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Tie Backs and Partner Allocation

A Model Based System for meter verification and monitoring

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Abstract/Introduction

This paper is addressing the operation and management of flow instrumentation in complex subsea and topside infrastructures. Special attention is given to situations where measurement inaccuracies may influence the allocation process over time and cause significant imbalance in the monetary flow, and eventually lead to legal disputes between partners over the allocated volumes.
This paper will offer a description of how a model based system can be used to overcome the challenges of describing measurement accuracy, need for reallocation, when/what to re-calibrate as well as a total overview of the flow instrumentation status– utilizing information from every instrument and device from subsea and downhole through multiphase meters, separators all the way through the custody transfer metering system.

A Condition based Performance Monitoring system for a *complete overview* of the instrumentation system including instrument status and accuracy indication is also described.

By utilizing flow modelling techniques, *fast fault detection* can be achieved to *minimize the need for re-allocation*. In a potential fault situation, an online model will provide backup calculations based on the existing instrumentation and include the custody transfer meters as the validator and total system watchdog.

In cases where re-allocation is required, the model can be used to provide model based re-calculation.

By tracking compositions from the wells to the fiscal metering point and comparing trends a well test advisory is given.

1 Challenge

In many fields the flow instrumentation is used for both managing the production process and allocation. If a biased instrument is allowed to influence the allocation process over time this can cause significant imbalance in the monetary flow, and could eventually lead to legal disputes between partners. Early detection allows the operator to take appropriate action and moves the response from unplanned events to planned operations.

Quality control of the upstream flow instrumentation system is normally done by verification using topside test facilities. Dedicated well meters may not be verified at all due to failure to produce a representative rate to test facilities. Therefore meter verification might only be possible during rare and costly test campaigns. Depending on the subsea architecture, such as in Figure 1, the tests themselves could also be very uncertain. Testing wells can also defer production. In contrast, pipeline flow meters can be verified at normal production rates. The difficulty of verification can lead to some meters operating with biases for long periods of time.

The challenge becomes how to verify and maintain the flow metering equipment while at the same time minimising production loss due to testing. A good metering system for the allocation process will also be a good basis for production optimization.

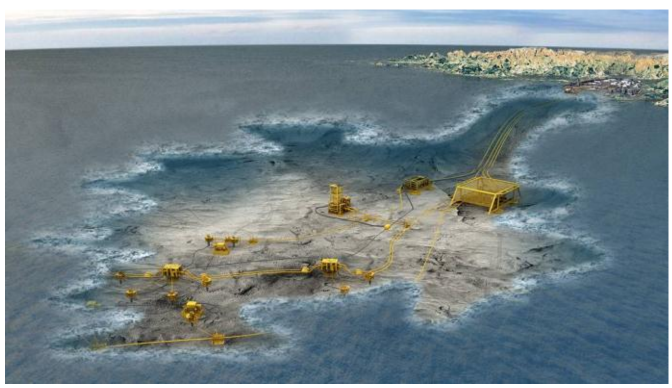

Figure 1 Complex subsea field infrastructure can make meter verification very difficult and costly

2 Model based system

A real-time model based system analyzes information from all available sources such as the process control system and production databases and present them in a unified way. Combining multiphase and fluid modelling with statistical analysis and mathematical optimization creates the foundation for condition based monitoring of the upstream process as well as the topside process facilities that can provide early error detection and bridge the gap between metering, allocation and well performance.

A model based system utilizes all available sensors such as temperature, pressure, pressure drop over choke and Multiphase meter (MPFM) primary instrumentation and calculated rates combined with the multiphase models in calculating the actual flow. By including all available information in the model based analysis redundancies can be exploited to enable a more fault tolerant system.

This paper describes an online model based system based on WATCH from FMC Technologies comprised of three different parts: Upstream module, Overall mass balance module and Well Test support module. WATCH is a common software platform for Metering, Production Performance, Flow Assurance and Asset Integrity systems. WATCH is used in more than 30 online field applications modelling more than 700 wells and have been installed encompassing both virtual flow metering systems (VFMS), Overall Flow Metering Systems (OFMS) and flow assurance advisory systems (FAS) using state of the art steady state and transient multiphase flow modes. Since 2011 the technology was expanded to include “Condition and Performance Monitoring” (CPM) of subsea equipment. Figure 2 shows a screen shot from an online VFMS application.

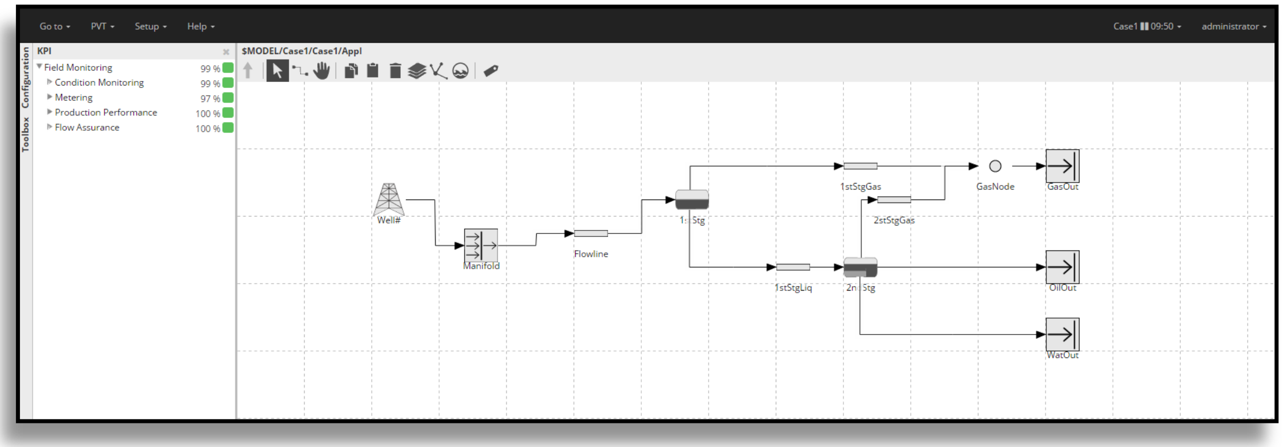

Figure 2 A screenshot from a model based monitoring system containing a single well, flowline and topside separation process

The Upstream Module includes the wells and subsea production network. The overall mass balance module uses the output from the Upstream Module, topside instrumentation and custody transfer metering system to calculate accurate status indications for all meters. The Well Test support module can flag wells as candidates for well tests. It can also help with the test itself by providing real time estimates of stabilization time and source tracking during a test, and, through the an integrated PVT package, act as a conversion tool between topside and subsea conditions, mass and volumetric rates.

Through these modules, early error detection, status indication for all meters, well test advice and real time support during well testing can be achieved. Figure 3 shows how the different modules interact. Each module can work alone, or together with any other.

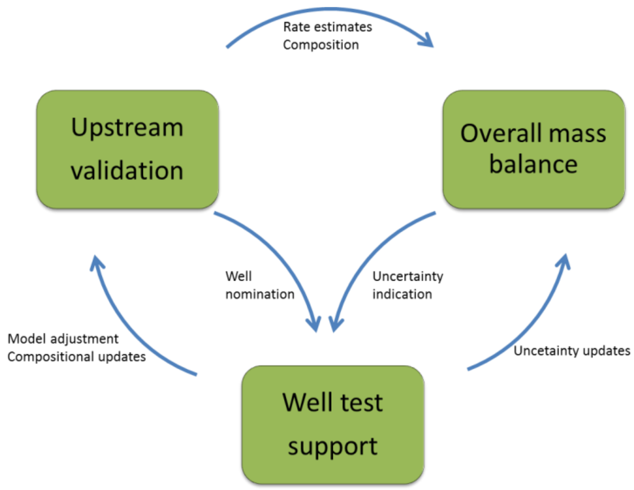

Figure 3 How the different modules can interact, each module can also work independently

2.1 Early fault finding

A model based system is able to compare sensors through mass, energy and momentum balances and in this way uses all available instrumentation to validate meters. Analysis is then performed using built-in statistical tools for error detection and mathematical optimization to extract information from the system, which is presented as technical conditions.
Early indication of meter failure reduces the need for re-calculation and allows the operator to include meters in scheduled maintenance tasks ahead of time and avoid unplanned maintenance and thereby reducing cost. An illustration of this is given in Figure 4.

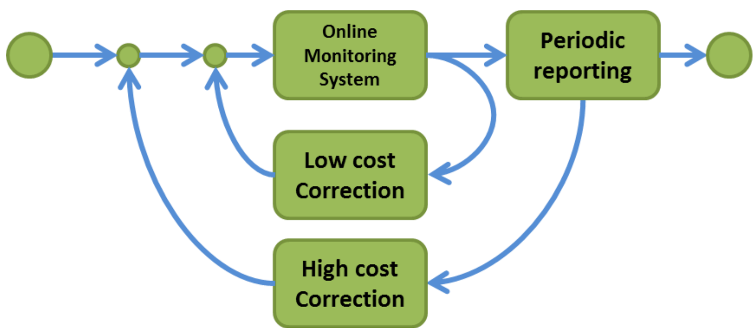

Figure 4 Detecting errors early allows minimizes the impact from errors

2.1.1 Technical Conditions

The technical condition of the meters is quantified by technical condition indexes (TCIs). The TCIs are normalized values that are aggregated upwards in an established hierarchy to the desired level, usually following the structure of the field layout or different use cases.

A technical condition is compounded of many parameters for example the availability of the tag, if the value communicated from the database within set parameters; frozen, max rate of change, min/max limits and comparing the meter with redundant or neighboring meters etc.
These are hard failures. The second contribution comes from the model based system, where the deviation between a calculated value and measured value is compared relative to the sensor and

model uncertainty. The statistical analysis performs Gross Error detection on the system and reports the Gross Error as an alarm and as a TCI indication as seen in Figure 5

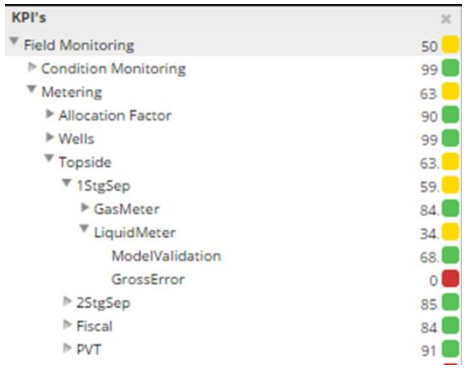

Figure 5 An example of how a TCI tree can be built up with according to specific users need, for Metering the application has detected a Gross Error in the 1st Stage Separator Liquid Meter.

The TCI's are organized in a tree structure so that each discipline receives relevant information for their use cases. Examples of different users could be:

- Allocation and metering
- Petroleum Technology
- Operations
- Maintenance
- Commercial reporting

This is illustrated in Figure 6.

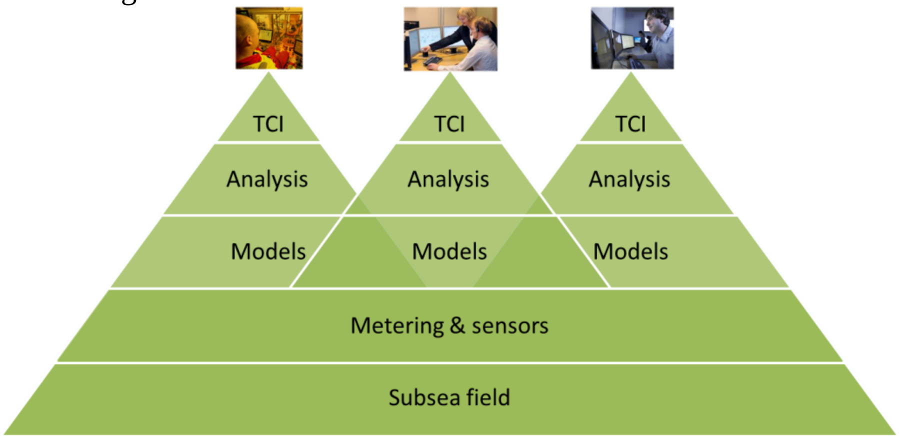

Figure 6 The TCI's are aggregated information reflecting the status of all layers under it and customized for each discipline

The TCI's are linked to a notification system which can be set up to send push notices as emails or other services such as SMS. This allows the user to get a quick overview and can locate errors quickly before they can create large negative impacts.

3 Overall Mass Balance

The overall mass balance is used to validate the well rates and topside meters against the fiscal metering stations.
WATCH includes process models for separation and merging of streams and integrates a PVT package which enables compositional tracking and accurate multistage flashing. This means that the mass balance is also a full compositional balance.

The mass balance is built as a high level robust model to represent the field layout with wells, templates, flow lines, gas lift and chemical injection lines.
An example of the model layout is given in Figure 7. Both virtual information and physical meters can be included together with PVT information. The input and output for the Overall Mass Balance is shown in Figure 8.

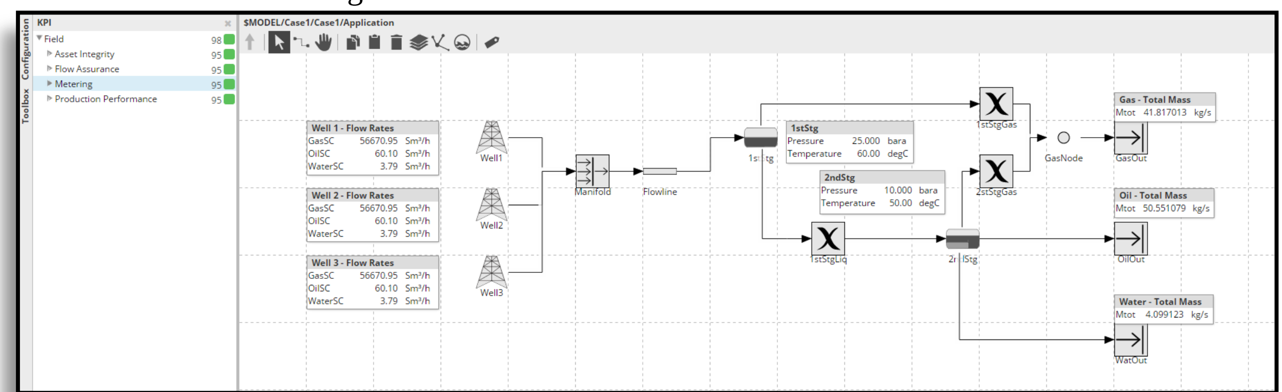

Figure 7 The mass balance follows the layout of the field which allows for an intuitive approach

3.1 Sensor uncertainty

Each measurement included in the mass balance has a specified uncertainty corresponding to the model and sensor uncertainty.

The initial uncertainty is taken from the data sheets for each meter; the result from the overall mass balance is used to adjust the assumed uncertainty and more accurately reflect the plant conditions.

The uncertainty specified for each meter increase the awareness of the operator on how each meter in the allocation system is currently performing.

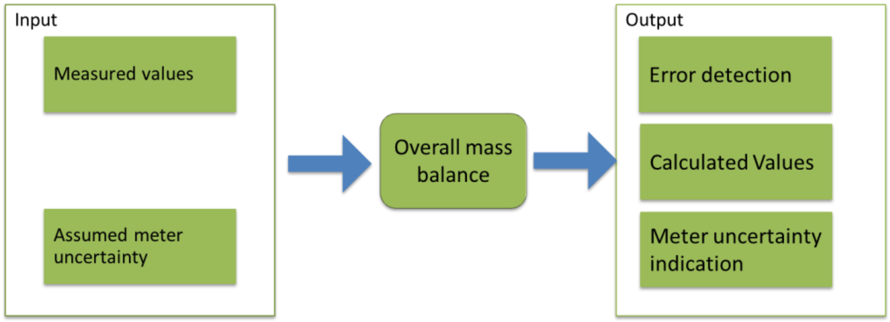

Figure 8 The Overall Mass Balance validates the input measured values and uncertainties and performs error detection.

Edvard Grieg is an oil field on the Norwegian continental shelf operated by Lundin Norway AS which will implement an Overall Mass Balance. The Overall Flow Metering System (OFMS) will be implemented for the process topside, in an effort to qualify this technology and bridge the gap from wells to fiscal metering station. The OFMS will also be used to perform monitoring and early error detection for the topside metering system as well as the wells. In addition Edvard Grieg will have traditional well instrumentation plus a dedicated MPFM for each well. All wells can be routed individually directly to a test separator for testing.

4 Upstream validation

The upstream metering validation is normally compromised of multiphase models covering the wells from inflow all the way to the receiving facilities topside or onshore. The model can also include gas and water injection networks.
In WATCH the wells are modelled using inflow correlations, steady state flow models for the wellbore and a detailed choke model. All the models are based on first principles for mass and energy balance and can easily be adjusted to match field conditions.

The upstream metering validation can also be used to estimate rates or other direct or indirect flow properties such as velocities, densities and phase distribution where no meters are available.

4.1 Brynhild

A WATCH FAS (Flow Advisory System) is installed on Brynhild, a field operated by Lundin Norway AS. The FAS implements several of the principles mentioned in this paper. Brynhild has two/three production wells producing into a common MPFM, the FAS is used to validate the MPFM and monitor the individual well performance.

By having the online and offline capabilities of the FAS the operators on Brynhild can quickly run simulations where they can test hypothesis and compare them with historical measured data from the field, this provides a deeper understanding of how the wells and field performs, and allow for more optimal operations.

4.1.1 Slugging

Well slugging was experienced on Brynhild. The FAS was used to identify that the slugging only occurred outside certain velocity constraints; a virtual velocity measurement was added in the FAS and could be directly applied for well control without any installation costs or commissioning period.

4.1.2 Water Cut increase

The MPFM on Brynhild is used as the primary tool for allocation and the FAS works as a verification and backup system. When the MPFM suddenly showed a 17% increase in WC the FAS was used to investigate whether the increase was due to an actual change in the production process fluid content or a problem with the WC measurement in the MPFM. As Figure 9 shows the total flow rate were slowly decreasing while the WC was increasing. The step increase in WC however is only present in the MPFM and not visible in the calculated rate from the FAS. The FAS rate is based on the model response for all pressures and temperatures. The pressure and temperature responses do not show any indication of a step increase of WC and this is reflected directly in the calculated WC. This indicates that the measured MPFM WC increase is not due to a change in the well performance. The independent verification of the MPFM gives the operator room for action, and avoids unnecessary tests or well shut downs.

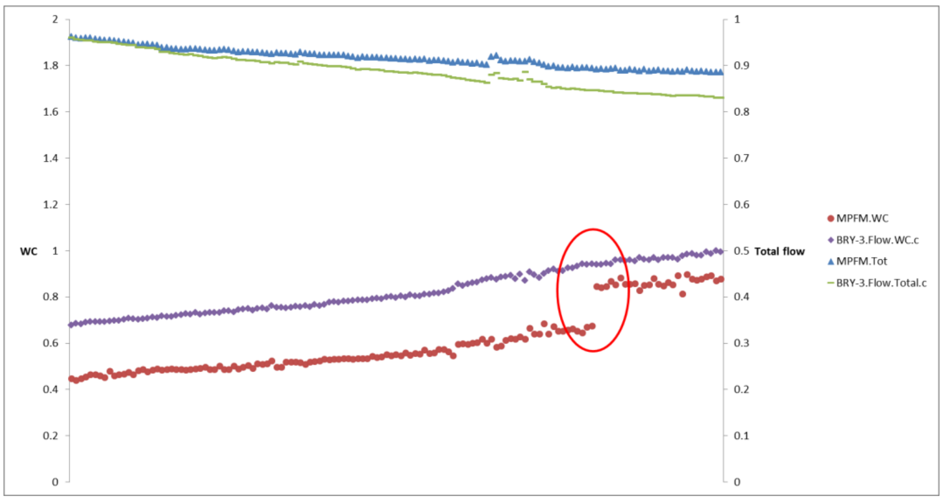

Figure 9 A water cut increase is measured in the MPFM, the FAS shows no increase indicating a mismatch between the pressure and temperature instrumentation and the MPFM. Values are normalized.

4.2 Out of range meter

Many operators' struggle with out of range meters, this can in some cases mean that the operator needs to defer production since the actual production is not known and safe operations are difficult.

In Figure 10 one such case is shown for a wet gas meter. The differential pressure sensor of the venturi of the meter is saturated meaning the full production rate cannot be measured. The VFMS calculated rate that normally would be used for backup and surveillance, is then used as the primary measurement. During the initial ramp-up in Figure 10 the meter is not saturated and we can see a good match between the measured value in red and the calculated value in green. Once the meter reaches saturation the calculated values can be used as a replacement avoiding deferred production.

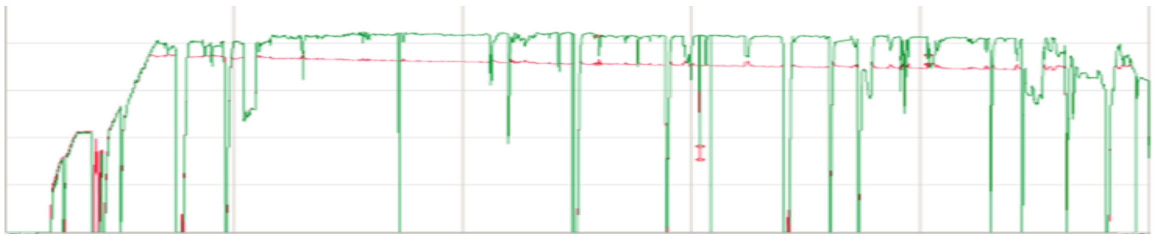

Figure 10 A saturated wet gas meter, the red line is the measured value and the green is the calculated value. The VFMS is used as a replacement allowing the operator to continue producing at high rates.

4.3 Offline tool and re-calculations

If significant errors have been detected in the metering system, a re-calculation can be necessary. Re-calculation is then performed on the impacted period, but since the error is known it can either be eliminated or compensated for. The model based tool can read data from the historical database; the error can be removed from the calculation, either by adjusting the model or excluding parts of the input.

4.3.1 Redundancy and backup to MPFM

The upper plot in Figure 11 shows an MPFM during first oil for a well. During the initial period the MPFM PVT was not configured, thus the flow rates were very inaccurate. In this period WATCH was used as the primary rate measurement, allowing the operator to monitor the production without the MPFM online. Once the MPFM PVT was configured, marked by a red circle in Figure 11**Error! Reference source not found.**, the WATCH system was adjusted to the MPFM rate and the entire period could be re-calculated using the offline capabilities in WATCH for more accurate production rates. The re-calculation is shown in red in the bottom plot of Figure 11.

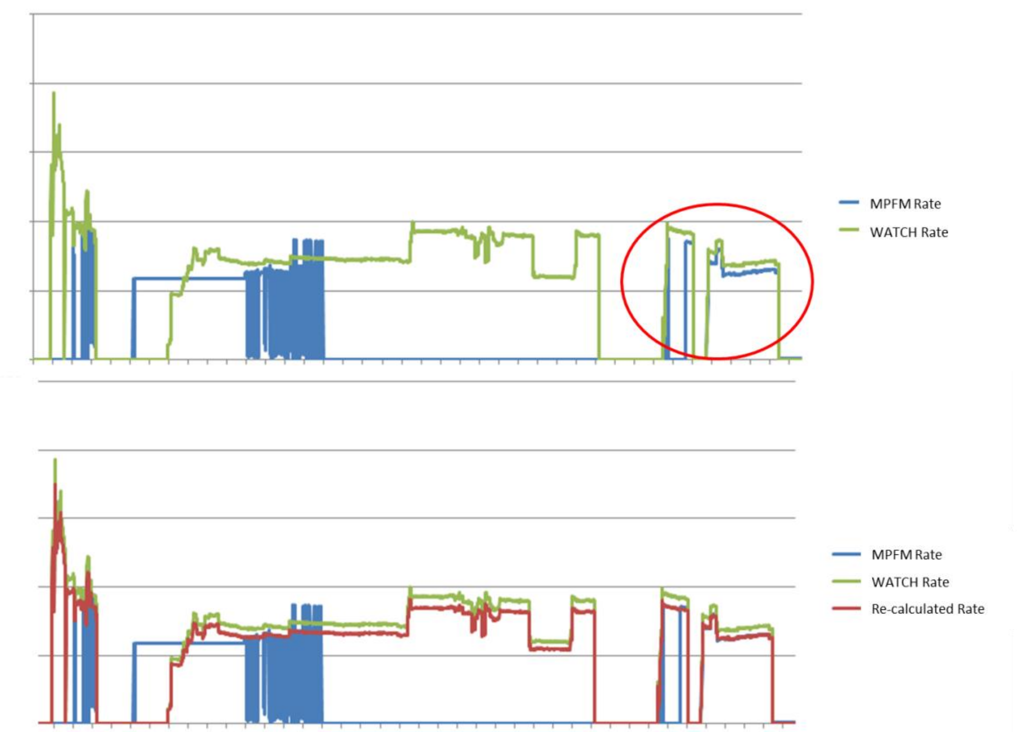

Figure 11 The top figure shows the WATCH as an online tool where WATCH was used as the primary measurement. The red circle shows when the MPFM came online. The bottom figure shows flow rates prior to and after calibration.

5 Well test support

The goal of the Well test module is to perform well tests only when required thus reducing testing time, number of well tests and costs due to deferred production.

5.1 Advice

By monitoring trends and changes in the well response, it is possible for the application to offer well test advice.
Deviations between the modelled response and the measured response indicate that a change has happened and the well is a candidate for test. The raw data is presented in Figure 12, while it is clear that some of the data stands out, without analysis it is difficult to see which producers contributes to the error.

Statistical analysis of the deviation between calculated and measured values provides this insight and correlates each well's contribution to the deviation. An example of this is given in Figure 13 where the deviation between the sum of subsea production and custody transfer system is correlated with the well production, especially B-13 and B-12 are candidates for the next well test campaign.

Figure 12 Well monitoring comparing the well production with topside metering. Without analysis it is difficult to find the contributors to each error.

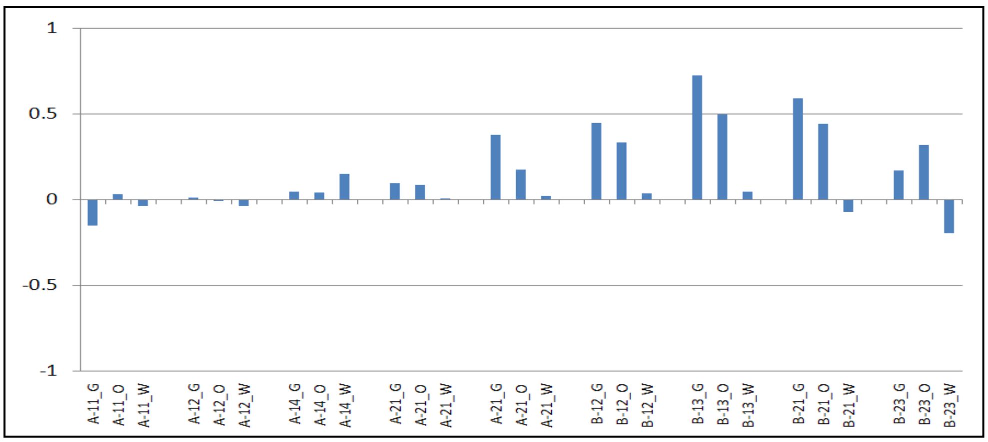

Figure 13 Statistical analysis can be used to identify which wells are recommended for test

5.2 Source tracking

One challenge with running tests on a subsea field is the stabilization times which are often conservatively estimated, leading to unnecessary test time.

By using transient models WATCH can calculate hold up and transportation time and use this to automatically track each wells production into the test meter or separator to ensure that the correct well fluid enters the testing facilities.

A graphical example is given in Figure 14. The y-axis shows the arriving fraction. The time axis is divided into 4 different sections

1. Initialization of the well test
2. Pipeline flushing, the fluid currently in the pipe is being produced out.
3. Transition period, final stages of flushing
4. Data logging, this is the optimal time for testing.

A model based tool can in this way calculate a real time estimate of the actual state of the system and stabilization time thereby optimizing test durations.

Tracking fluid residence time and stability enables the operator to minimize the period on test without compromising data quality.

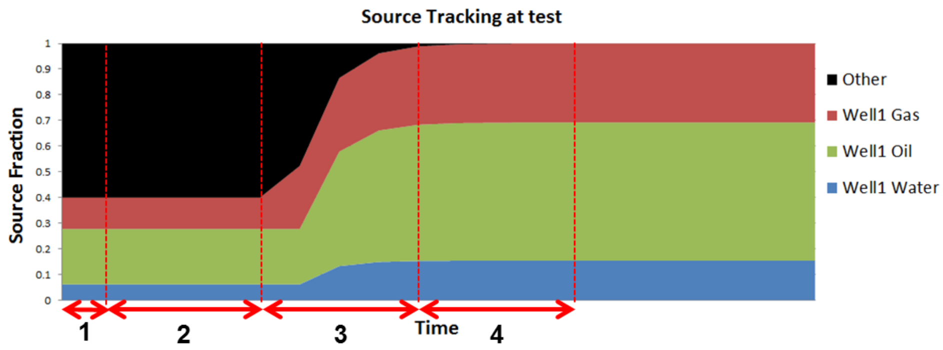

Figure 14 Example of source tracking during a well test, 1: Verify test conditions. 2: Flow line flushing. 3: Transition period. 4: Data logging.

5.3 Rate conversion and PVT calculations

One of the challenges when performing well testing is the calibration process. The measured rates are usually performed at very different conditions, such as the difference between pressure and temperature for the test separator and well head. It could be that the subsea instrumentation accurately measures mass rates, while the separator measurements are volumetric.

Fully compositional calculations convert between flow rate at volumetric or mass rates and fractions between any given set of conditions.
They convert actual rates and fractions at the well and compare them to the measurements made topside; it is also possible to compare the performance at several specified conditions at the same time. This saves the operators time and reduces the uncertainty in the calibration process.

6 Flexible installation and maintenance

The WATCH system is a software installation and has a very flexible installation package with its own web server and web GUI. A web browser and an open connection to the server is all that is required to access the system, together with the appropriate credentials. This makes it very well suited for organizations where the daily operations are split between onshore and offshore and allows easy collaboration. The Watch software can also connect to a multitude of data sources such as the production control system or to the customer database through one of several supported protocols. As seen in Figure 15.

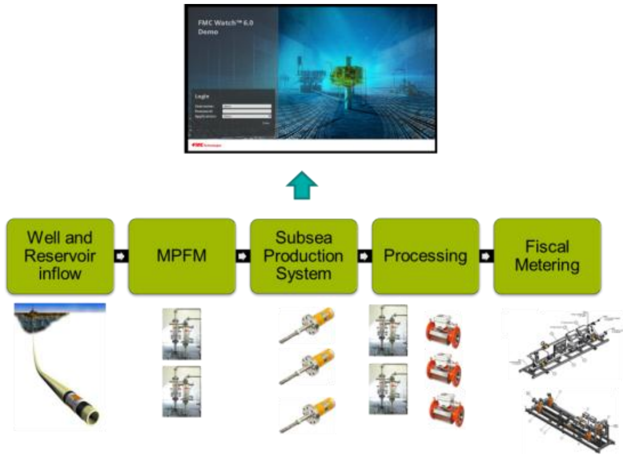

Figure 15 The model based system gathers data from all data sources available

7 Summary

The paper has described a real-time model based system that can analyze information from all available sources and present them in a unified way in an online overview.
The overview is customized for each profession and allows the operator to get a quick status overview of the field.
The automated error detection can notify users quickly in the event of sensor, meter or communication failures in the system and depositions in the production system. This enables systematic and efficient verification of meters and well production and allows operators to only test when needed.
The model based system enables fault tolerant operations of the online system and maximizes the value of the available information reducing costs for the operator and maintains metering quality through field life.