Transformers Health Management
and
Condition Monitoring System

Product Description

August 2019

Table of Contents

Acronyms

ABN	Abnormal Gas Rate, an index of the extent of (abnormal) deviation of the transformer gas creation rate from normal rate (as determined by CIGRE).
CI	Critical Infrastructure
CT	Calculated Temperature
CSV	Comma Separated Values file type
CVS	Corporate View Screen
DB	Data Base
DGA	Dissolved Gas Analysis
DOT	Direct Oil Temperature
EPRI	Electric Power Research Institute
FA	In cooling systems, Force Air, Oil Natural
GIC	Geomagnetically Induced Current
GSU	Generator Step Up transformer
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IR	Infra-Red
KVA	Kilo-Volt Ampere
NLTC	No Load Tap Changer
mHLS	mPrest Homeland Security
MW	Mega-Watt
NEI	Normalized Energy Intensity, a new analysis method for transformers
OA	In cooling systems, Oil Natural, Air Natural

OLTC	On Load Tap Changer
OPS	Opening Screen
PD	Partial Discharge
ppm	Parts per million
PTX	Power Transformer Expert, analysis system developed by EPRI
PVS	Plant View Screen
RFI	Radio Frequency Interference. Also, the name of the sensor that measures RFI.
SCADA	Supervisory Control and Data Acquisition, a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management
SQL	Structured Query Language
SOP	Standard Operation Procedure
Tank	Main oil tank of the transformer
TDCG	Total Dissolved Combustible Gases = the sum of H2, CO, CH4, C2H6, C2H4, C2H2
TDHG	Total Dissolved Heating Gas = the sum of CH4, C2H6 and C2H4
Transfix	Online DGA system manufactured by GE
TVS	Transformer View Screen

1 Introduction

Power transformers (GSU, ATO) are mission critical components in the operation of energy utilities. Transformer failure can have a severe adverse effect on generation, transmission and distribution operations, resulting in negative customer experience. This could cause financial, operational, perceptional and environmental damage. Energy utilities use a variety of different methodologies to monitor the status and health of their transformers, based on industry best practices and research. These methodologies are a combination of various measurements aggregated from SCADA systems, as well as load and temperature measurements, and the most common practice of Dissolved Gasses Analysis (DGA).

With no methodology being definitive, different utilities not only need to choose which one to use, but also how to apply them. For example, how often to sample the various indicators, and how to interpret the results. Incorrect interpretations, resulting in false-positives or false-negatives have a significant financial impact on operations, should a "healthy" transformer be shut down, or a failing one left working and is damaged. Due to the significant impact of a power transformer failure, they warrant real-time monitoring of various parameters including load, oil temperature, temperature rise, vibration, dissolved gases, and more.

mPrest's Transformer Health Management (THM) system is a near real time transformer health monitoring system for determining and managing the health of power transformers, detecting abnormalities and providing alerts when adverse events are predicted. The THM product belongs to mPrest's Asset Health Management product family.

mPrest's THM introduces a first-of-its-kind solution. Based on mPrest's orchestration and optimization, system-of-systems infrastructure, the system aggregates information from multiple sensors, and uses advanced analytical algorithms to give operators a near real-time indication of their transformers health, as well as predicting failures. THM's predictive capabilities allow utilities to avoid transformer malfunction, failure and blowouts that may have detrimental effect on utility's standing.

mPrest's THM system collects various relevant parameters (load, oil temperature, temperature rise, vibration, dissolved gases, and more) and analyzes the data in near real-time to detect anomalies and conditions that could lead to failure or impairment of the transformer's ability to remain in service, or warrant maintenance or repair. The system presents clear, easy to understand visualization of chosen matrix of standards, validates the data and produces alerts for anomalies or thresholds. The system also follows up on maintenance actions performed and can evaluate which actions should be taken based on actual system status.

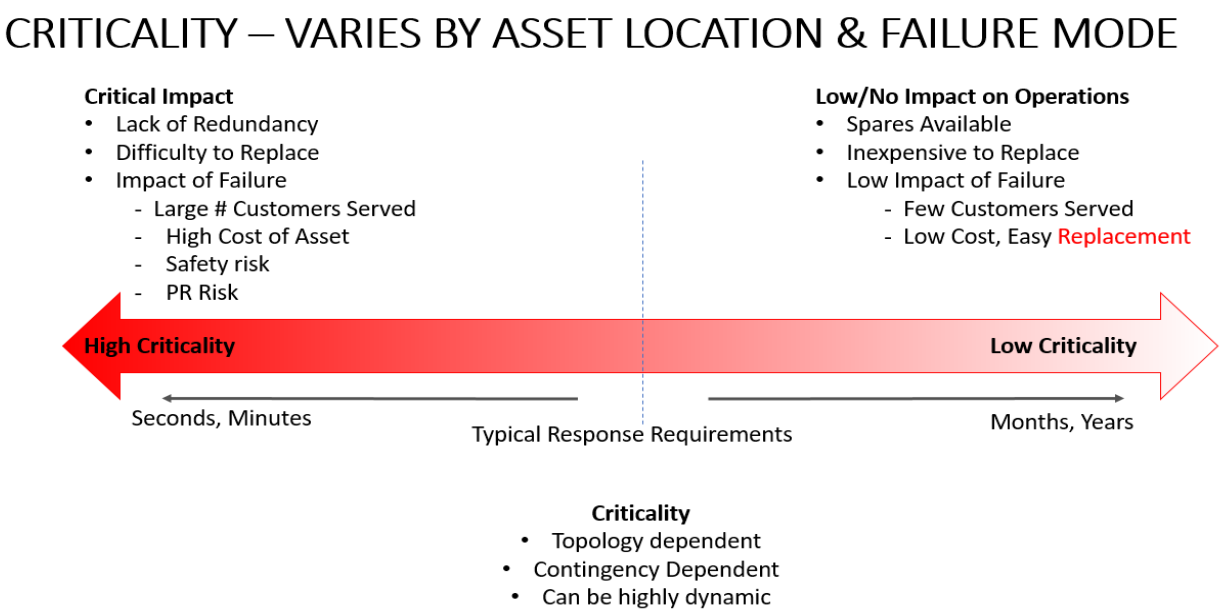


Figure 1: Asset Criticality

Implementing mPrest's THM system will reduce risk of malfunction or failure of an essential part of the utility infrastructure and would help optimizing operations, finance and environmental footprint.

2 Functionality

2.1 Application Views

In order to monitor easily the current situation of the grid and infrastructure, mPrest built an intuitive dashboard, presenting all relevant metrics across the grid. Different dashboards can be viewed based on pre-defined permissions. The application is accessible to approved users from a standard Web browser interface. Navigation is performed using general views and drill downs.

2.1.1 Corporate View

The home screen of the THM application is a corporate map view, indicating the overall network with general status indicators and elements. An example of the Corporate view is indicated in **Figure 2**.

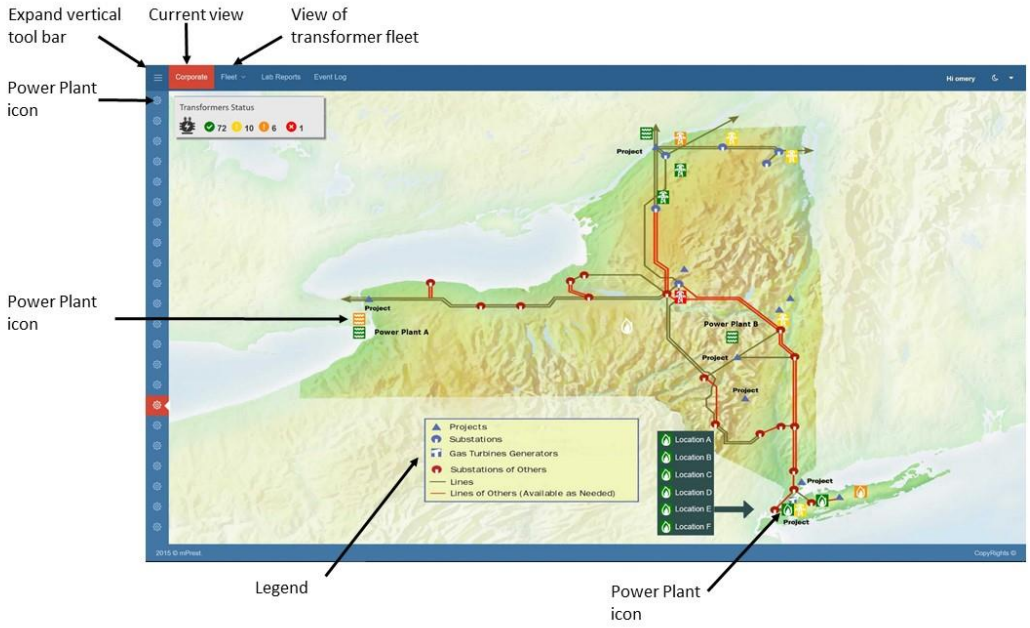


Figure 2: Corporate View

The corporate view shows the location of power generating sites, indicated by clickable icons presenting the state of the least stable transformer at each plant site:

Icon[1]	Color	Significance
,	Green	All transformers at the site are in normal operational condition.
,	Orange	There is a warning of mid-severity for one or more transformers at the site.
,	Red	There is a high severity alert for one or more transformers at the site.
,	Gray	The site is not operational.

These icons summarize the status of all transformers in the grid:

Symbol	Color	Significance
	Green	Count of transformers in normal operational condition
	Orange	Count of transformers with a mid-severity condition.
	Red	Count of transformers with a high -severity condition.
	Gray	Count of transformers that are not operational or not connected to the THM system.

[1] is the icon shape for transformers at hydro-electric plants. is the icon shape for transformers at gas-fired plants.

2.1.2 Fleet and Fleet Rank Views

From within the Corporate view, the user can navigate to a Fleet View of all transformers monitored by the system, as illustrated in **Figure 3** below.

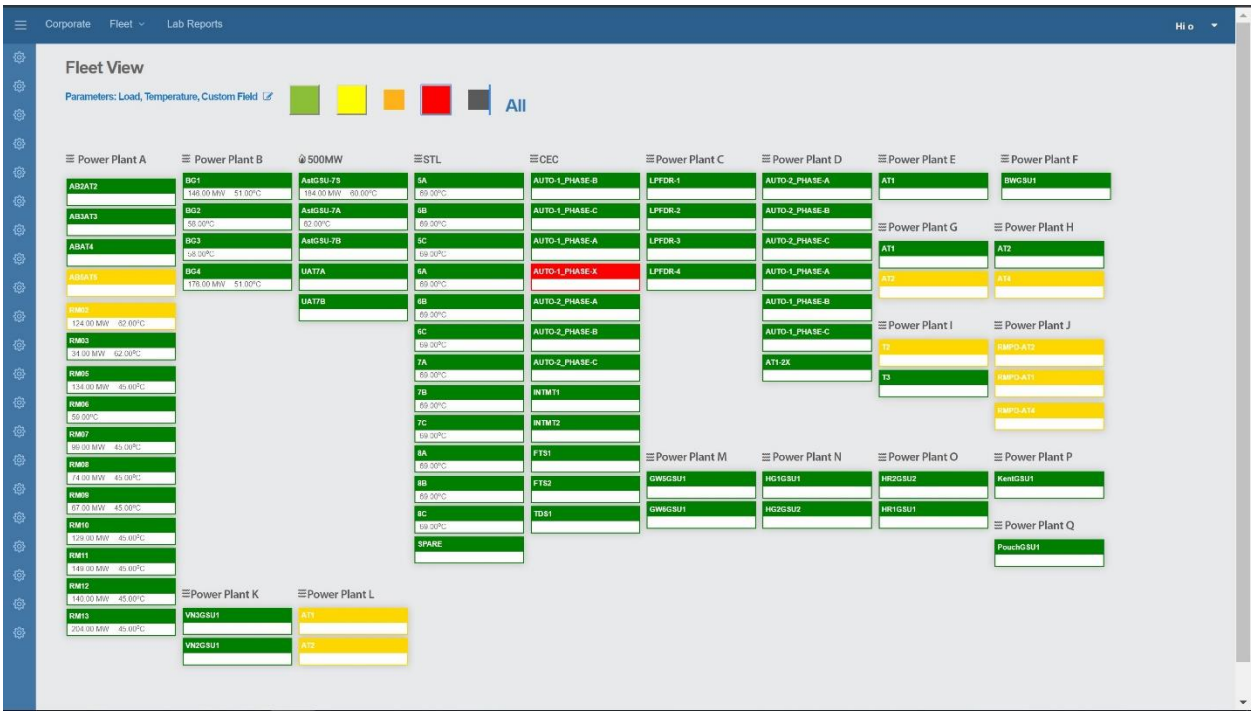


Figure 3: Fleet View

This view summarizes:

- The state of all transformers in the fleet.
- Every transformer's load
- Each transformer's top oil temperature.

It also allows the display of customized fields that include additional statistics from monitored points, such as:

- mA: Detects transformer vibrations
- IR: Infrared camera, source of temperature readings
- RFI: Detects radio frequency interference
- GIC: Detects geomagnetically induced current, necessary to isolate generated RFI

From the Fleet View, the user can navigate to the Fleet Rank to see all transformers sorted by their health status, as shown in **Figure 4**. This view shows the Long and Short Term Severity Index, the Long and Short Term Attention Index, and the Criticality Index for each transformer.

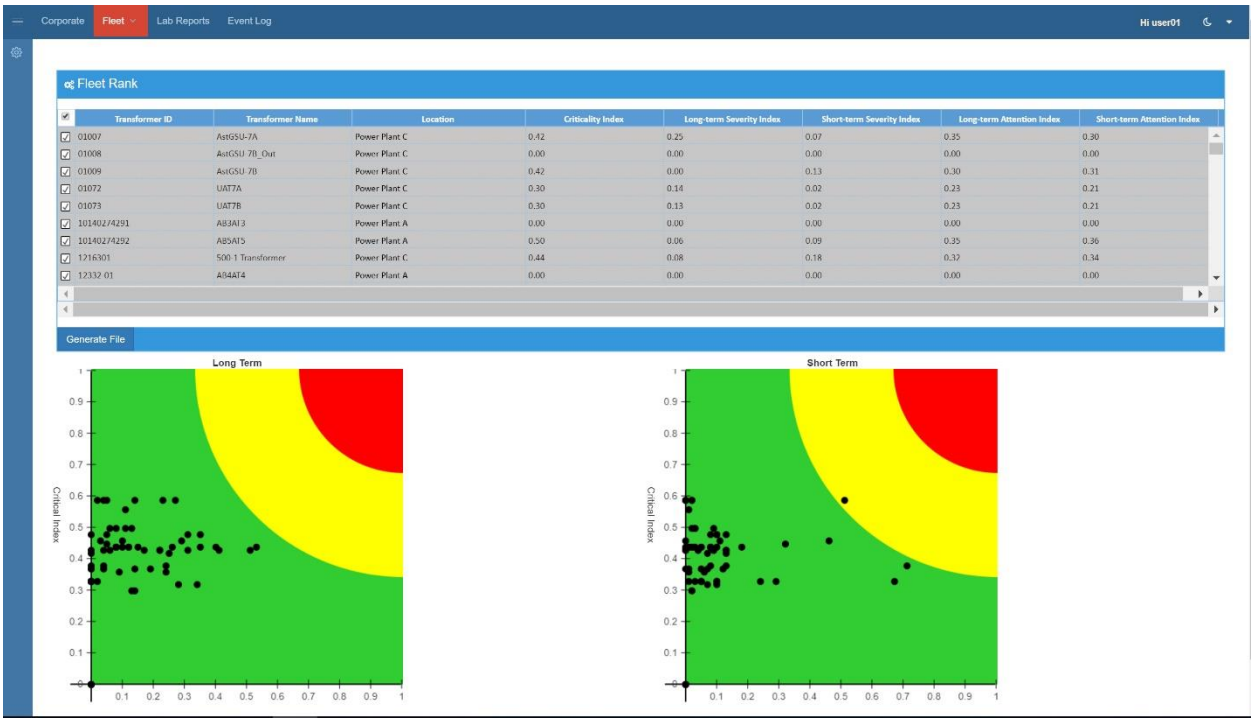


Figure 4: Fleet Rank View

2.1.2.1 *Long and Short Term Severity Index*

The Severity Index is a transformer attribute computed by an algorithm in the system. There are long and short term versions of this attribute. The index changes with the measured states of a transformer. It is possible to set thresholds for the two indexes in accordance with the corporate standard.

2.1.2.2 *Long and Short Term Attention Index*

The Attention Index is a transformer attribute computed by an algorithm in the system. There are long and short term versions of this attribute. The index changes with the measured states of a transformer. The Attention Index indicates if a transformer indication must be considered for treatment in the short term or the treatment can be postponed for a later time.

2.1.2.3 *Criticality Index*

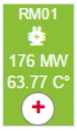
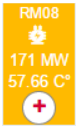
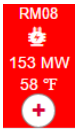
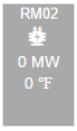
This index is computed by the engineers to rank the importance of individual transformers to the electrical grid. A transformer of high criticality would likely be relatively large. An outage of that transformer would have a major effect on the grid. An outage of a transformer of low criticality would, by itself, not have a significant effect on the grid.

2.1.3 Individual Power Plant View

Any individual power plant can be navigated to from the Corporate view as shown in **Figure 5**. This view provides a picture of the power plant and displays the status icons for all of its transformers together with a load indicator and availability indicators for SCADA and the database.

Figure 5: Power Plant View

The transformer icon color represents the state of each transformer as described below.

Icon	Color	Significance
	Green	The transformer is in normal operational condition.
	Orange	There is a warning of mid-severity for the transformer.
	Red	There is a high severity alert for the transformer.
	Gray	The transformer is not operational or not connected to the THM system.

Each transformer icon presents the top oil temperature of the unit.

The transformer icons bear "**+**" symbols to indicate the state of their attached sensors:

Sensor		
	MA	Vibration detector

RFI	RFI	Radio Frequency Interference sensor
GIC	GIC	Geomagnetically Induced Current sensor
Bushing	Bushing	Sensor on the HV Bushing
Transfix	DGA	Sensor that detects gases dissolved in the transformer oil (for example – Transfix)

The list of operational and not operational sensors can also be displayed:

+ Icon Color		Sensor State
+	Red	At least one connected sensor not operational
+	Green	All connected sensors are operational

The sensors have the same color scheme as the **+** sign plus gray – gray is for unconnected.

The status indicators for the centralized interfaces are green when they are connected and gray when disconnected:

Icon Color		Sensor State
	Green	Database is connected and operational.
	Red	Database is connected and failed.
	Gray	Database is off or not connected.
	Green	SCADA is connected and operational.
	Red	SCADA is connected and failed.
	Gray	SCADA is off or not connected.

2.1.4 Transformer View

The Transformer View presents the operational status of a selected transformer and its malfunctions, if any. Results of the Dissolved Gas Analysis (DGA) samples and the standards calculation status are reported in the DGA section of the window, shown in **Figure 6**.

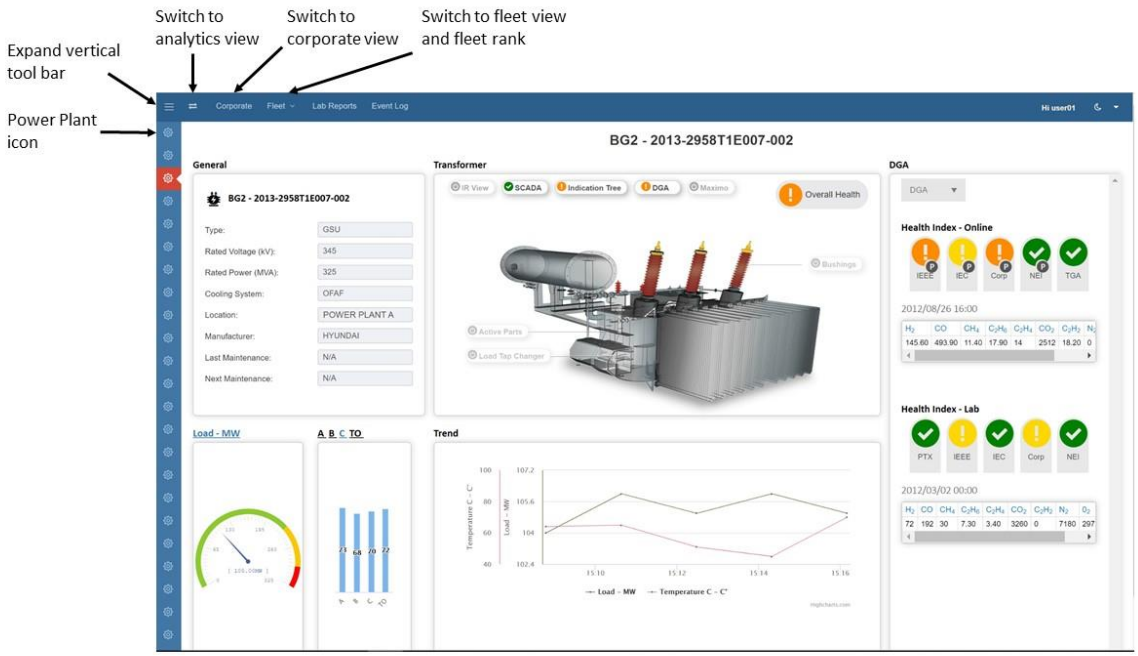


Figure 6: Transformer View

The different sections of the Transformer View are described below.

2.1.4.1 General Section

This section provides the following general information about the selected transformer:

- Type
- Rated Voltage Max (KV)
- Rated Power Max (MVA)
- Cooling System
- Preservation System
- Location
- Vendor
- Last maintenance date
- Next Maintenance date

2.1.4.2 DGA View

In the **Transformer View**, the user can display the **Health Index** and **Overall Health Index**.

Health Index Component	Description
PTX	Transformer Analysis method based on Electric Power Research Institute (EPRI) software.
IEEE	IEEE 57.104 standard.
IEC	IEC 60599 standard.

Health Index Component	Description
Corp	Corporate standard based on IEEE. Provides an option to edit its thresholds in accordance with corporate best practices.
NEI	Normalized Energy Intensity, a new analysis method.
ABN	Abnormal gas rate. Provides the tool-tip “Gas Rate Abnormality.”
Overall Health Index	Reflects the warning with the worst severity of all above standards and methods — the severity can be based on one standard. The list of the included methods can be edited manually to exclude a single gas or a group of gases from a particular method or even a whole method.

For all components:

- If transformer serviceability is normal, the DGA icon color is green.
- If the warning of mid-severity is reported, the icon color is orange.
- If the warning with the highest severity is reported, the icon color is red.

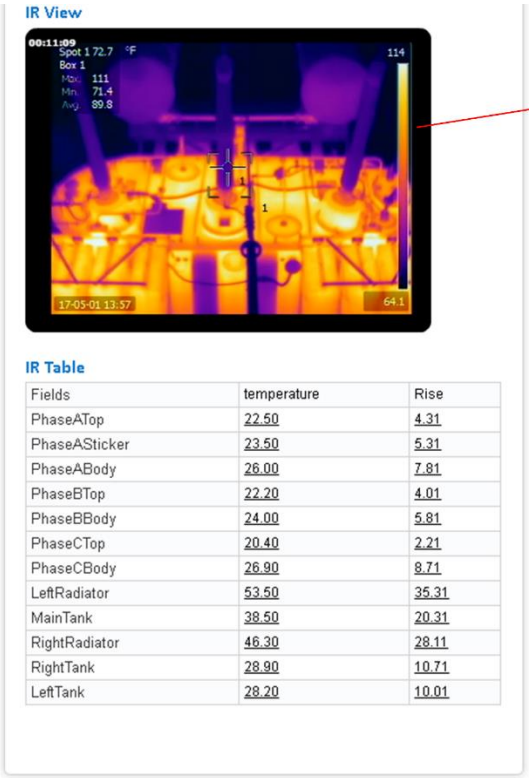
Last DGA Results is a table presenting the last Transfix and Doble laboratory reports of the measured gas concentrations with the report dates.

2.1.4.3 IR View

The IR View button carries a status indicator:

Color	Significance
Green	All IR sensors are operational.
Red	At least one IR sensor is disconnected.

Detailed **IR View** and **IR Table** can be displayed for each transformer.



Fields	temperature	Rise
PhaseATop	22.50	4.31
PhaseASticker	23.50	5.31
PhaseABody	26.00	7.81
PhaseBTop	22.20	4.01
PhaseBBody	24.00	5.81
PhaseCTop	20.40	2.21
PhaseCBody	26.90	8.71
LeftRadiator	53.50	35.31
MainTank	38.50	20.31
RightRadiator	46.30	28.11
RightTank	28.90	10.71
LeftTank	28.20	10.01

The source of the **IR View**, the IR camera, provides live video and measures temperatures in 12 locations on the transformer. The color violet indicates low temperature while yellow indicates high temperature. The picture of the unit is in the same colors as the thermometer to indicate temperature gradients.

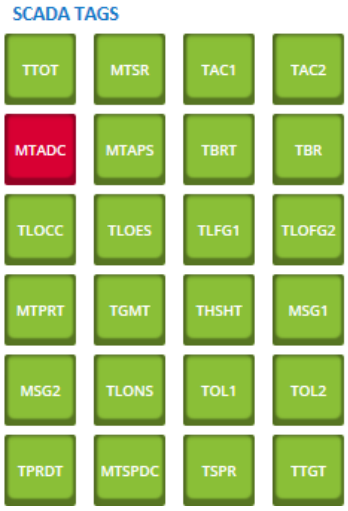
The table displays the temperatures of the transformer components. The “rise” column indicates the difference between the ambient temperature and the transformer temperature. Each row in the table of IR temperature or Rise represents the last measurement at the specific hot spot.

You can view information on the temperature trend of selected components in the **Trend.**

2.1.4.4 SCADA TAGS

The SCADA button indicates a status indicator:

Color	Significance
Green	All SCADA sensors are operational.
Red	At least one SCADA sensor is disconnected.



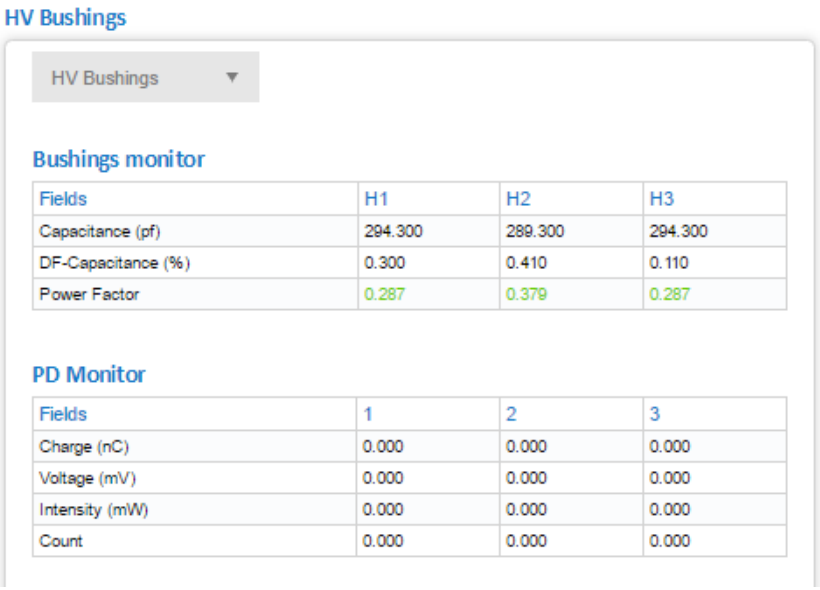
The 24 tags are presented in two colors:

- Normal status – green color
- Abnormal status – red color

In the above illustration, MTADC is the MainTransfAnnunciatorDC, which is the DC source of the Main Transformer Annunciator. The red color indicates that there is an alert, reported by SCADA, regarding the specific SCADA element.

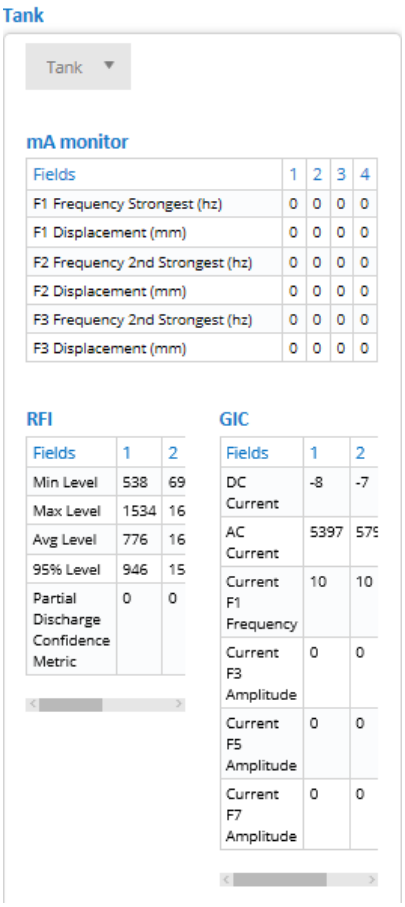
2.1.4.5 High Voltage (HV) Bushings

HV Bushings represent the high voltage bushings of the unit.



2.1.4.6 Tank Readings

The mA, GIC and RFI sensors installed on the main tank provide readings.



2.1.4.7 *Load Section*

The load gauge displays the transformer load in MW units and indicates if the load is normal in accordance with predefined Transformer rating thresholds. The indicator is in the green region for normal operation, in the yellow region if a warning should be expected, and in the red region if the transformer is malfunctioning.

The load trend line can be viewed from the load gauge.

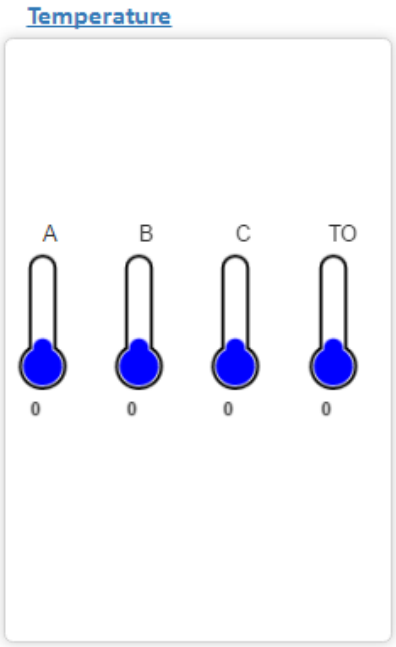
2.1.4.8 *Temperature Section*

This section displays the following temperatures:

- TO – on top of the oil tank.
- A, B, C – near the windings for the three phases of the transformer.

Blue means normal temperature; orange means warning; and red means faulty, in accordance with predefined thresholds.

The trend line of the temperature can be displayed.



2.2 Analyzing Transformers Performance

From the Transformer View, transformer performance can be analyzed by the user for a selected date range of data using the Analytics Menu Ribbon, shown in **Figure 7**.

Figure 7: Analytics Menu Ribbon

The data in the reports depend on the selection of  for transfix values, or  for laboratory gas values, except for the **Key Gas** view, which depicts only a currently selected single DGA sample. Each of these values can be selected for display, or any other analytic view can be selected. These views are described below.

The data in the reports depend on the selection of  for transfix values, or  for laboratory gas values, except for the **Key Gas** view, which depicts only a currently selected single DGA sample.

2.2.1 DGA Summary View

Based on various standards, this view summarizes the analysis of the transformer's performance.

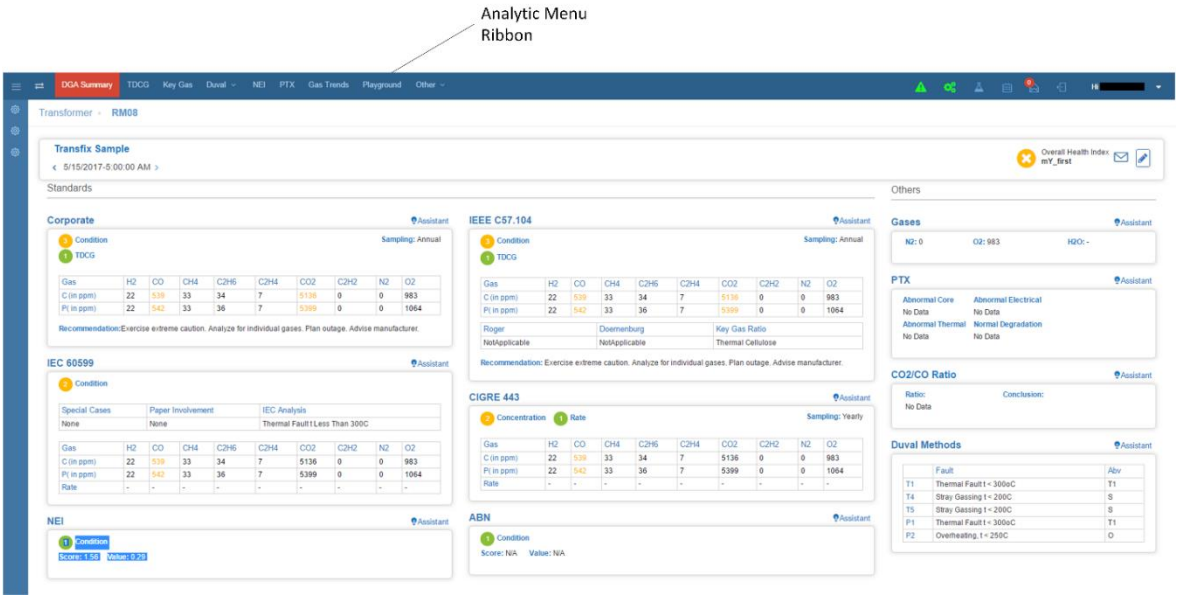


Figure 8: DGA Summary View

The above statistics are from a Transfix sample.

Note that a number of sections corresponding to different standards display circled numbers labeled **Condition**. The numbers are computed according to the standards. The colors are assigned by the system:

Color	Significance
Green	The transformer is in normal operating condition.
Orange	There is a warning of mid-severity for the transformer.
Red	There is a high severity alert for the transformer.

For more information, see IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers, IEEE Std. C57.104-2008.

There are additional colored circles for TDCG and CIGRE (**Rate** circle). The colors are also assigned by the system and have the same significance.

2.2.1.1 Overall Health Index

The Overall Health Index is a health status computed from all sensors and methods available to the system, based on DGA only. This index can be customized by the user.

2.2.1.2 Email Alerts

The form shown below lets the user create a list of recipients for emailed alerts.

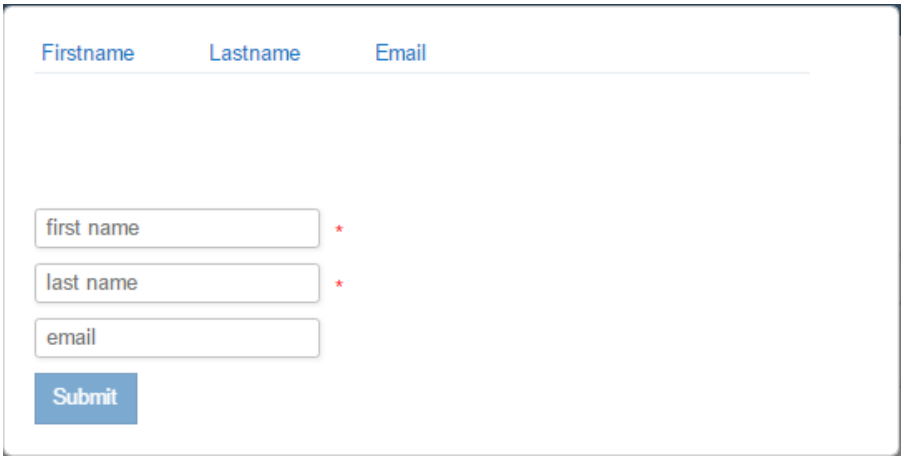


Figure 9: Email Alerts Form

The following is an example of an email alert:

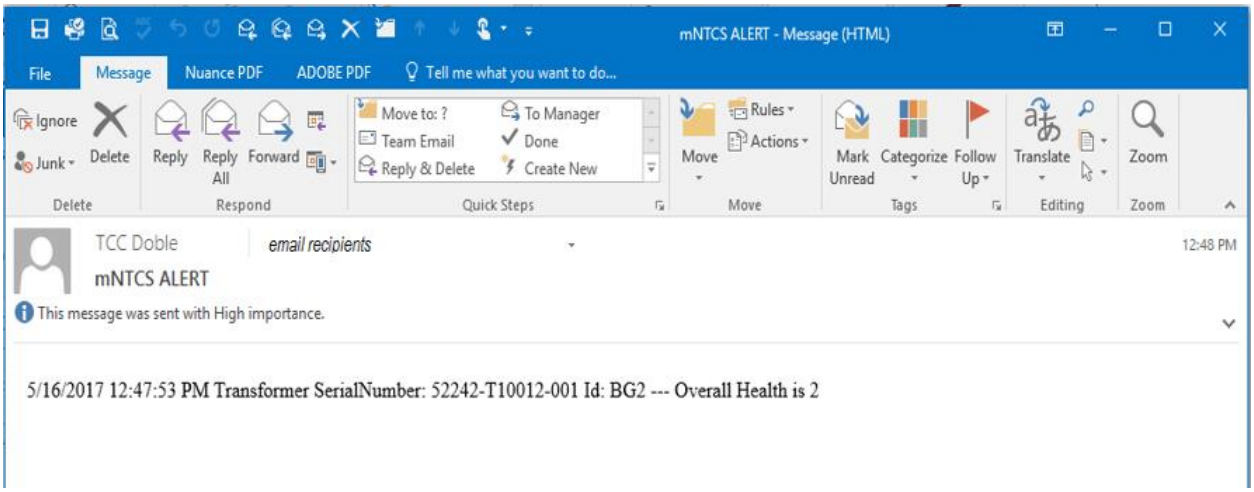


Figure 10: Email Alert Example

2.2.1.3 Editing the Overall Health Index Configuration

This feature lets you modify the Overall Health Index by blocking or allowing particular standards or gases in the calculation.

Note: You must be an expert in the standards to edit this configuration.

2.2.1.4 Corporate Section

The index, rate, and sampling period can be displayed. The sampling period is evaluated from the Total Dissolved Combustible Gas (TDCG) concentration and rate of accumulation. If a rate of accumulation is not available, the concentration index is used. The concentration index is evaluated from the concentrations of the individual gases presented in this section's table.

The table lists gas concentration in parts per million (ppm).

Recommendation Only an expert in the standards related to oil analysis should use this section to help determine a transformer problem.

2.2.1.5 IEEE 60599 Section

In the Gas table, line C lists gas concentrations.

Line P lists predicted gas accumulation rates

Line Rates lists gas accumulation rates.

2.2.1.6 NEI Section

Condition: The NEI value is directly related to the amount of faulty energy dissipated in the oil. The NEI value is calculated as follows:

$(77.7CH_4 + 93.5C_2H_6 + 104.1C_2H_4 + 278.3C_2H_2) / 22400$ kJ / kL.

The NEI score is an attention index between 1 and 4. The NEI condition and index are calculated from the NEI value using thresholds.

The condition is represented by colors, as follows:

Green: Normal

Orange: Warning

Red: Faulty

2.2.1.7 IEEE C57.104 Section

The gas concentration is displayed by attention indexes between 1 and 4 and by colors, as follows:

Green: Normal

Orange: Warning

Red: Faulty

The IEEE C57.104 table describes in line C the concentration of gases in PPM.

Line P lists predicted gas accumulation rates.

Note The expert operator can use the **Recommendation** for help deciding the transformer's problem.

2.2.1.8 CIGRE 443 Section

CIGRE 443 Table: Describes in line C the gas concentration in PPM. In line P, it describes the predicted gas concentrations.

It describes, in line Rate, gas accumulation rates.

The circled Concentration score is the summary of the concentration condition in Row C.

The circled Rate score is the summary of the Rate condition in the Rate row.

2.2.1.9 Gases Section

This section presents a list of gasses such as N_2, O_2 and a liquid such as H_2O.

2.2.1.10 PTX Section

PTX is a measure of the likelihood of a specific fault.

PTX was developed by the Electric Power Research Institute (EPRI).

This section describes the following transformer anomalies:

- Abnormal Core
- Abnormal Electrical
- Abnormal Thermal
- Normal Degradation.

2.2.1.11 CO2/CO Ratio Section

The content of this section is based on the measured CO2 and CO gas concentrations.

2.2.1.12 Duval Methods Section

A Duval method is only used when gas concentrations are above normal.

The Duval Methods **Table** lists faults evaluated by the following methods:

- T1 - Duval "Classic" Triangle is used for general analysis.
- T4 - Duval Triangle 4 is used for further analysis of low temperature faults (PD, T1 or T2 in the "Classic" triangle).
- T5 - Duval Triangle 5 is used for further analysis of high temperature faults (T2 or T3 in the classic triangle).
- P1 and P2 - Duval Pentagon 1 and 2, which are intended for complementary information.

The abbreviations in the Duval Methods **Table** are expanded as follows:

- Partial Discharge – PD
- Possible Carbonization – C
- Stray Gassing – S
- Thermal fault – T1
- Overheating – O

2.2.1.13 Displaying Gas Trends in Gas Trends View

In the DGA Summary, you can select a gas to display its trend.

The **Gas Trends** view appears and displays the trend line graph of the selected gas.

2.2.2 TDCG View

This view is a chart of the Total Dissolved Combustible Gases (TDCG) concentrations:

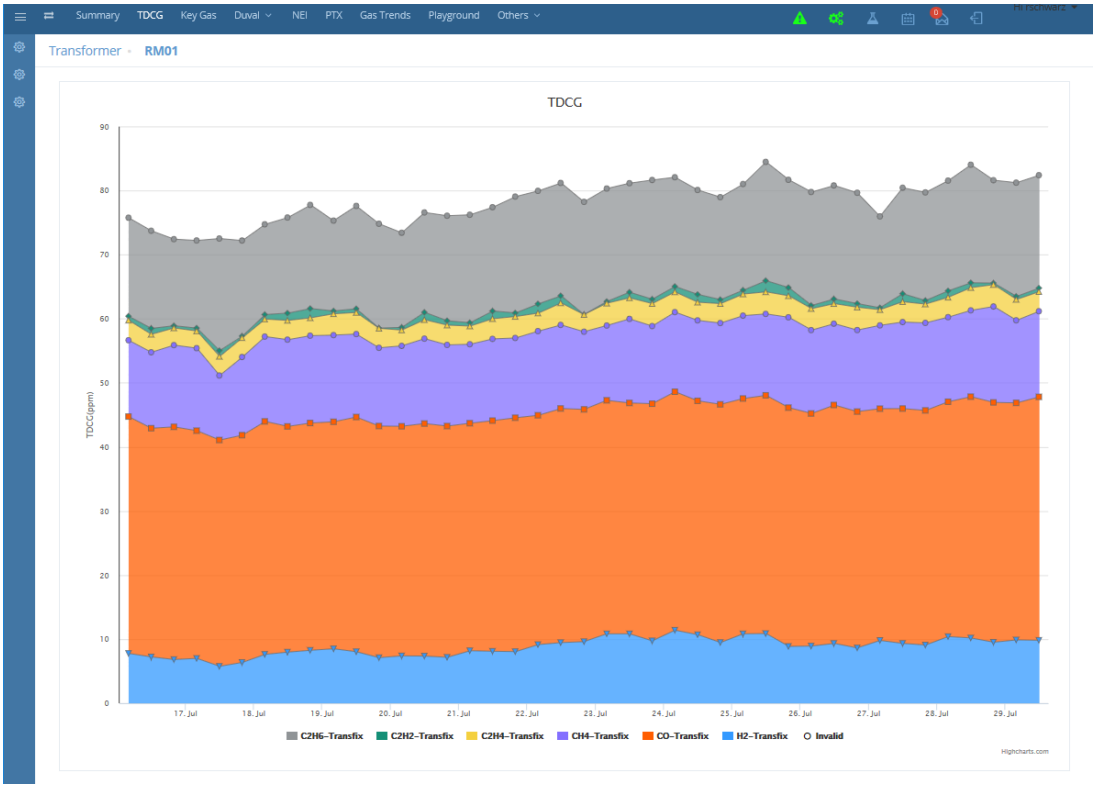


Figure 11: Total Dissolved Combustible Gases (TDCG) concentrations view

A mouse-over on the chart provides the values of the DGA gas sample on the specific dates on the time axis.

The X-axis is the timeline on a dynamic scale dependent on the range of the dates that were picked.

The Y-axis presents the gas concentration in PPM. The gases in TDCG are vertically stacked to provide a sense of their proportionality in the sample.

2.2.3 Key Gas View

For a selected transformer at a specified date and time, this view reports a comparison of concentrations of key gases against thresholds for four (4) deterioration conditions:

- Arcing in oil
- Partial discharge in oil
- Overheated oil
- Overheated cellulose: Thermal fault in insulation paper

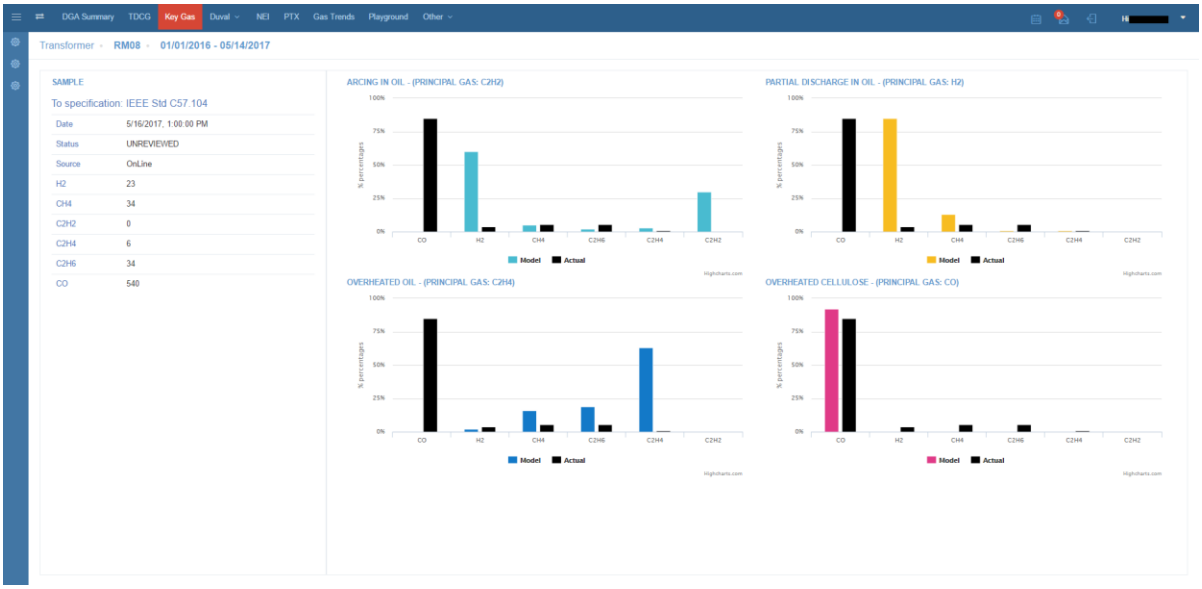


Figure 12: Key Gas View

2.2.3.1 Arcing in Oil

Arcing is an electrical current breakdown of the oil insulator between transformer windings or coils, or between coils to ground. The Arcing in Oil bar graphs present the concentrations of the six gases: CO, H2, CH4, C2H6, C2H4, and C2H2.

The bar graphs indicate the percentage of each gas as a proportion of the six gases. The azure bar graphs represent the threshold model and the black graphs bar are the actual measured concentrations.

2.2.3.2 Partial Discharge in Oil

Partial discharge is an electrical partial breakdown of the oil insulator. The Partial Discharge bar graphs present the concentrations of the six gases: CO, H2, CH4, C2H6, C2H4, and C2H2.

The bar graphs indicate the percentage of each gas as a proportion of the six gases. The orange bars represent the threshold model and the black bars are the actual measured concentrations.

2.2.3.3 Overheated Oil

The Overheated Oil bar graphs present the concentrations of the six gases: CO, H2, CH4, C2H6, C2H4, and C2H2.

The bar graphs indicate the percentage of each gas as a proportion of the six gases. The blue bars represent the threshold model while the black bars are the actual measured concentrations.

2.2.3.4 Overheated Cellulose

The Overheated Cellulose (low-thermal-conductivity material such as paper) bar graphs present the concentrations of the six gases: CO, H2, CH4, C2H6, C2H4, and C2H2.

The bar graphs indicate the percentage of each gas as a proportion of the six gases. The violet bars represent the threshold model while the black bars are the actual measured concentrations.

2.2.4 Duval Views

The Duval window presents Duval's Triangle and Duval's Pentagon analytical methods.

2.2.4.1 Duval Triangle

This view presents Duval's Triangle Analysis method.

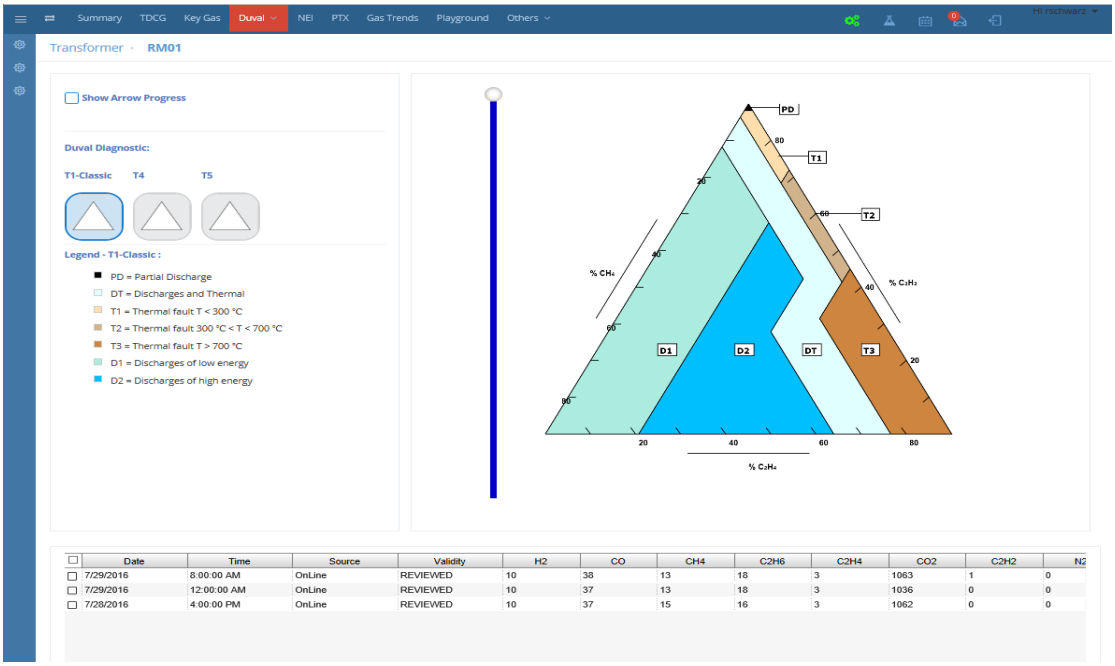


Figure 13: Duval Triangle view

2.2.4.2 Duval Pentagon

This view presents Duval's Pentagon Analysis method.

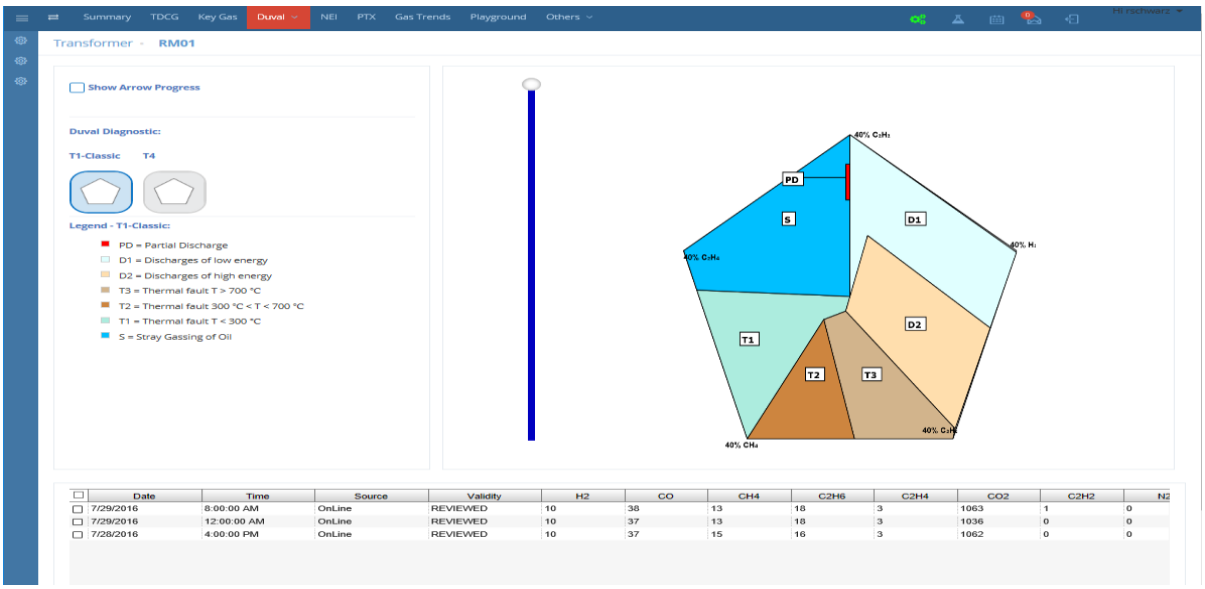


Figure 14: Duval Pentagon view

2.2.5 NEI View

The Normalized Energy Intensity (NEI) value is directly related to the amount of fault energy dissipated in the oil.

The Normalized Energy Intensity (NEI) method provides a health score between 1 and 4. The view reports the NEI score and value over a period of time to the user and the final NEI score calculation. The NEI Score and Value are both evaluated using thresholds.

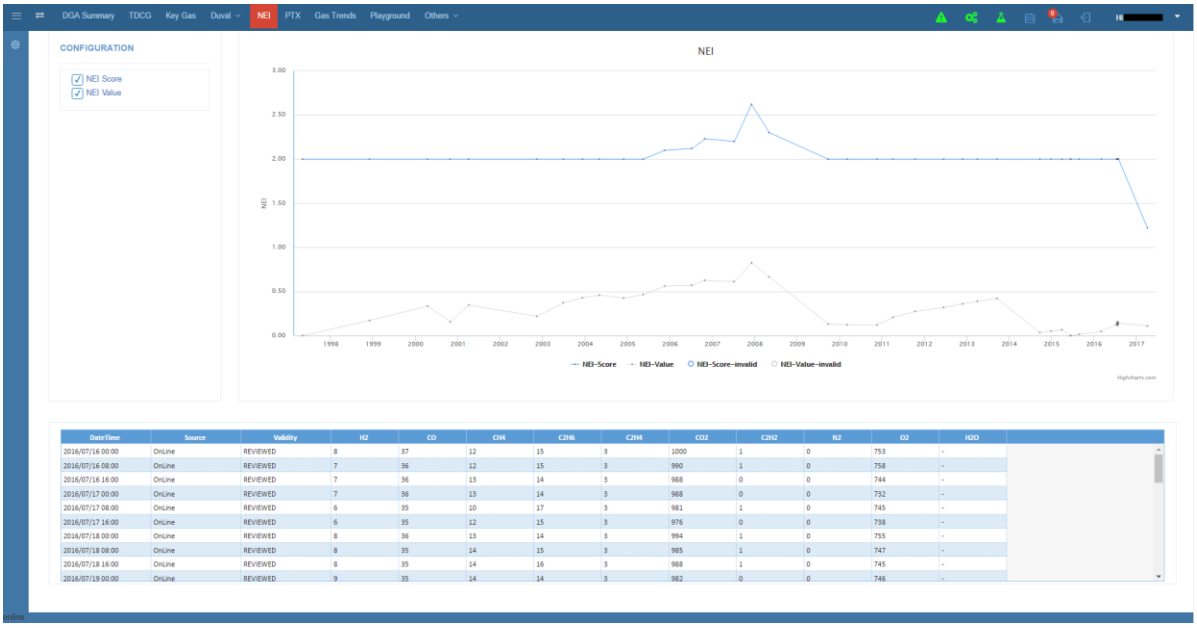


Figure 15: Normalized Energy Intensity (NEI) view

2.2.5.1 NEI Score

This graph presents:

- Score of Online Transfix Samples – based on the calculation performed with Transfix gas samples.
- Score of Offline Lab Samples - based on the calculation performed with Lab gas samples.

The data from Transfix samples and/or laboratory gas samples appear in the X-Y line graph.

A display of the characteristics of a particular point on a graph can be seen using the mouse tooltip.

2.2.5.2 NEI Values

NEI value = $(77.7CH_4 + 93.5C_2H_6 + 104.1C_2H_4 + 278.3C_2H_2) / 22400$ kJ / kL.

The data from Transfix samples or laboratory gas samples appear in the X-Y line graph.

A display of the characteristics of a particular point on a graph can be seen using the mouse tooltip.

Panning and zooming of the displays is allowed.

2.2.5.3 Detailed Data Table

The Detailed Data Table includes the following items:

- Date – when samples were taken
- Time – when samples were taken
- Source – Online or Laboratory

- Validity, for example, “REVIEWED”
- DGA samples (H2, CO, CH4, C2H6, C2H4, CO2, and C2H2) and other samples like N2, O2 and water-H2O, if present.

2.2.6 Power Transformer Expert (PTX) View

This view reports the PTX indexes for a selected transformer through line graphs plotted against time on the X axis:

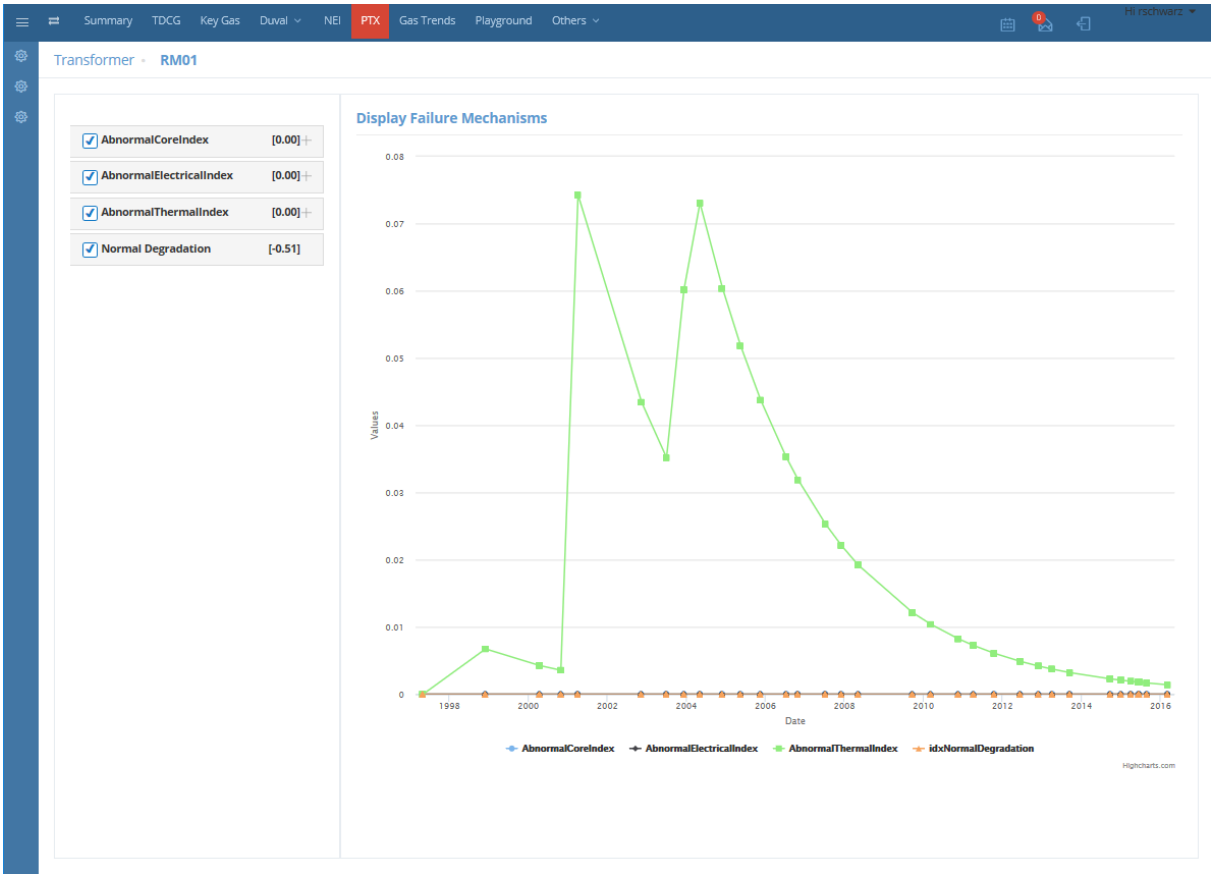


Figure 16: Power Transformer Expert (PTX) View

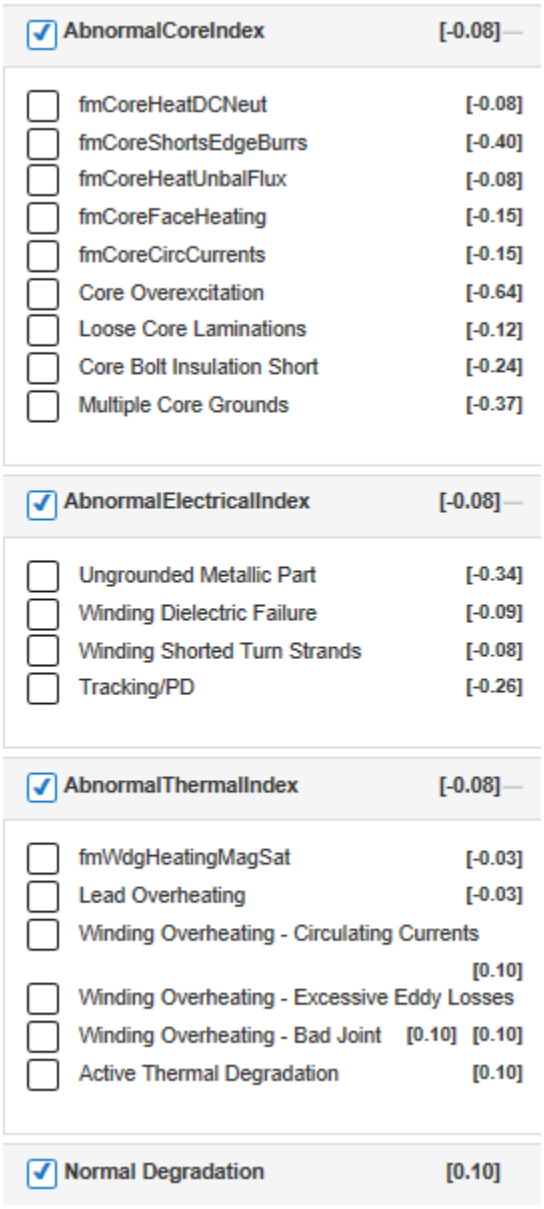
There are four (4) health indexes corresponding to the potential contributors of a fault:

- Abnormal Core Index – abnormalities in the transformer core
- Abnormal Electrical Index – abnormalities in the non-core electrical parts
- Abnormal Thermal Index – abnormal heat in the insulation paper of the transformer
- Normal Degradation – degraded performance due to normal wear and tear

The name of each index indicates the source of the measurements that comprise the index. Each index is calculated based on the related fault contributors.

The input derives from laboratory reports.

The following shows the expansion of all of the indexes:



To select a subcomponent of an index, select its checkbox. Up to all subcomponents can be selected.

2.2.6.1 Abnormal Core Index

The Abnormal Core Index is a transformer health index used for Short Term Fleet Rank evaluation.

2.2.6.2 Abnormal Electrical Index

The Abnormal Electrical Index is a transformer health index used for Short Term Fleet Rank evaluation.

2.2.6.3 Abnormal Thermal Index

The Abnormal Thermal Index is a transformer health index used for Short Term Fleet Rank evaluation.

2.2.6.4 Normal Degradation

The Normal Degradation contains a transformer health graph used for Long Term Fleet Rank evaluation.

2.2.7 Gas Trends

The Gas Trends option enables the expert user to explore, to observe, and compare relationships between DGA gases measured over a specific time interval.

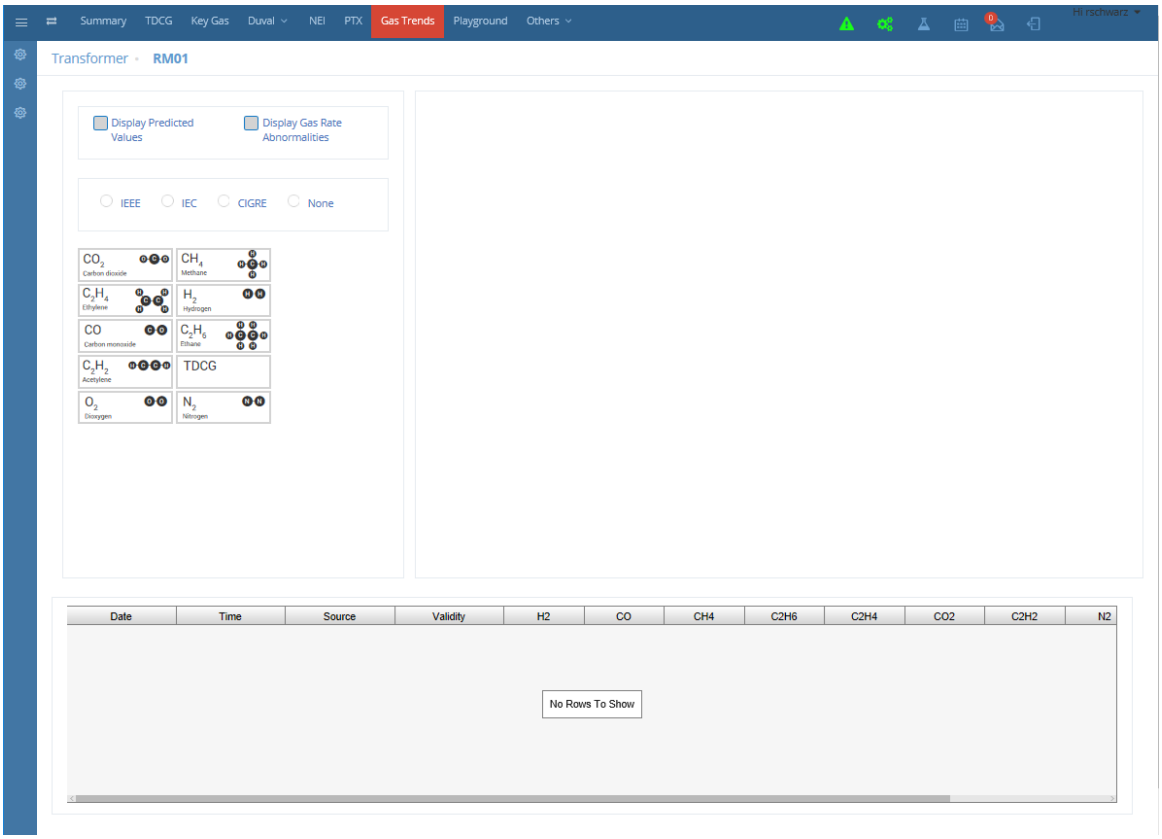


Figure 17: Gas trends view

The **Display Predicted Values** and **Display Gas Rate Abnormalities** options may be disabled.

Note These options are enabled when they are calculated or detected by the system. Prediction values depend on the amount of the historic DGA samples. Abnormalities depend on the behavior of the gases (changes in their rates).

A table of the gas readings is posted below the **Gas Trends** graph.

2.2.8 Playground

This option enables the expert user to drag and drop parameters and display the graphs the system produces in response.

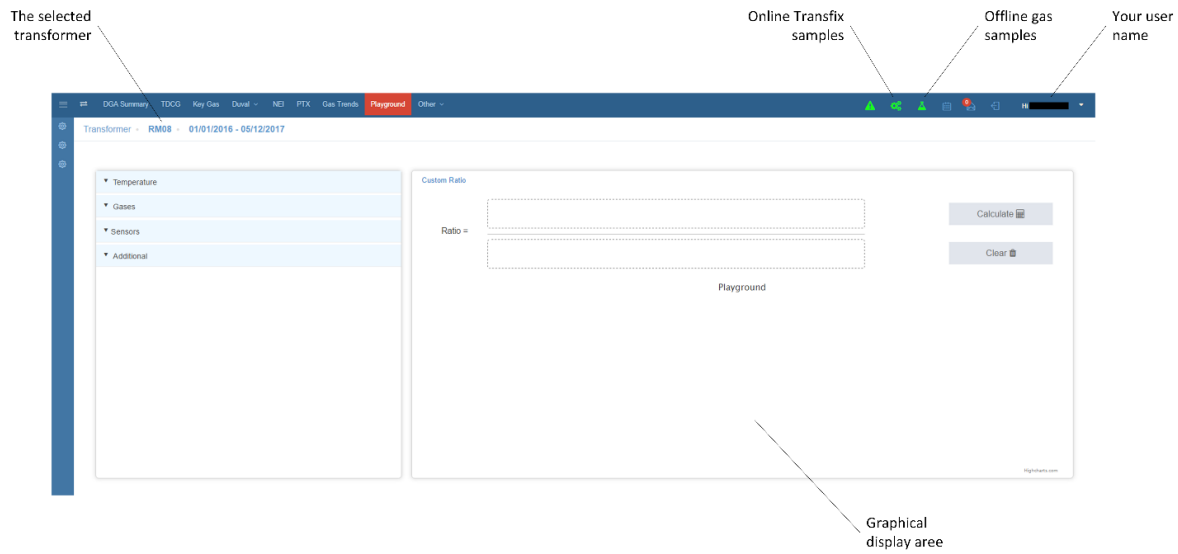
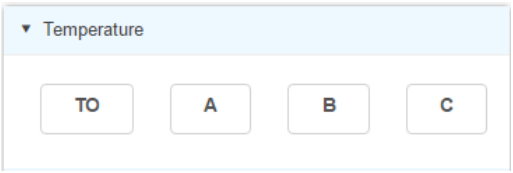


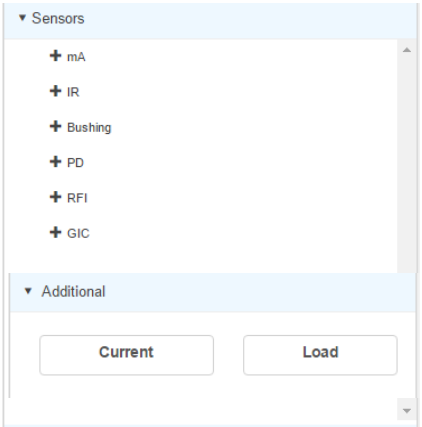
Figure 18: Playground view

The center of the window incrementally displays the results of your work as you progress through your analysis. There are four sources of data. You can select the groups and within the groups in any combination. You need to make at least one selection to display at least one graph. These are the four groups:

- Temperature
- Gases
- Sensors
- Additional

This is what the four groups look like when expanded:





The temperature data is from four sources:

- TO – on top of the oil Tank.
- A, B, C – near the windings for the three phases of the transformer.

Below the graphs are overlapping brief legends which display the colors associated with over. each graph. Your mouseover displays a tooltip that describes the graph you are hovering over.

Annotations for the y-axes are displayed to the right of the graphs.

Example for H2 Gas and Selection of Load:

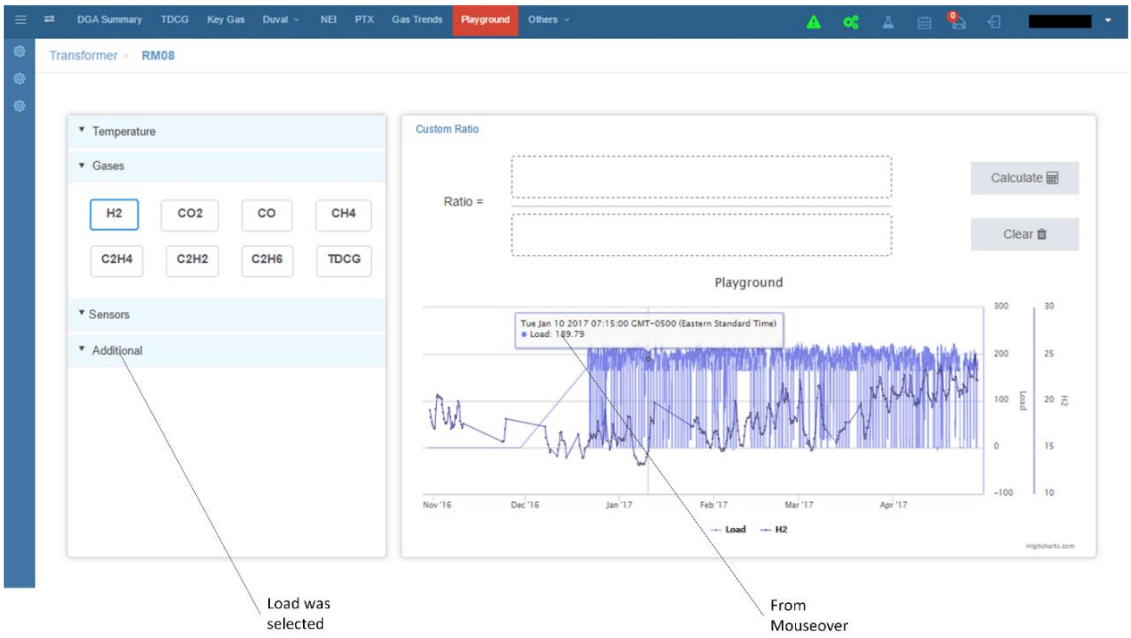


Figure 19: Examples of H2 gas and Selection of Load in the Playground view

2.2.8.1 Data Point Values

A detailed description of the date, time, and quantity values is shown in the data point values view.

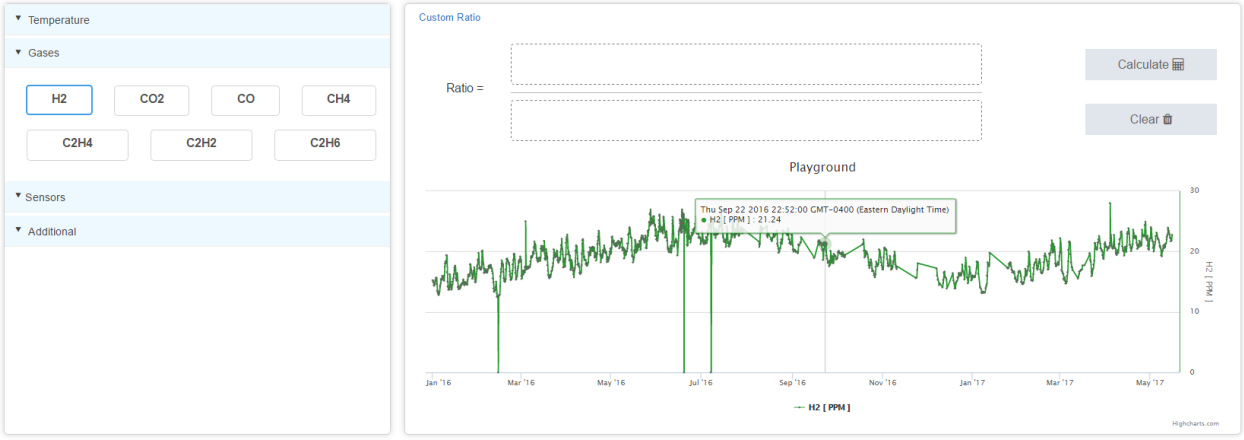


Figure 20: Data Point Values view

2.2.9 Other Views

The **Other** option allows you to choose between these analytical tools:

- **Data Table** option – details the gas samples data
- **Manual Report Insert** option – allows you to enter an offline lab DGA sample
- **Import Doble** option – allows you to import a Doble report
- **Event Log** option – is a view of all system events
- **Setting Rules** – Set rules for reporting events or other actions

2.2.9.1 Data Table

This table details the data from the gas samples from a particular transformer. The display depends on the pre-selection of the transformer and the pre-selection of the dates through the **Date Picker** icon  .

These tables provide detailed views of DGA gas samples and validation status of the recorded observations.

The columns include the following:

- Checkbox – When selected, the calculations of the standard are included in the table.
  - IEEE
  - Corporate
- Status – The sample validation code, which is one of these:
  - UNREVIEWED – The online sample is initialized as unreviewed.
  - REVIEWED – Laboratory sample is manually initialized as reviewed. Online samples receive status of REVIEWED after syntactic validation process.

  Syntactic validation process — The software checks reported gas sample values and looks for valid numerical values. Non-numerical or negative values are rejected. Numbers must be non-null, not infinity, and between pre-determined logical boundaries.

  - VALID – Sample was manually set as valid (used for manual override for validation processes).
  - INVALID – one or more gases in the sample does not pass the syntactic validation process or the sample is manually set as invalid (used for manual override for validation processes).

  A syntactically valid gas sample can still be invalid. Gas samples are also checked for consistency with their trend line. A window of 60 samples is taken to establish the start of the current trend. Spikes are noted as automatically pending for inclusion in a new trend line:

  - AUTOMATICALLY_VALID – All gases in the sample belong to a consistent trend.
  - AUTOMATICALLY_PENDING – If a spike is detected in a sample, it becomes AUTOMATICALLY_PENDING. After 14 additional samples, the software determines if the AUTOMATICALLY_PENDING sample is part of a new trend or an isolated spike. If the spike is determined to be part of a new trend, it is AUTOMATICALLY_VALID.
  - AUTOMATICALLY_INVALIDATED – If the sample remains an outlier, it is AUTOMATICALLY_INVALIDATED.
- Time stamp
- One column for each type of gas. The quantities are in ppm.

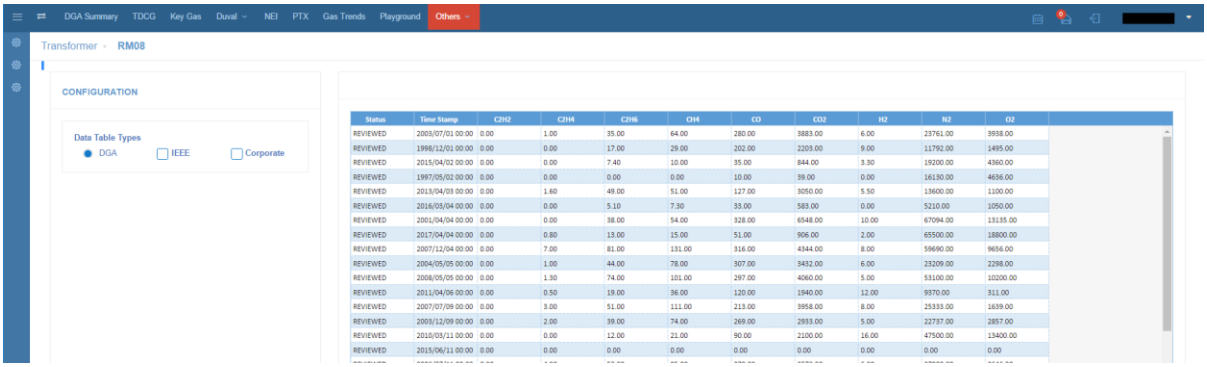


Figure 21: Data Table view

Each column can be sorted. The display can be filtered.

The table displays only those rows that meet the criterion in the selected column.

2.2.9.2 Manual Report Insert

The user can insert additional data into a report.

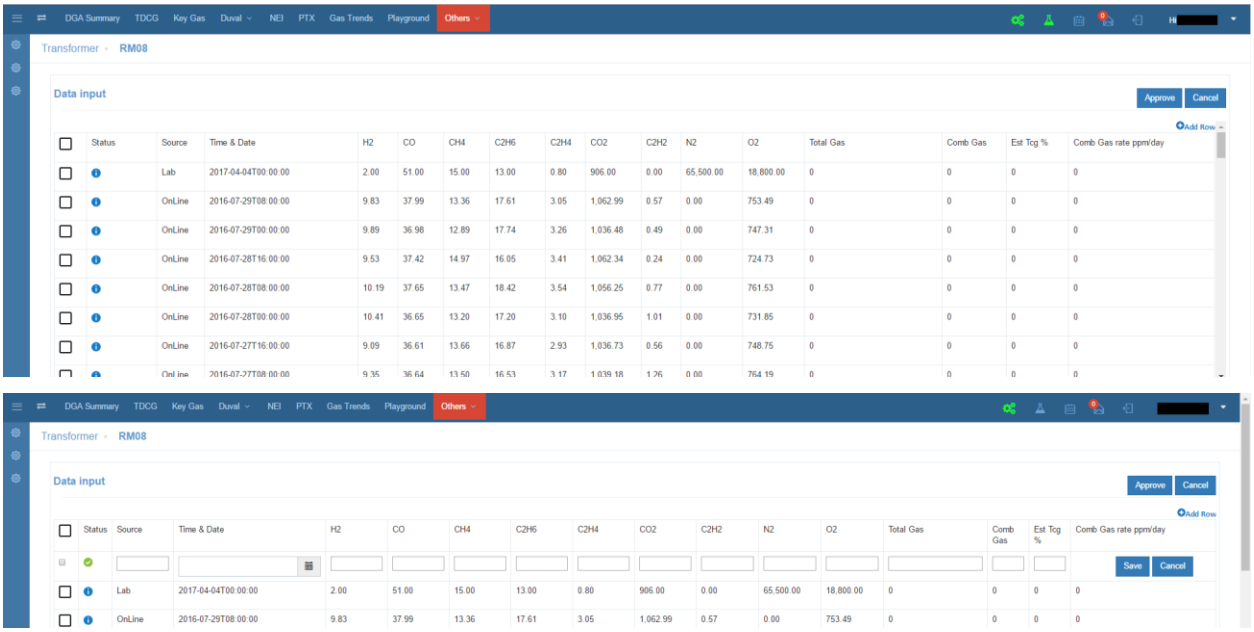


Figure 22: Inserting data into reports

2.2.9.3 Event Log

An event log window is shown below.

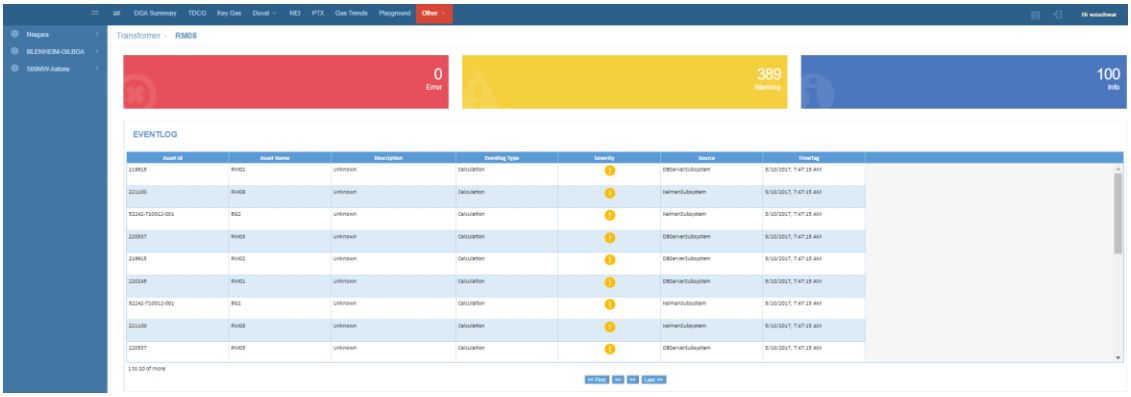


Figure 23: Events log

The colored squares in the log heading summarize the number of error and severity warnings and the number of fully operational assets in the log:

Color in the Heading	Color and Symbol Significance
Blue	Fully operational assets
Yellow	Assets with problems
Red	Assets with errors

Description Column

The following values appear in this column:

- **Connected** – The asset is connected to the system.
- **Disconnected** – The asset is disconnected from the system.
- **Unknown** – the state of the asset is unknow.

Eventlog Types:

There two Eventlog types:

- **Calculation** – From calculations performed on an on-going basis by the system
- **Message** – System update notification on processes

Severity:

The symbols are explained here:

Symbol in the Severity Column	Color and Symbol Significance
	The asset is fully operational.
	There is a problem in the asset.
	Error in the asset.

The log can be downloaded as a CSV file or spreadsheet.

2.2.9.4 *Setting Rules*

There are rules built into the software. However, you can add new rules and edit rules that you or other users have added.

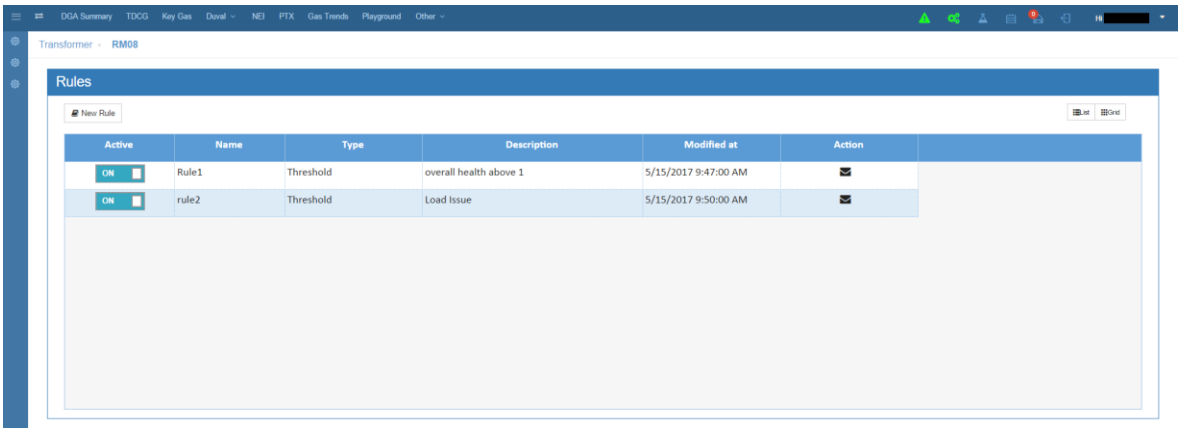


Figure 24: Rules setting

3 Advisory Module

The THM product includes an Advisory Module, used to track changes in the overall health index of monitored assets and trigger an event that activates predefined rules. A Standard Operational Procedure (SOP) can be defined for each event type and displayed along with the specific event. A lifecycle process is supported for each event. This workflow is shown below.

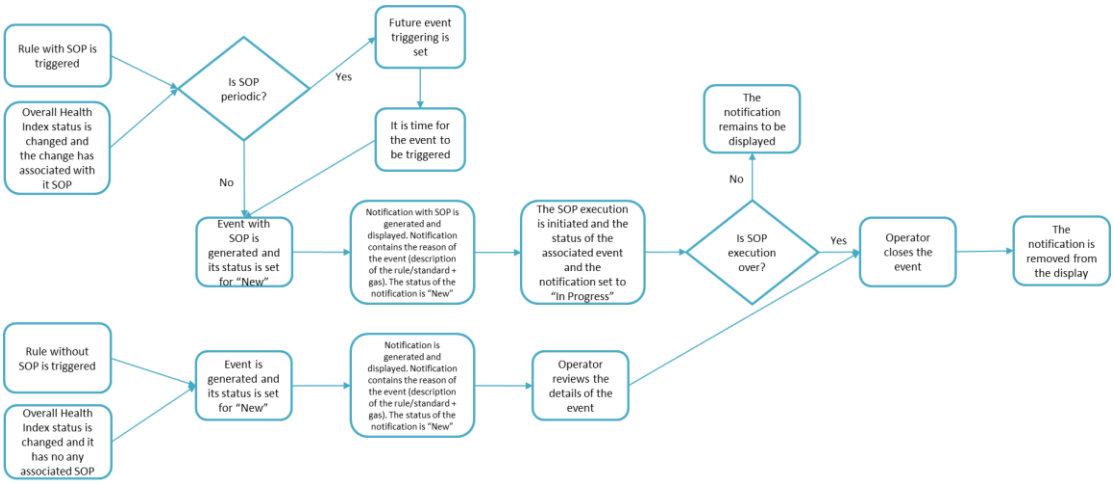


Figure 25: Event Workflow

The following section provide more details on the Advisory Module functionality.

3.1 Notification Panel

All system displays can optionally contain a Notifications panel, as illustrated below. By default, it is placed on top of any other display in the right-hand side of the window and can be collapsed by the user.

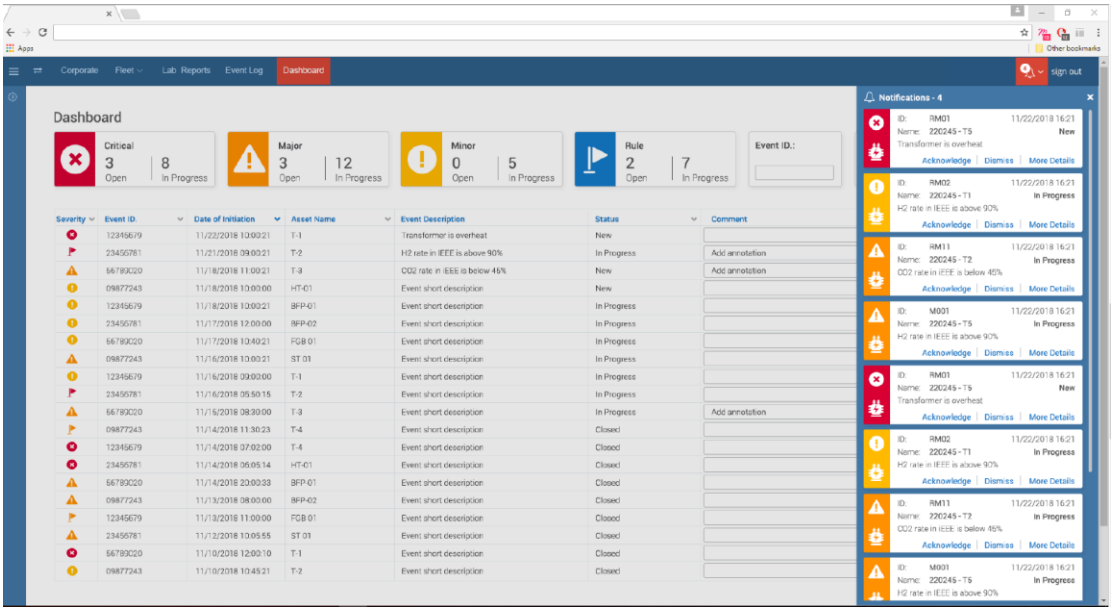


Figure 26: Notification Pane

The Notifications panel contains the notifications of all events that are active in the system. The total number of active notifications are displayed in the panel's header. The notifications are sorted by time with the newest on top. The panel supports scrolling.

If the notification panel is collapsed, each new notification triggers a sound and is displayed on the main ribbon (both monitoring and analytic) as follows: 

The notification displays a count of the total number of active notifications and blinks until the panel is expanded again.

3.1.1 Notification details

Each notification in the panel contains the following details:

- Severity – red if based on the latest severity of the overall health index of the associated asset that triggered the event or blue if it was generated by a rule.
- Event ID
- Asset name as defined in its nameplate
- Event generation date
- Reason for the notification as calculated by the system, according to the method or standard that triggered the event. In case of triggering the event by rule, its description is displayed as the reason for the event. The length of the field is limited to a single line. In case of insufficient space for displaying the whole message, the rest of the message is replaced by "…" and the hovering the mouse tooltip over the item displays the full message.
- "Dismiss" button – removes the notification from the list and closes its association with the event.
- "Acknowledge" button – changes the status of the notification and moves it to the bottom of the list.
- "More details" button – accesses the event details form for seeing additional details of the event and the associated asset.
- The status of the notification: one of the following values ("New", "Acknowledged").

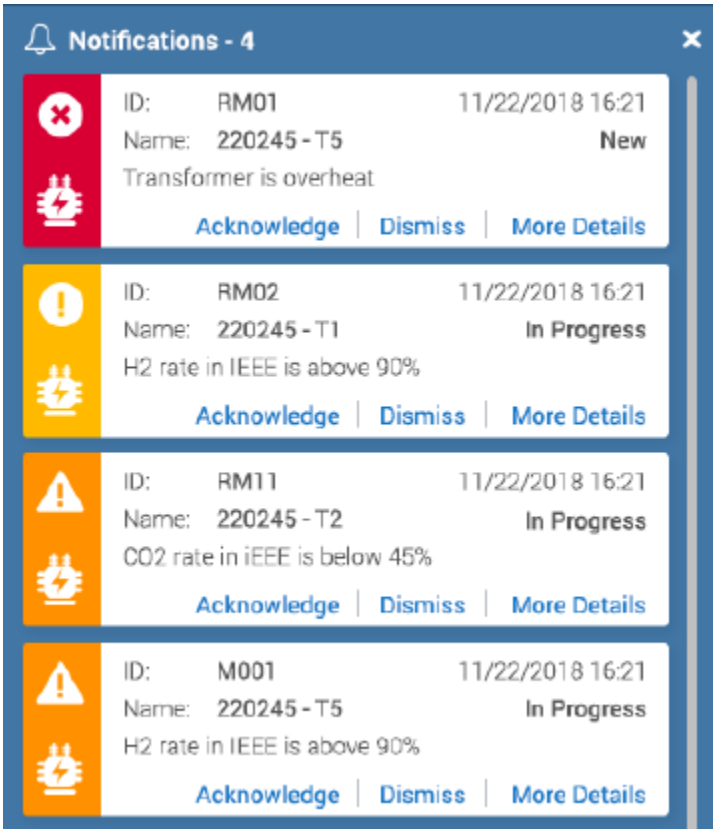


Figure 27: Notification Examples

3.2 Events Log

The Event Log window is illustrated below. By default, events are sorted in order from the latest event to the oldest event. The table supports sorting the rows by column (except for the “comments” column). The events log will contain all events that were ever generated, even if they are already closed. The operator is able to filter the table according to the events status to avoid being overwhelmed by a large number of events in the display.

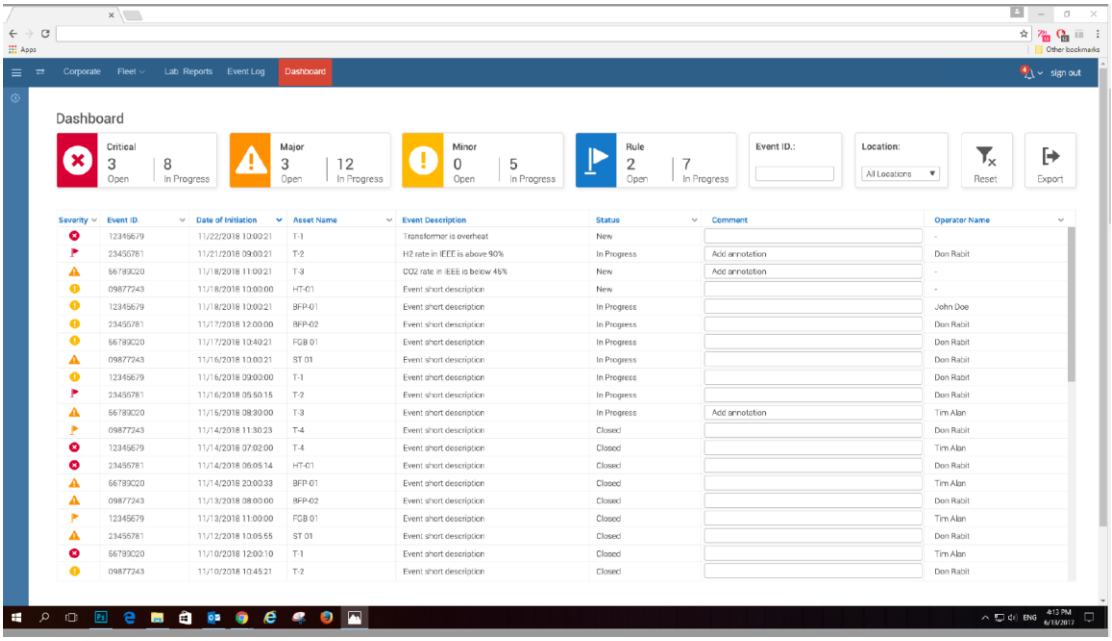


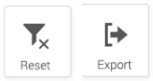
Figure 28: Events Log

The table contains the following columns:

- Event Severity
- Event ID
- Event initiation date
- Asset Name
- Event description (should be duplicated from the reason in the associated notification)
- Event status (see the existing statuses in the **Error! Reference source not found.**par **Error! Reference source not found.**).
- Comment: Should be an editable field.
- Operator name: the name of the operator who dismissed or acknowledged the notification or N/A if it is still active or the person that executed the recent step of the associated SOP.

The widgets shown in the dashboard of the Event Log are predefined, selectable filters for events that are “New” or “In Process”.

The user can easily reset the display to filter the list with the most recent events displayed at the top, as well as export the table into an XLS format by simply selecting the icons in the display.



The event severity is indicated by colors, which are assigned automatically.

Color	Significance
Red	Critical Events
Orange	Major Events
Yellow	Minor Events
Green	Normal Operation

Blue	Rules Applied to Events

3.2.1 Event Details

Any event in the Event Log can be selected to display details on that specific event.

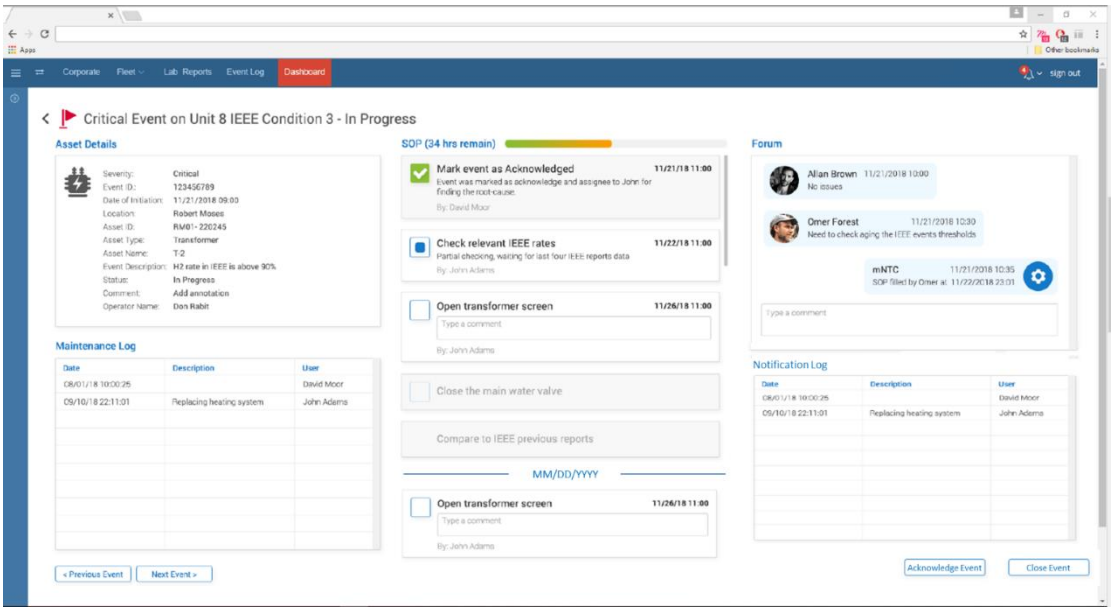


Figure 29: Events Details

The Event Details view contains the following information:

- The title containing the description of the event and its current status.
- The nameplate of the asset associated with the event.
- Maintenance log of the asset.
- All past instances of the associated Standard Operations Procedure (SOP, described later) if defined, including the current status of execution for all SOPs, sorted according to time of arrival from latest to earliest.
- Forum (Chat) to enable the operators to share their ideas and insights regarding the specific event with each other.
- Notification Log – with the full list of all SOPs associated with the specific event notifications that were ever generated.

3.3 "SOP Editor" view

Following is an illustration of the SOP editor. This display enables the operator to define a new SOP and associate it with the OI status change or existing rule. It also will enable the user to edit the existing SOP.

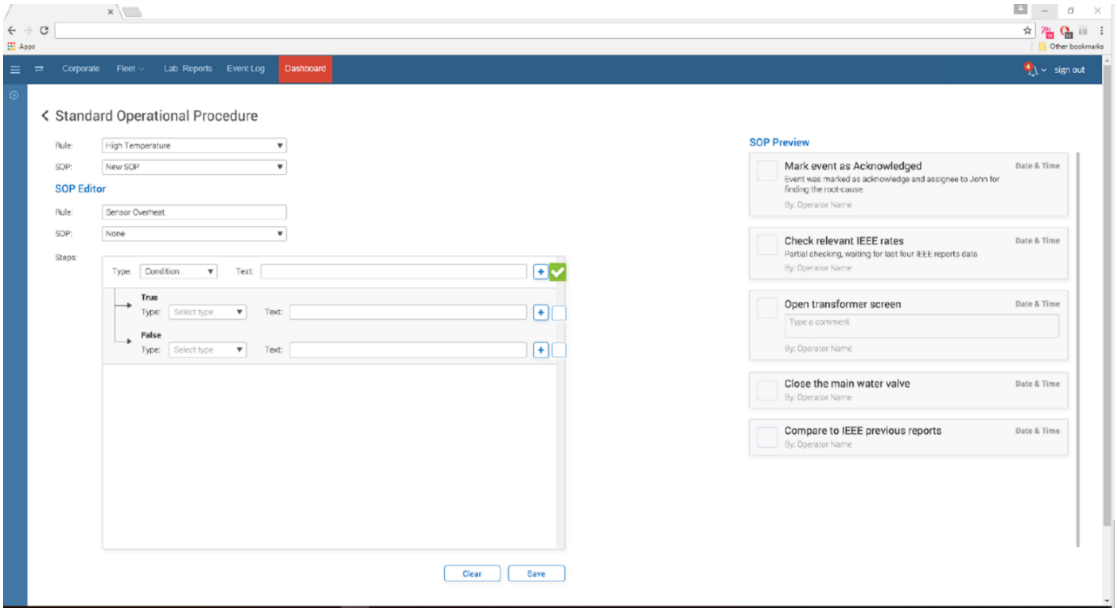


Figure 30: SOP editing view

The "Select rule…" field is a drop-down menu with the list of the existing rules and all potentially possible changes of the OI status (for example, from "Green" to "Red" and back). Every rule that is defined in the system is added to the list. To keep the menu simple, its content is shown in groups of "Rules" and "Overall Health Index" lists which by can be collapsed.

The field "Select SOP…" is a drop-down menu with the list of the SOPs that are associated with the previously selected rule or OI status change. It is disabled if no rule is selected. It also contains "New" as a default option that is displayed on top of the list.

Once the rule and "New" or any of the existing SOPs are selected, the information can be edited. In the case of selecting the existing SOP, it will upload the full definition of the SOP. Otherwise, it remains empty.

The SOP editor component contains the following:

- "SOP name…" is the editable field to insert a new name or edit the existing name of the SOP.
- "Periodic…" is a field to define the cycle of the SOP. It is a list that contains the following values ("Once", "Daily", "Monthly", "Quarterly", "Semi-annually", "Annually").
- "Type" is a field that enables the user to define the type of the step in the SOP. It contains the following values - "Checklist" and "Condition". The "Checklist" is the default value.
- "Text" is a field for inserting the text of the step in the SOP.
- + is a button to add one more step. If the type of the previous step is "Condition", it will automatically generate two steps, one for the case when the condition is "True" and another for the condition "False".
- Checkbox symbolizes if the comment should be added to the SOP step. It is selected by default.

The "Preview" component displays the real time definitions result.

3.4 Rules Engine

The Rules Engine provides the user a method to define rules for every single gas of DGA reports (both lab and online), SCADA tags, prediction of each gas and the alerts of the DGA online device (Transfix or any other). Additionally, the rules engine supports setting the same rule for a group of the units in the fleet, avoiding the need to set the same rule for each asset individually.

The "Rules engine" is an option in the main system toolbar.

3.4.1 Rules Editor

The rules editor supports the following capabilities:

- Adding threshold-based rules for a single gas (i.e. concentration and rate).
- Adding rules to check the status of the alerts (SCADA tags, Transfix alerts).

Additionally, the system automatically generates an event in the case of disconnection of one of the sub-systems (Maximo, PI, Gas analyzers (i.e. Transfix), USI, IR Camera, EPRI suite).

The display supports selection of units that will be monitored by the specific rule.

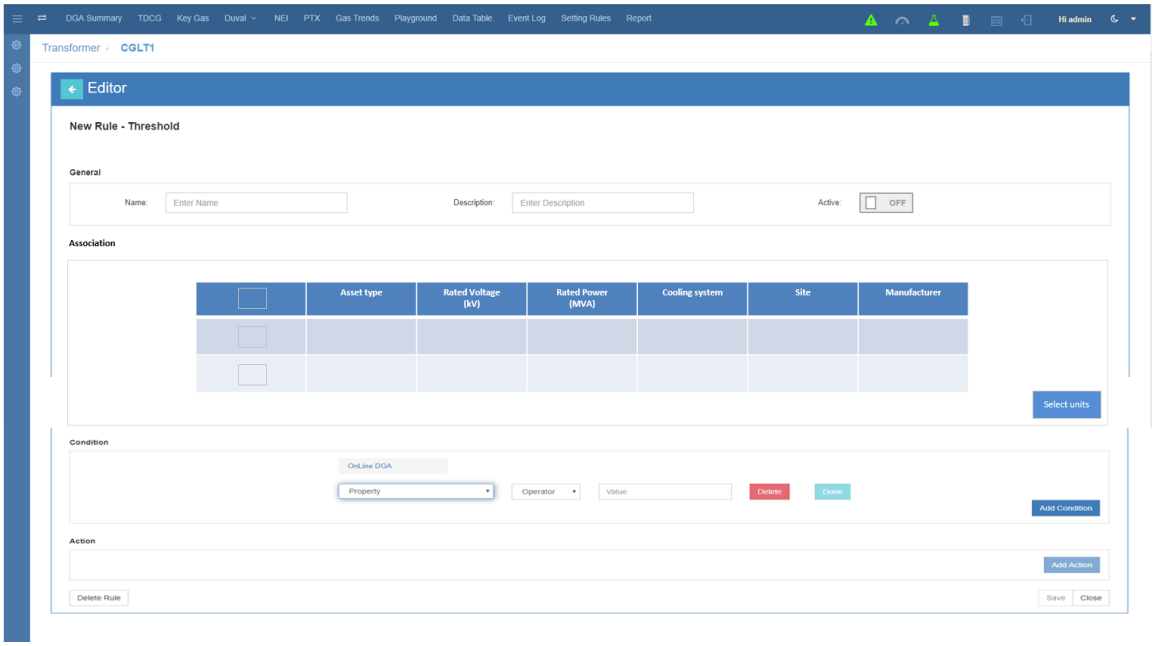


Figure 31: Rules Editor view

This section of the display presents the table with all items monitored by the system units. It contains the following columns:

- Checkbox –select this unit to be associated with the rule.
- Asset type – LTC/GSU
- Rated Voltage

- Rated Power
- Cooling system
- Site
- Manufacturer

The checkbox at the top supports "Select all" functionality for all actually presented units (after potential filtering) in the table. Additionally, the table supports filtering by selecting a specific value in each of the columns.

The system has the following options in the list of the available **conditions**:

- Online/Offline DGA -> Single gas -> Concentration/Rate/Prediction -> H2, CO, CH4, C2H6, C2H4, CO2, C2H2, N2, O2, H2O, CO2/CO
- SCADA -> Tags -> all associated with the specific unit tags. Prior to displaying the list of the tags, the system ensures that only one unit is selected in the "Association" component and presents error message otherwise. In case of selecting one of the tags, the only available operation is "=" and the only available values are "True" and "False".
- Sensor -> Gas Analyzer -> all associated with the specific device alerts. Prior to displaying the list of the alerts, the system ensures that only one unit is selected in the "Association" component and that the specific unit has a gas analyzer installed on it. Otherwise, it presents an error message. In case of selecting one of the alerts, the only available operation is "=" and the only available values are "True" and "False".

The system can also generate an event based on severity and send an email notification.

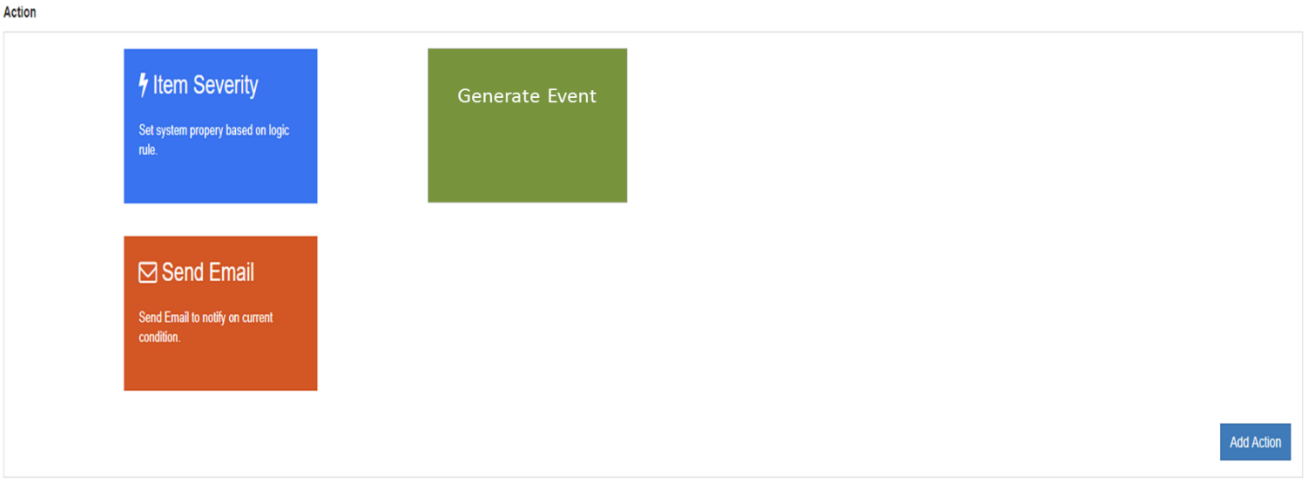


Figure 32: Rules Notification Options

4 Supplementary Tools in Analytical Menu Ribbon

	Displays events that occurred during the selected time interval. An event can be a standard computation that resulted from invalid samples or maintenance that was performed.

	Presents the analysis reports related to Transfix online gas samples. Enables toggling for event displays, including maintenance events and gas samples. Clicking it changes it from • Green: events are shown. • To gray: events are not shown.
	Presents the analysis reports related to laboratory (Doble as an example) offline gas samples. Enables toggling for event displays, including maintenance events and gas samples. • Green: events are shown. • To gray: events are not shown.
Pick a Date	Presents the date ranges for the selected transformer's data. It allows the operator to select, from all the date ranges, the specific ones to be presented in the analysis reports. 
	Makes available the forum where you can write and participate in a discussion about the condition of the transformer in question. 

5 Condition Levels

The conditions reported in THM are from a four-level criterion to classify risks to transformers for continued operation at various combustible gas levels. The criterion uses both concentrations for separate gases and the total concentration of all combustible gases. See **Table 1**.

Status	H2	CH4	C2H2	C2H4	C2H6	CO	CO2	TDCG[2]
Condition 1	≤ 100	≤ 120	≤ 1	≤ 50	≤ 65	≤ 350	≤ 2500	≤ 720
Condition 2	101–700	121–400	2–9	51–100	66–100	351–570	2500–4000	721–1920
Condition 3	701–1800	401–1000	10–35	101–200	101–150	571–1400	4001–10000	1921–4630
Condition 4	>1800	>1000	>35	>200	>150	>1400	>10000	>4630

Table 1: Dissolved Gas Concentrations in ppm[3]

- Condition 1: TDCG below this level indicates the transformer is operating satisfactorily. Any individual combustible gas exceeding specified levels should prompt additional investigation.
- Condition 2: TDCG within this range indicates greater than normal combustible gas level. Any individual combustible gas exceeding specified levels should prompt additional investigation. Fault(s) may be present.
- Condition 3: TDCG within this range indicates a high level of decomposition. Any individual combustible gas exceeding specified levels should prompt additional investigation. Action should be taken to establish a trend. Fault(s) are probably present.
- Condition 4: TDCG exceeding this value indicates excessive decomposition. Continued operation could result in failure of the transformer.

6 Health Indexes

The default Overall Health Index is combination of different standards and is based on the analysis of gases found in sampled oil. The following standards have indices of health and are used in the THM system:

- Corporate, mainly based on IEEE
- IEC 60599, provides health and analysis of failure
- IEEE C57.104, provides health and a set of analysis tools
- CIGRE 443, provides guidelines on health and a sampling interval
- NEI, provides health score between 1 and 4
- PTX, from EPRI, source of health indexes
- CO2/CO, an index to account for changes in paper insulation
- ABN, based on CIGRE, is an index of the extent of (abnormal) deviation of the transformer gas creation rate from normal rate

IEC 60599, IEEE C57.104, CIGRE 443, and NEI use thresholds for defining the condition of the transformer.

The following gases can be included or excluded from a customized Overall Health Index:

- H2

[2] TDCG does not include CO2, which is not a combustible gas.
[3] The numbers in **Error! Reference source not found.** are in parts per million of gas in oil.

- CH4
- C2H6
- C2H4
- C2H2
- CO
- CO2

6.1 Alerts

The system can be configured to send automated email notifications upon reaching a Health Index greater than one (1).

7 User Permissions

The mPrest THM solution is accessible to users from any standard Web browser. Users are required to login to the service with their Usernames and credentials. In some cases, the application is installed behind a corporate Firewall and is thus available for remote connection only over a corporate VPN.

The THM solution supports integration with Active Directory (AD). Three (3) built-in authorization groups are pre-defined in the product and should match the Roles definitions of AD users' groups.

8 Methodology

8.1 Common industry diagnostic techniques

The most commonly used technique to determine transformer health is based on Dissolved Gas Analysis (DGA). This technique can be based both on offline (lab-based) and online models. Several different methods exist which analyze gas level measurements. These are listed in **Table 2** below:

Name	Details
PTX	Transformer Analysis method based on Electric Power Research Institute (EPRI) software
IEEE	IEEE 57.104 standard
IEC	IEC 60599 standard
Corp	Configurable corporate standard based on IEEE. Provides an option to edit its thresholds in accordance with corporate best practices
NEI	Normalized Energy Intensity, a new analysis method
ABN	Abnormal change in the rate of gas

Table 2: Common Industry Diagnostic Health Indexes

Various additional transformer metrics can be measured to provide insight on its status and health, as indicated in **Table 3** below.

Name	Details
IR Sensors	Provide temperature readings on various transformer components, based on IR camera
Bushing Monitoring	Readings on the bushings, such as capacitance
Geomagnetic Induced Currents	Sensors to detect GIC
RFI	Detectors used to isolate internally generated RFI
Tank Vibration	Tank vibration sensor
Tank Temperature	Oil tank temperature sensor
Acoustic Emission	Detects acoustic emissions from the transformer
SCADA Readings	Various sensors reporting by SCADA, e.g. DC source of the Main Transformer Annunciator
Transformer Load	Current load on the transformer

Table 3: Non-DGA sensors used to monitor transformer health

8.2 mPrest Methodology and Technology

mPrest has designed, developed and field proofed superior analytical methodologies to provide a much more accurate identification of transformers status, and better prediction of future failures before they occur.

There are two different types of methodologies:

- **mPrest DGA Abnormality Trend Analysis (ABN)** – Valid for Online DGA readings, ABN is a new algorithm designed to improve and complement standard DGA methodology and provide higher sensitivity to potential catastrophic failures, detecting them far ahead of other DGA techniques, by monitoring abnormal changes in the rates of the gases in the transformer.
- **mPrest combined Overall Health Index** – combining information from a variety of the sensors and different DGA techniques discussed above (as available on a particular transformer), this methodology provides analysis of the health and future status of a transformer beyond just a DGA check, by checking states and trends for many more parameters in the transformer environment.

mPrest's diagnostics have been evaluated by EPRI. The results have been proven superior to other DGA methodologies. The mPrest THM solution has been proven to detect faults with better accuracy and to predict them earlier than other tested methodologies.