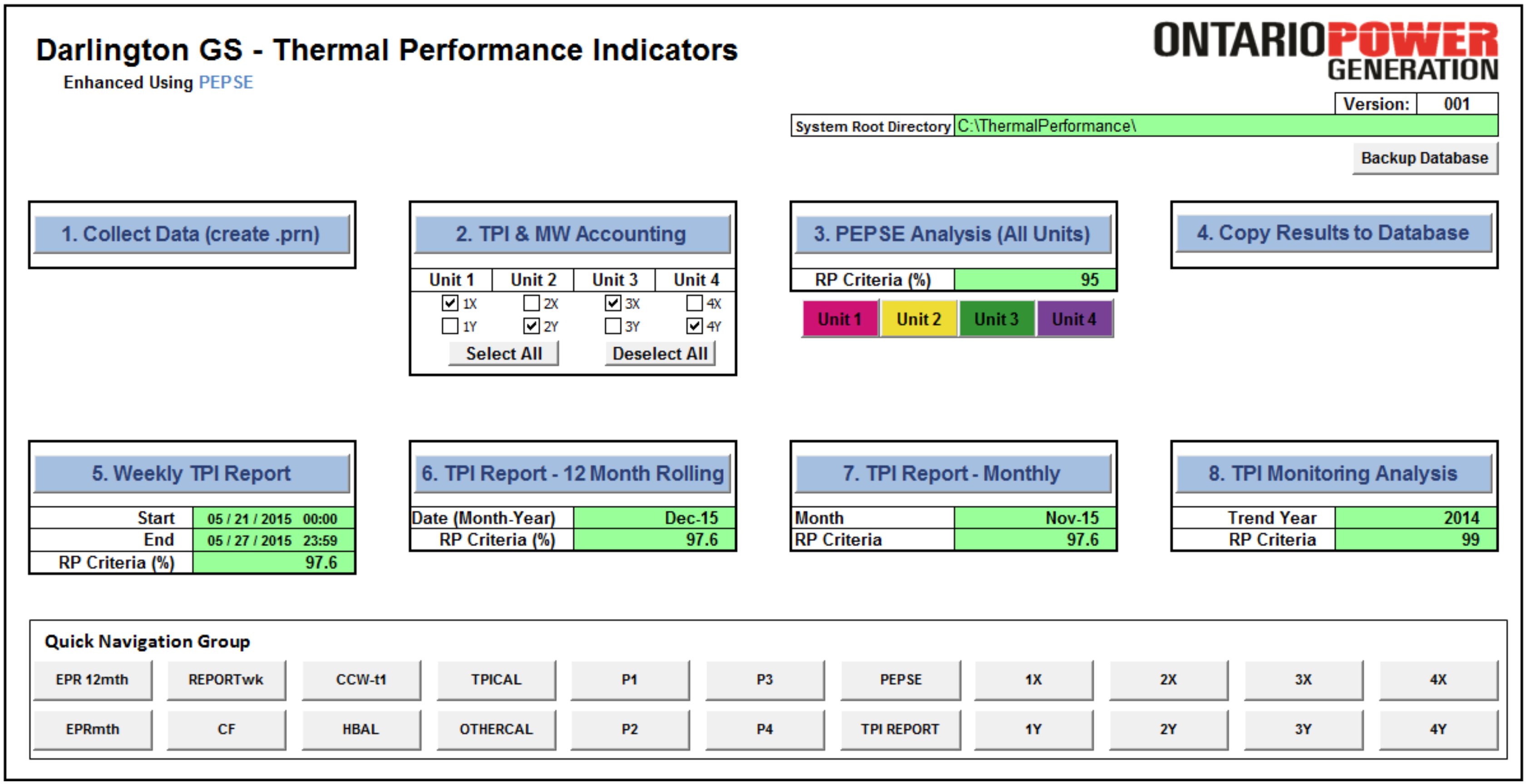
PEPSE Method –

Object Linking and Embedding (OLE) Automation

- The use of PEPSE is automated through the spreadsheet program for the routine calculations.
- The PEPSE five cases used for TPIs calculations are automated.
- The automation controller (Microsoft Excel) uses a scripting language Visual Basic for Applications (VBA)
  - ✓ Collect data
  - ✓ Send data to a PEPSE model
  - ✓ Run model calculations
  - ✓ Show model results
  - ✓ Save data and results to database
  - ✓ Use steam tables

User Interfaces

The execution time for the software is expected to be typically in the order of a few minutes, for reporting occurring once a week.



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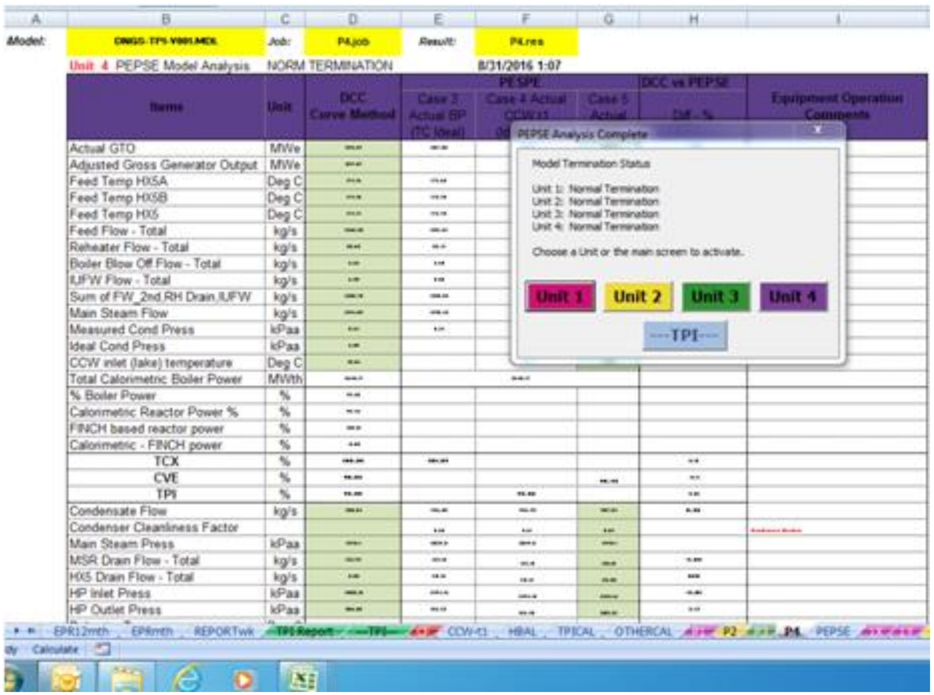
Execution of PEPSE Analysis

The execution time for the PEPSE analysis for all for units is about 40 seconds.



Execution of PEPSE Analysis

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Results and Data Storage, Trend Plot

- Spreadsheet databases
  - ✓ Calculated results and input data
    - Current database - save all the data of the most recent five years
    - Historical database – save all the years data
- Trend plots – monitoring, analysis
  - ✓ All raw data
  - ✓ Calculated results
  - ✓ The X-axis & Y-axis
    - a time or any other data points of the database.

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Output Report

- **TPI Weekly Report - the key output of the software**
  - ✓ A summary of the key thermal performance indicators
  - ✓ Megawatt loss accounting,
  - ✓ Condenser ball cleaning updates
  - ✓ Actions assigned to each unit to recover the lost megawatts.
- **Colour-coded grading for the calculated TPI, TCX, CVE, TPE, NPL**

Indicator	Green Excellent	White Nominal	Yellow Marginal	Red Unsatisfactory
TPI	TPI ≥ 99.5%	99.0% ≤ TPI < 99.5%	98.5% ≤ TPI < 99.0%	TPI < 98.5%
TCX	TCX ≥ 99.75%	99.5% ≤ TCX < 99.75%	99.0% ≤ TCX < 99.5%	TCX < 99.0%
CVE	CVE≥99.75%	99.5% ≤ CVE < 99.75%	99.0% ≤ CVE < 99.5%	CVE < 99.0%
TPE	-0.25% ≤ TPE≤ +0.25%	-0.50% ≤ TPE≤ -0.25% Or +0.25% < TPE≤ +0.50%	-1.0% ≤ TPE< -0.50% Or +0.50% < TPE≤ +1.0%	TPE< -1.0% Or TPE> +1.0%
NPL	NPL≤ +0.1%	0.1% < NPL≤ +0.3%	0.3% < NPL≤ 0.5%	TPE> 0.5%

- **TPI Report Example**

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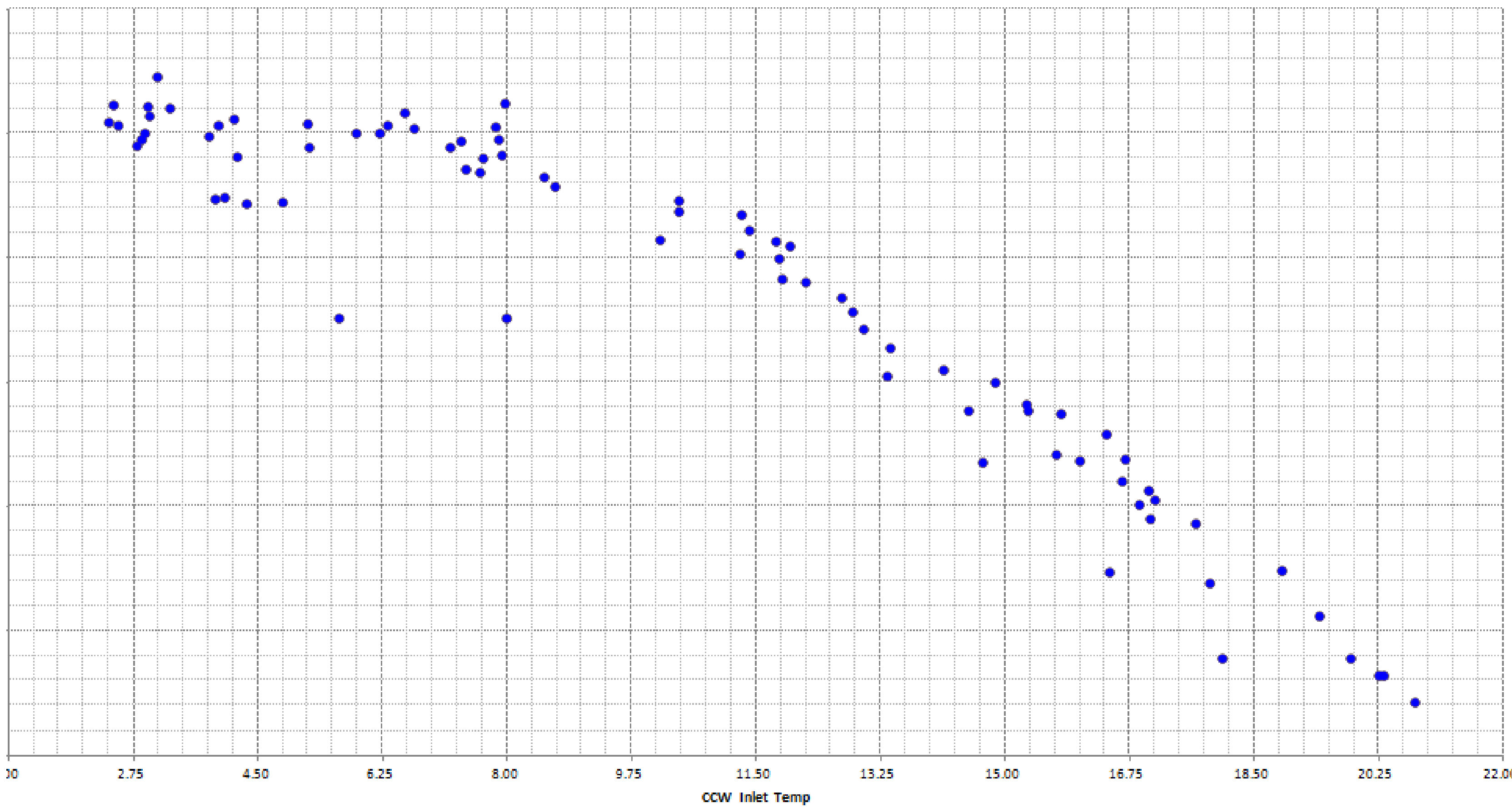
PEPSE Application

PEPSE Expected MWE @Actual CCW t1 and actual BP-Case 5



Software Attributes

- Functionality
  - ✓ Executed on Standard Windows7 Office Computer
- Reliability
  - ✓ 100% reliable when station LAN is available
- Usability
  - ✓ Require minor training
- Maintainability
  - ✓ Performed in the Microsoft Excel interface as well as VBA coding
- Portability
  - ✓ Require the station Windows 7 LAN environment.

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Main Interfaces

- System Interfaces
  - ✓ DCC system, PEPSE software
- User Interfaces
  - ✓ Manual inputs including correction factors, dates, etc
- Hardware Interfaces
  - ✓ Minimum standard issue Windows 7 Office Computer
- Software Interfaces
  - ✓ Microsoft Excel embedded with VBA as well as PEPSE model

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Thanks!