Leak Detection System - LDS

Product description

Document Revision List

REV	DATA	AUTHOR	DESCRIPTION
01	11/26/2013	L. Castiglioni	New document format update
02	17/05/2022	M. Pentolini	Compliance with ISO 27001

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1. Introduction

1.1 Document purpose

This document describes the main functionalities of eXPert LDS (Leak Detection System) real time environment, in particular:

- Leak Detection System (LDS) philosophy;
- LDS identification methods;
- LDS interface supported;
- LDS simulation.

In general hardware and software infrastructure is based on products projected, developed and distributed by s.d.i. automazione industriale.

2. LDS System

2.1 LDS System Philosophy

2.1.1 Process fluid characterization

Software tools for computing main thermodynamics gas proprieties the are the most important components in order to implement a well-run mathematical dynamic pipeline model.

In general, application requires using the thermodynamic tables for single or multi-component fluids.

According with the input and output pipeline available data and measures, the thermodynamic tables will produce the calculated gas properties, starting from three independent thermodynamic coordinates (ex: pressure, specific enthalpy and fluid composition), for all the operating range specified for the plant.

When fluid to be characterized is composed by different elements (i. e. gas), pipeline model is in general realized assuming that its composition is a constant parameter each time, correction could be realized using different tools:

- Plant operator modification via HMI interface between design constraints;
- On-line acquisition from field instruments (ex. Gascromatographs).

Composition correction implementation way is evaluated each time depending on system architecture and specific customer requests.

At the end of this process, pipeline model realized is a “robust” model, which ensure detection of leaks also with small composition changing (if applicable).

2.1.2 Software Modules

Following modules compose the LDS software package:

- Data acquisition and validation;
- Real time pipeline model;
- Pipeline leak detection and localization algorithms;
- Limit values management;
- Operator alarms generation and diagnostic functions;
- Pipeline simulator.

2.1.2.1 Data acquisition and Validation

Acquisition module communicates with the SCADA to exchange real time plant data, in detail:

- Collects from SCADA Real Time Data Base at specified time intervals following data:
  - Process values and their status indicators (available, out of range, out of scan, …);
  - Valves status (open/close) and their status indicators (available, out of scan, alarm,…);
- Writes into SCADA Real Time Data Base at the end of every computation cycle following data:
  - Leak detection alarm and alert status to draw the attention of operator to perform actions related to the system status changing;
  - Leak estimated value;
  - Mass leak integrated value;
  - Estimated leak localization;
  - Process estimated status, this is a set of estimated values of the process variable in the pipeline;
  - Diagnostic indicators and values to measure the on line performance of the mathematical model (iteration steps, solution numeric precision, ..).

Validation module performs following processing on data retrieved from SCADA:

- Full measures validation;
- Invalid measure estimation.

All data acquired from SCADA Data Base have quality status indicators; module examines these status indicators to know the validity of each measure.

For all invalid measures (BAD status indicator), software module computes a substitutive value using appropriate algorithms, in this way values computation can go over, as far as possible, problems related to or missing measures.

Therefore the invalid value substitution is a combination of two methods:

- *Mathematical*: using a value computed by the process dynamic model;
- *Statistic*: using an estimation algorithm based on statistical method.

2.1.2.2 Real-time Pipeline Model

Software module computes the thermo-hydraulic status evolution of the whole transport network, using SCADA collected values to assign the boundary input/output conditions.

LDS package uses differential equations with a non-linear partial derivatives based model to obtain an accurate dynamic description of the pipeline.

The differential equations, with independents variables: t = time and x = space, represent the three fundamental conservation laws:

- Conservation of mass (continuity equation);
- Conservation of momentum;
- Conservation of energy.

For pipeline modeling is used a method called “out of phase cells” to build a discrete model with equations in the time and space variables, dividing entire pipeline into a finite number of segments of different length.

This direct integration method showed in numerous applications a very high level of accuracy in describing mass transport phenomena, momentum and energy conservation in pipeline modeling; also, it assures a robust and efficient numeric solution method.

From the model point of view the pipeline can be subdivided in different segments of different length, each characterized by a mean pressure value. This allows building dynamically, step by step, a true pressure and flowing profile for the whole pipeline.

Are needed two different classes of data to configure the pipeline mathematical model and then to perform the tuning step:

- Physical geometric data:
    - Length and diameter of the pipeline tubes;
    - Altimetry profile of the pipeline;
    - Diameter, thickness and characteristics of the pipe materials;
    - Pipe external thermal conditions;
- Environmental data:
    - Pressure loss and thermal profile between line input and line output at nominal load conditions.

Number of cells used for pipeline modeling is a good compromise between computing “power “ available for process simulating and accuracy desired.

2.1.2.3 Pipeline Leak Detection and Localization Algorithms

This module detects the pipeline leaks by evaluating differences between the field values and the on line model’s computed values.

Module can detect gas leaks also if there is no fluid flow in the pipeline; aren’t valid operating condition PSD or ESD pipeline states, this means that pipeline model is going to follow anomalous situations but no leak alarms will be displayed.

In the following we will refer to the most usual process condition when the fluid is flowing into the pipeline in permanent or transition regimen conditions.

In general, leak indexes calculation is performed utilizing two different methods, both used at the same time:

- **Mass balance (MB)**

  Leak index calculation is based on mass balance analysis between input and output measures. This method use the model-estimated fluid mass accumulated into the pipeline. This estimated value is very accurate due to the characteristics of the used mathematic model.

  Continuously the mathematic model corrects the unbalance of the flow rate, taking into the account the distributed mass accumulation value.

  The monitoring time needed to detect a leak depends on the loss value in a reverse way.

  eXPert LDS uses dynamic alarm limits to inform the operator of possible leaks. These limits are corrected automatically taking into account the true pipeline load (flow rate), in order to maintain unchanged the percentage confidence limits.

As a final result we obtain an estimation of the quantity of fluid leakage and consequently it's possible to compute the total (integrated) quantity of mass fluid loss.

- **Pressure and flow method (PF)**

  This method uses the loss index by considering the mass balance at pipeline position where pressure measures are available.

  The algorithm analyzes the difference between the measured pressure drop and the correspondent value computed by the real time pipeline mathematical model. Leakage events create variables variation which are related using propagation equations in the pipeline. Analysis of induced waves propagation allow estimation of event intensity (when possible), position and time stamp.

So, the difference, between computed pressure drop value and measured pressure drop value is directly connected to differences of the input/output flow rate due to the possible fluid leak.

Comparing results from both leak detection methods, system can identify leaks on the pipeline in a better way because are used, in a combined way, information which come from different physical phenomena in order to identify anomalous operating conditions (deviation from standard operating conditions).

Characteristics of each method can be summarized as described below:

- **Mass Balance method (MB)**: is a leak detection method very accurate that can identify leaks, also very small leaks, observing system conditions on long time intervals (various hours). This method, based on a mass integral calculation, can't identify leak position.
- **Pressure and Flow method (PF)**: is a leak detection method that can identify big leaks long pipeline, leak identification time is related to moment when pressure and flow waves are founded at the nearest pressure measuring point to leakage; this means that identification time also depends on pipeline project.

In general, system will generate alert and alarm reports that allow operators to evaluate pipeline state and leaks; operators can identify a leakage noting that a series of alarms (alarms that persist in alarms page) is presented in alarms page, this phenomena which convince operators that an anomalous trend is in progress and an anomalous situation is reached. Some spurious alerts can be generated related to system border conditions (ex. start/stop of compressors, operations on pipeline, ...); anyway these alerts and alarms during steady operating conditions will disappear and operator will check absence of leakages from normal conditions displayed on general HMI interface of **MB** and **PF** methods.

2.1.2.4 Limit values management

Independently of method used, the computed values of the loss indexes must be verified with adequate values to quantify the confidence level to assign to status detection of possible leak. Goal of this procedure is:

- Reduce the operator alerts and alarms;
- Increase the confidence limits of every alert or alarm.

System allows three different modes to manage these parameter values:

- Manually: values are assigned by operator;
- Semiautomatic mode: values are computed by system but operator can change them manually;
- Automatic mode: the parameter values are automatically system computed.

The LDS system will automatically change the limit's values if:

- Some process measures are invalid and it is necessary to estimate their values;
- The process operating conditions are critical, like after an intervention of plant protections.

The adopted policy is to augment the limit's values proportionally to the critical operating level.

2.1.2.5 Operator alarms generation and diagnostic functions

The LDS system provides two different alarm levels:

- Pre-alarm level (also called alert) to indicate a warning condition to the operator;
- Alarm level: to confirm to the operator a previous warning and to indicate a more concrete possibility of pipeline leakage.

Each alarm level has its own graphic representations to give immediate information to operator.

The software assigns the alarm level using the following parameters:

- Drop magnitude of the loss indexes reported to the actual limit values;
- Frequency of the event: event n-time repeated in succession in a time period. Time period and frequency value are settable by the operator;
- Logical combination of the two previous conditions;
- Leak detected by one or both methods.

2.1.3 Operator Interface

The operator interface is based on several Video Display Unit (VDU) pages dedicated to the package parameterization, program monitoring and functional commands.

The interface structure is based on the following architecture:

- Display pages for the configuration, setup and memorization of the whole system parameters;
- Display pages for the real time pipeline simulator monitoring and command (input parameter setting, ...). The operator has the possibility to visualize and compare temperature, density, pressure and flow rate profiles measured

values with the on line mathematical model computed ones, for the whole pipeline

- General plant synoptic page displays both the acquired measures and the model-calculated values. From this page, the operator can require the profile pipeline visualization for the main process measures:
  - Pressure;
  - Density;
  - Fluid composition;
  - Mass flow rate;
- Alarm page: with alarms, diagnostic information about the model and the leak detection modules performance (numerical precision, computing CPU load, number of step, confidence result's levels, ..);

- Real time and historical trend displays for the main variables;
- Detailed diagnostic pages for the two Leak Detection methods (**MB** and **PF**);
- Detailed Leak Detection status page. This page display all alarm and alert conditions plus:
- Current limit's values;
- Numerical values of loss indexes;
- Current loss estimation;
- Total accumulated estimated mass loss.

2.2 Leak Detection System (LDS)

Following scheme summarize information flow between software modules involved in LDS procedures.

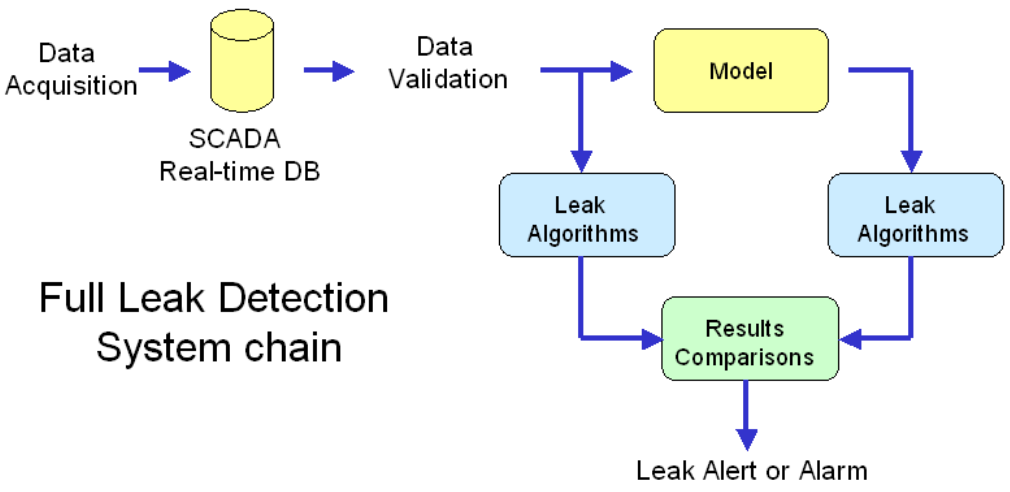

Figure 1: Leak Detection System architecture

Leak detection chain is composed by following steps:

- Data Acquisition: is the process which picks-up plant variables from SCADA DB;
- Data Validation: process which controls data values and estimates, if needed, via mathematical or statistical way all values not acquired;
- Pipeline Status Estimation: using data acquired and integrated by Data Validation procedure, a model works over these data to estimate real pipeline situation in a working condition without leaks (standard conditions);
- Leak Algorithms: Are defined two distinct algorithm methods based on Mass Balance (MB) and Pressure and Flow Rate (PF) which work at the same time on filed-data and model-data;
- Results Comparisons: This step is used to identify leaks comparing and identifying differences between results produced by two methods previous described;
- Leak Alert or Alarm: two levels of leak detection are ensured, Alert in order to alert operators about a possible leak phenomena and Alarm in order to give advice about a real leak over pipeline; in both of previous situation leak alert or alarm also a confidence level indicator is given.

2.3 LDS System Interface

LDS system has a graphic interface based on the same real-time modules used in standard HMI interface adopted in eXPert SCADA/DCS product; in next pages are shown hardcopy (from a gas pipeline) of most important components of a LDS system.

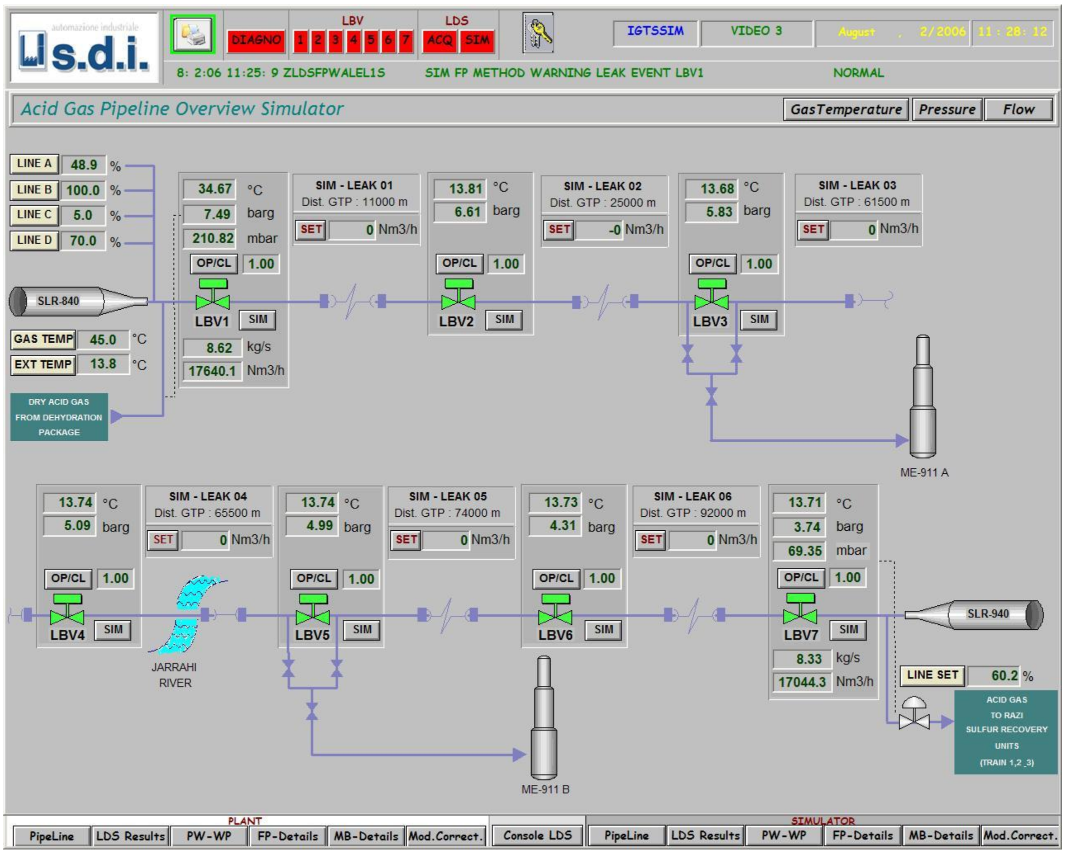

Figure 2: General pipeline monitoring interface from P&ID scheme

In general LDS system is composed by a general pipeline synoptic realized starting from P&ID schemes, representation shows main system elements with measures and status signals acquired from control and monitoring system. Depending on the level of interaction required, interface can be provided with command window in order to realize actions directly on field devices.

In previous page are available buttons for activating trend about most important process variables where is shown the profile long pipeline, in particular:

- Mass flow (Figure 3);
- Pressure (Figure 4);
- Temperature (Figure 5).

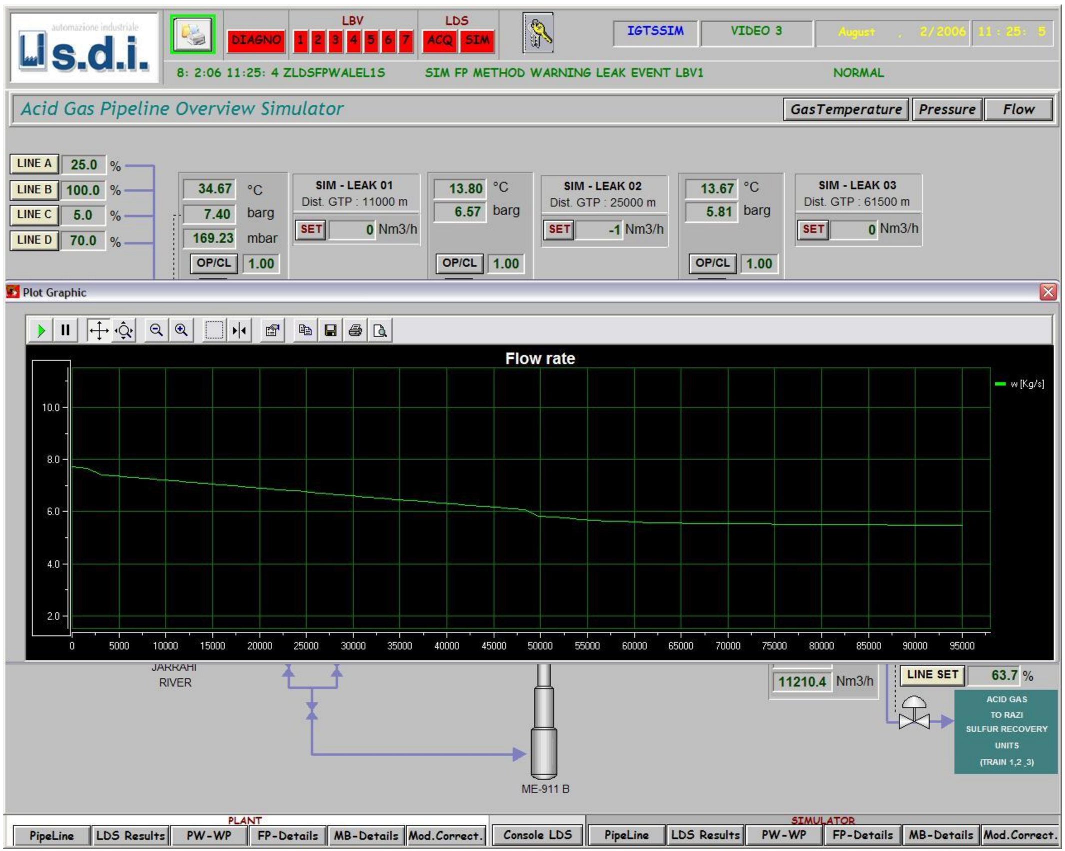

Figure 3: Mass flow profile long pipeline after a simulation of leak

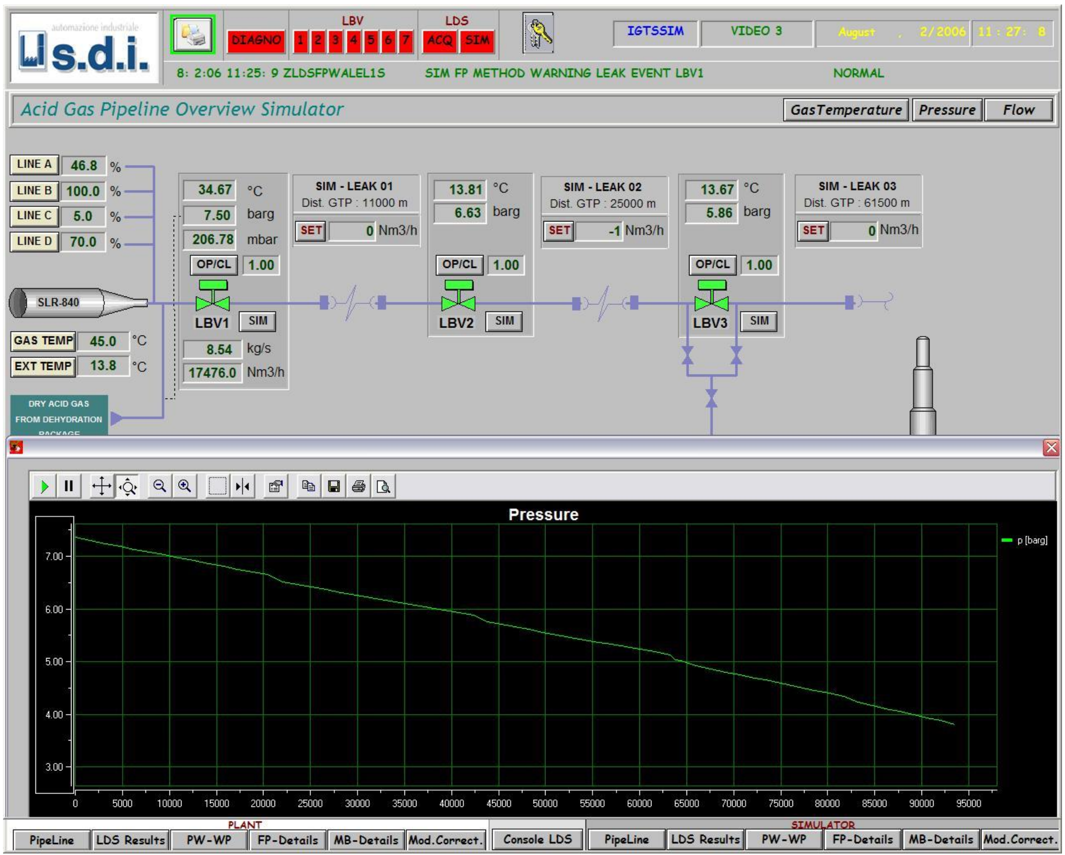

Figure 4: Pressure profile long pipeline after a simulation of leak

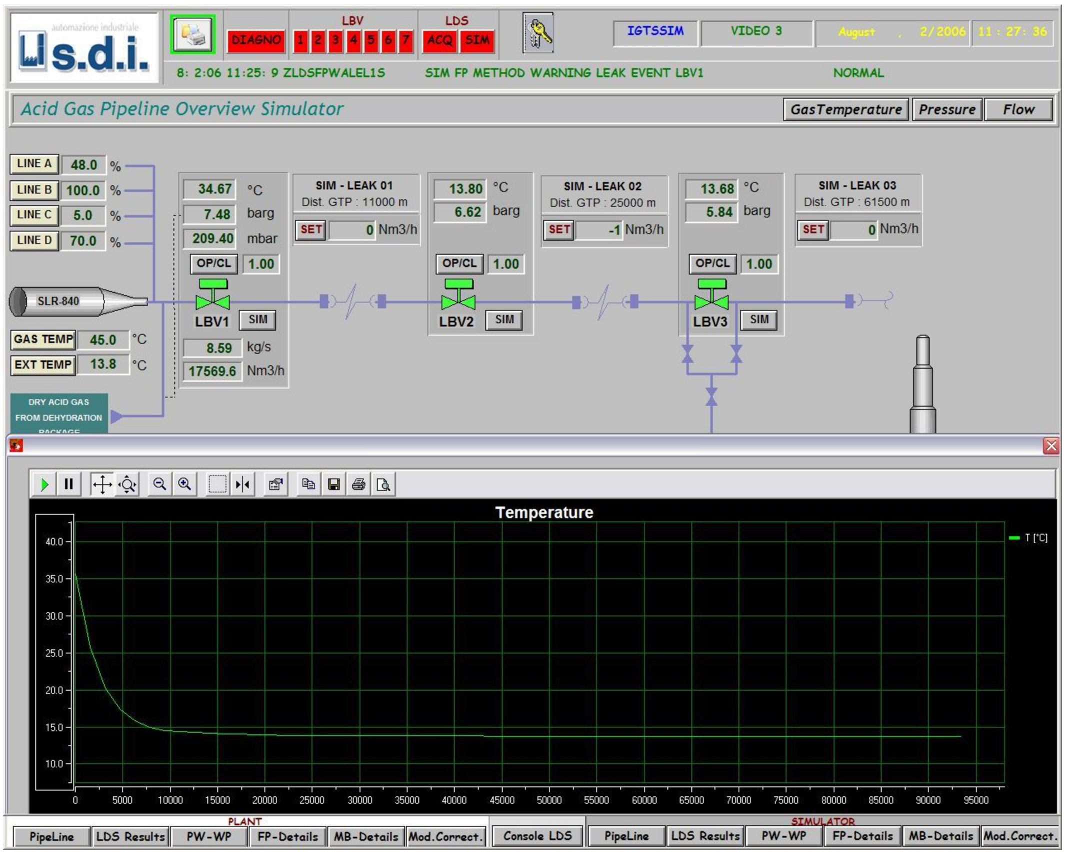

Figure 5: Temperature profile long pipeline

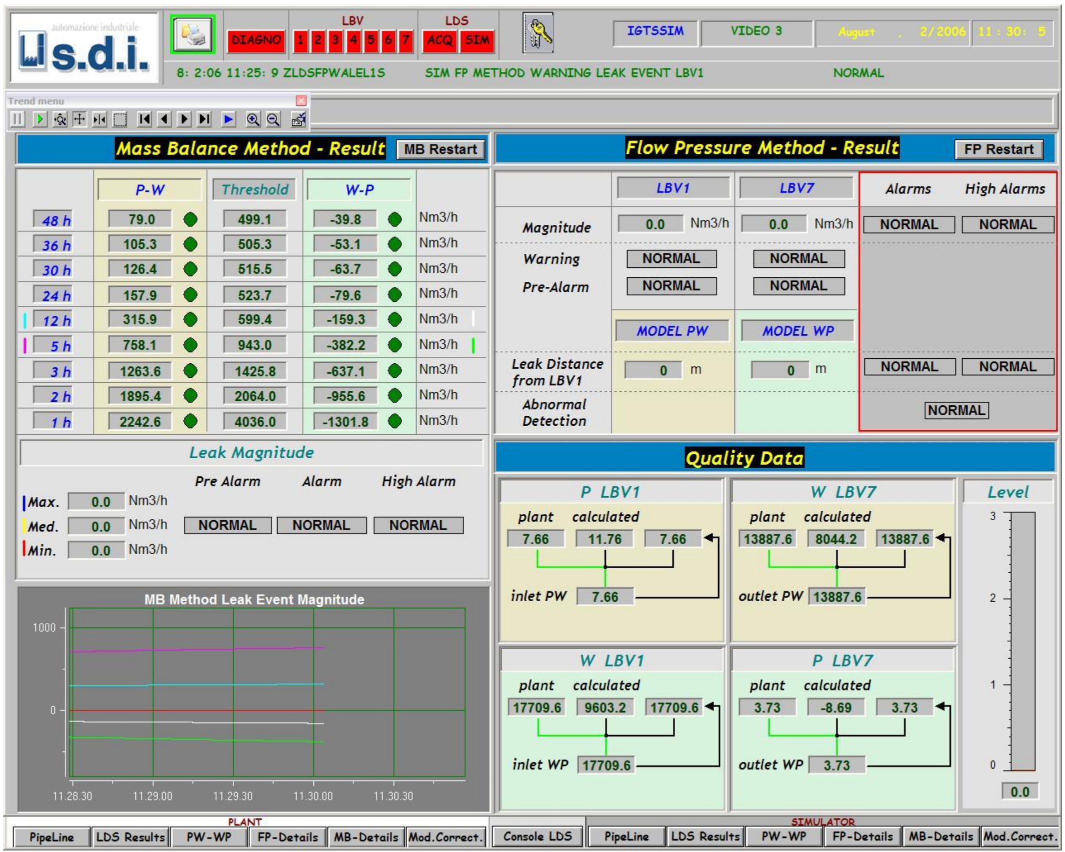

Figure 6: General interface about MB and PF leak detection methods

eXPert LDS product is provided with different interfaces directly connected with leak detection algorithm that give overall (Figure 6) and detailed information about state of algorithms in process.

Overall interface gives a general overview about leak identification process based on two method previous described (MB and PF). Section MB shows alert and alarm status identified by validation of integral mass calculation with constraints inserted; this section shows also an estimation of leakage in terms of minimum, medium and maximum value calculated. Section PF instead shows value of leakage estimated at ends of pipeline (in example shown stations 1 and 7) and related alarms. General scheme is completed by information about quality and type of data used for computation, in particular a discrimination is done showing if measures used for model computation are field measure (come from plant) or calculated measure (calculated indirectly from pipeline model). Using calculated variables from model is possible make up for lack of field values when problems on field devices (RTU, PLC, instruments, ...) occur. This function is available until significant process data are collected so model can be connected correctly with process; if information are unavailable or with bad qualifiers for a long time period system will work on last valid data acquired waiting for reconnection to monitored process.

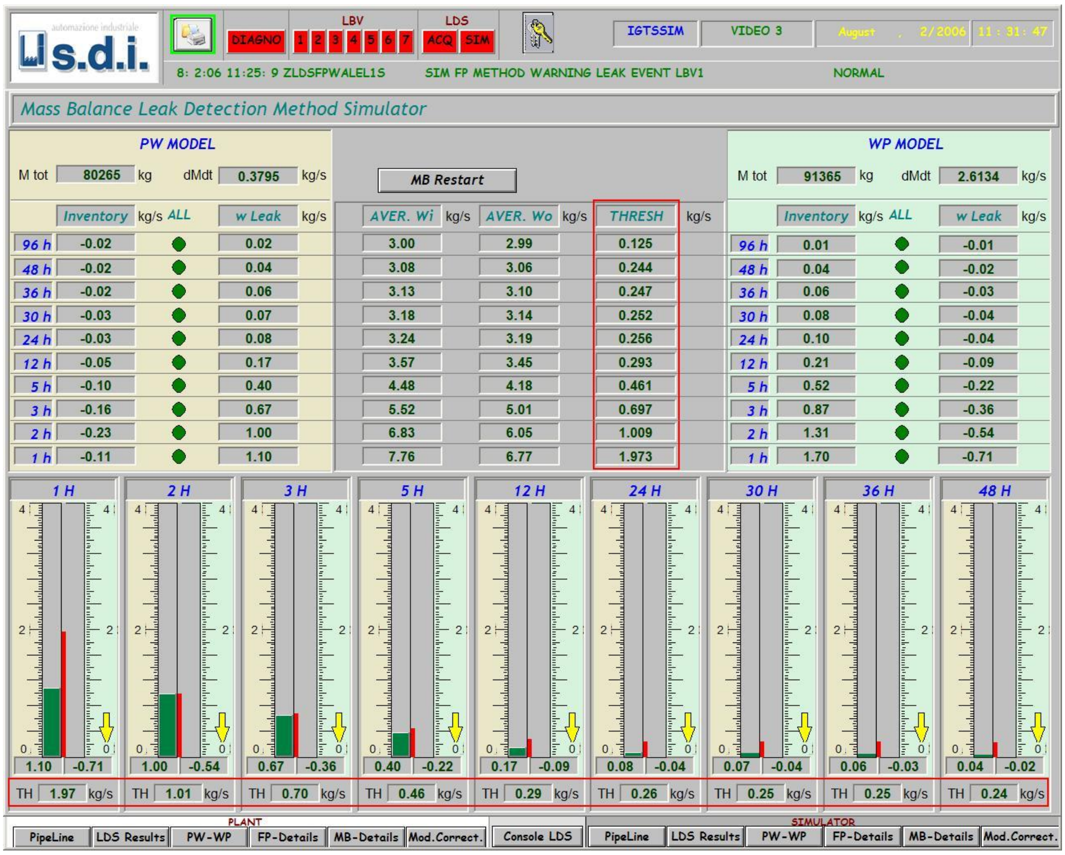

Figure 7: Detailed state interface about MB leak detection method

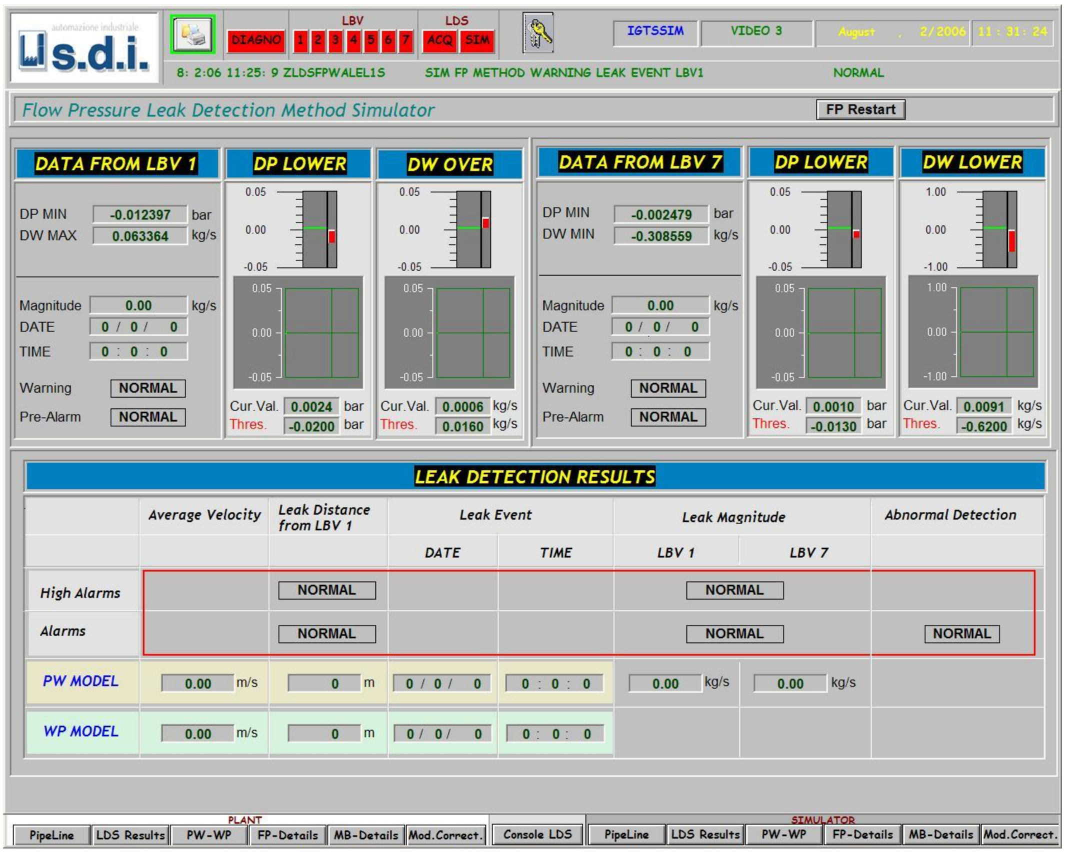

Figure 8: Detailed state interface about PF leak detection method

Each leak detection method has a dedicated interface page where are shown detailed information. MB interface shows all thresholds set used for comparisons and alarms generation, integrated leak value calculated on different temporal horizon monitored (1 hour, 2 hours, ..., 48 hours); each histogram shows information about system working trend so operators can evaluate if anomalous situation is connected with a transitory phenomenon or a permanent phenomenon (that means a real alarm situation).

PF method interface shows information about flow and pressure waves identified at the ends of pipeline in order to perform a cross check of anomalous states detected on the basis of predefined time interval.

In order to fit, in the best way, simulated model with real process and reduce spurious warnings and alerts two models are in general realized using field variables (Pressure (P) and Mass flow (W)) crossing data with simulated value; in particular:

- **PW Model**: inlet pressure and outlet flow acquired from filed, outlet pressure and inlet flow calculated using internal model;
- **WP Model**: inlet flow and outlet pressure acquired from field, outlet flow and inlet pressure calculated using internal model.

In steady operating conditions pressure and flow profile long pipeline estimated by two models are almost superimposed, when a disturbance happens model PW and WP will change their state moving in a phase displacement condition until both of them will identify the same variation, after that situation models will move together toward another superimposed state (Figure 9).

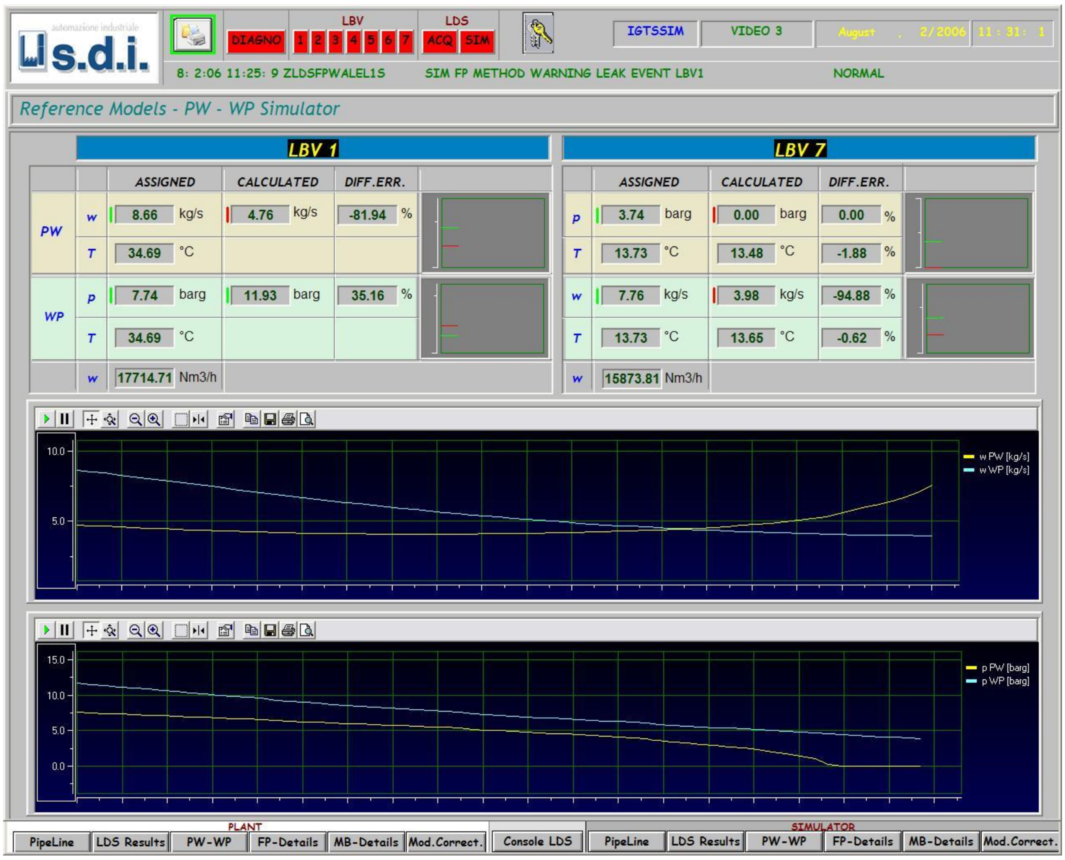

Figure 9: PW and WP models state interface

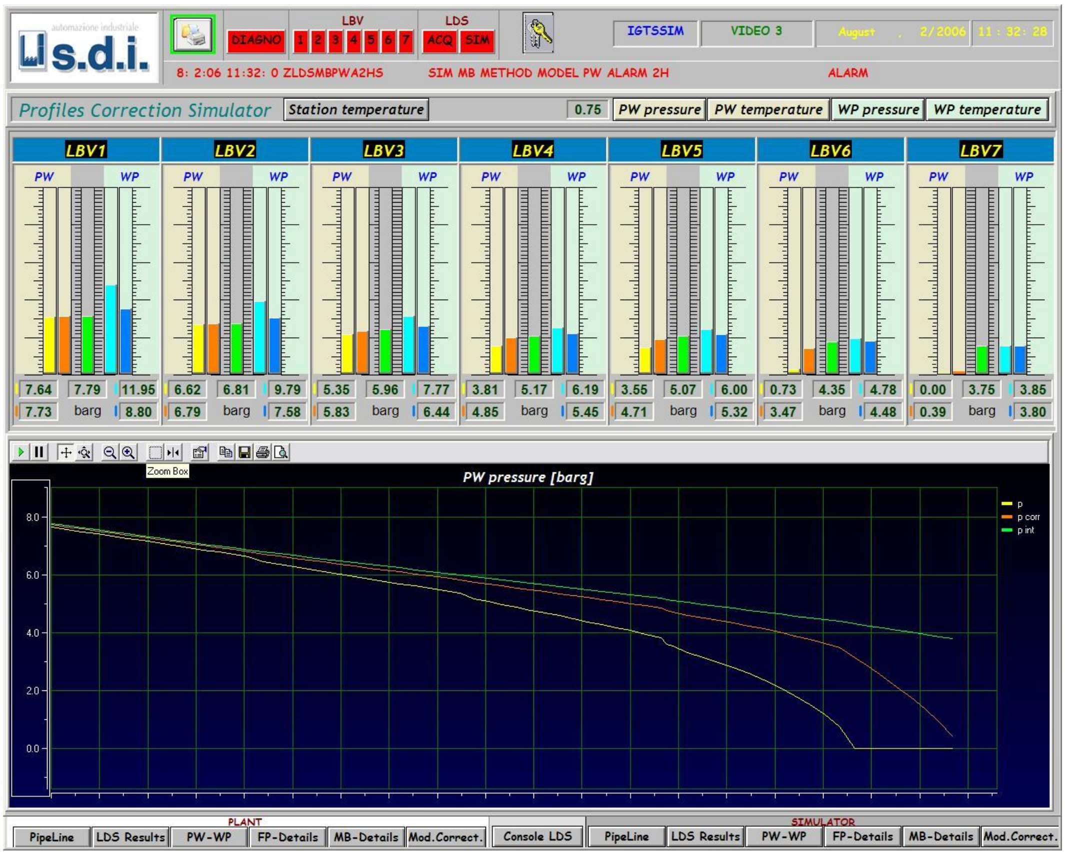

Figure 10: On-line model parameters correction interface basing on intermediate pressure information

If intermediate pressure measures are available, model developed basing on pipeline project can be enriched with these new information in order to fit in the best way real conditions. A synoptic interface is provided to realize model tuning (small entity) during site activities (Figure 10).

2.4 LDS System external data exchanging

eXPert LDS product can be connected with other external systems using standard communication drivers in a master/slave architecture, this means that OPC, MODBUS RTU/ASCII/TCP, IEC 870.5.101, IEC 870.5.104 protocols are available and can be used for data exchanging with SCADA or DCS systems.

2.5 LDS System Simulator

2.5.1 Pipeline Simulator

Basing on real-time pipeline model developed for LDS, optionally a true real time simulator can be added to system. It's being based on the same mathematical model used for the leak detection algorithms.

Simulator proposed is characterized by the same operator console already described for LDS system; this console works on simulated variables, instead field values, so model can be hooked up to real condition in order to reach same field operating state. Simulator, starting from this state, can be unhook and can be used:

- By engineers, to execute actions on pipeline and analyze system evolution;
- By operators, for training.

Moreover the LDS system can be activate in two modalities:

- *Simulated mode*: all data necessary to leak detection function are calculated by the simulator and not acquired from control system (SCADA/DCS);
- *Real mode*: all data necessary to Leak detection function are process values acquired from the control system (SCADA/DCS).

The LDS system console allows the operator or the system engineer to:

- Activate leaks of variable flow rate in predefined positions on the pipeline;
- Remove the leaks previously introduced;
- Manually modify the input variables to simulate and evaluate a possible pipeline scenario.

The availability of the process simulator can be exploited also for different aims, like:

- To verify the behavior of the system in more realistic conditions, during the Factory Test (FAT);
- To allow the on line analysis of different process situations, by comparing the field acquired measures with the simulator-computed values and the values of the on-line model synchronized with the process;
- To verify the precision and the behavior of the LDS also if the process is not connected, during the On Site Test (SAT);
- To utilize the simulator results to build an Operator Guide for the main plant operations.

Is important to signal, that simulator previous described is only a simulation environment for testing pipeline system under different operative conditions, it is not a complete and on-line environment for testing and designing pipeline or other elements; in fact in simulator described aren't available some functions like following:

- Capability to simulate different pipeline design conditions (size, length, thickness, ...);
- Capability to simulate different pipeline fluid.

moreover model hasn't been designed for test and simulate all field plant and device with real and detailed operating conditions, for example:

- About plant facilities are modeled only characteristics related to pipeline operating conditions and not complete and detailed plant element characteristics (i.e. for pumps or compressors: set-point change ramps , for valves: real opening and closing procedures, for plants: automations implemented, …);
- Situations related to out of work of devices;
- ESD and PSD states;
- ...

Anyway, eXPert modeling suite is a real powerful real-time simulating platform and, if required, a simulator with higher detailed model of boundary elements can be supplied.