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Assessment of allocation systems: combining Data Validation & Reconciliation scheme and PVT simulations

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Abstract

For increasingly complex production systems, the traditional allocation processes appear to be less suitable and an alternative methodology is required. An assessment was carried out on a large wet gas allocation system containing more than 120 wells. The assessment was based on an approach that combines the Data Validation and Reconciliation (DVR) methodology and process simulations to accurately calculate the reconciliation factors applied to each well. It was found that the current imbalance and the allocation method complies with requirements stated in the agreement between stakeholders. The assessment provided much insight in the sensitivity of the overall gas balance and provides prioritization of the improvements to minimize the imbalance. A more balanced allocation system leads to a fairer division of the accrued revenues.

1. Introduction

Allocation methods are applied in the oil and gas industry to compensate for the imbalance in measurement systems. Reconciliation of the measured values is possible if redundancy in the measurements is present. Different approaches to resolve this imbalance are designed [1] and the choice of the allocation method depends on the agreement between the stakeholders.

The need for more fair allocation methodologies is increasing nowadays due to the fact that accurate metering at every relevant element of a production process is either very expensive or physically (near to) impossible, taking into account recent trends such as deepwater field development, use of subsea production systems, enhanced oil recovery and tie-backs of pipelines from smaller fields. This leads to the sharing of production or transport facilities and meters for different wells, which in turn leads to more complex allocation systems [5].

The industry is driving towards more efficient operation which leads to more small field tie-ins in existing allocation systems. The same cost efficiency may lead to the choice of the operator to omit metering or use alternatives like virtual flow metering [4].
Also, more small-size operating companies are buying (depleting) fields from larger operating companies, leading to more stakeholders in an allocation system. Change in the allocation procedure, the number of stakeholders or the operating conditions in an allocation system, requires an assessment on the procedures in place to critically evaluate the impact on the stakeholders such as Finance, Operations and Reservoir Engineers.

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2. Allocation systems

A general allocation system is outlined in Figure 2 1. The allocation system is divided into three measurement stages: wells, well head platforms (WHP) and the custody transfer (CT) location. In case of a general multiphase flow measurement system, the gas, oil and water flow rate is measured. In Figure 2 1, these flows are evaluated in terms of the measured mass flows $\hat{\dot{m}}_k$,, where k = g, o, w indicating the phase **g**as, **o**il and **w**ater respectively. The allocated mass flows after reconciliation will be denoted by $\dot{m}_k$. The reason for taking the mass flows is to take into account interphase mass transfer within the entire allocation system as will be explained in section 4. In general, each measurement is taken at different thermodynamic conditions, i.e. at different pressures and temperatures. The change in thermodynamic conditions is indicated by the valves in Figure 2 1.

The measurements at the CT location are typically considered as exact, meaning no uncertainty or bias is attributed to that measurement. Therefore, these measurements are equal to their reconciled values.

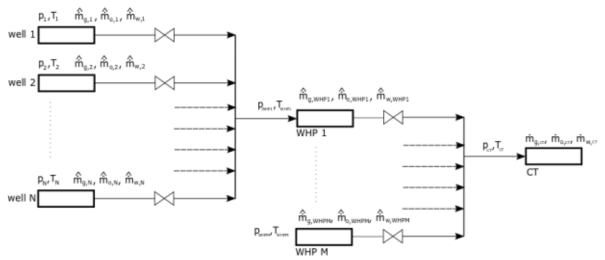

Figure 2-1: Schematic representation of a subsection of an allocation system with N wells feeding into a well head platform. A total of M well head platforms feed into the custody transfer location

The most common allocation methods used in the industry are By-Difference (BD), Pro-Rata (PR) and Uncertainty Based (UB) allocation or a combination of these methods. These methods are commonly evaluated in terms of standard volume flow rates, indicated by Q_k. In the proceeding sections these methods will be elaborated for a simple two-stage allocation system with N wells for phase measurement Q_k at standard conditions, as outlined in Figure 2.2. The advantages and disadvantages of the allocation methodologies are briefly described.

All allocation methods rely on the concept of redundancy in measurements. The most common type is spatial redundancy in which multiple measurements are measured again in a combined stream, as depicted in Figure 2 1 where multiple well measurements are measured at the well head platform as a combined stream. The redundancy of an allocation system is defined as the number of measurements plus the number of constraints (balance equations) minus the number of unknowns. In the example just mentioned, the redundancy is one and the system is called over-determined.

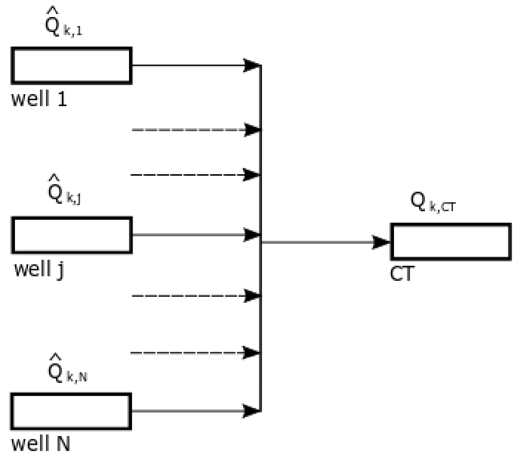

Figure 2-2: Schematic representation of a two-stage allocation system.

2.1 Allocation By difference

The By-Difference (BD) allocation method attributes the imbalance of the allocation system to one of the well measurements. Considering the allocation system in Figure 2 2 and applying the BD allocation method to the measurement of well j, results in the mathematical procedure

$$Q_{k,i} = \hat{Q}_{k,i},\ \forall\ i \neq j$$
$$Q_{k,j} = Q_{k,\mathrm{CT}} - \sum_{i \neq j} \hat{Q}_{k,i} \qquad \textbf{(1)}$$

where the hat indicates the measurement value and the value without hat the reconciled value. The resulting relative uncertainty of the measurement of well j, denoted by $u^*(Q_{k,j})$, can be calculated if the relative uncertainties of the other measurements are known and is given by

$$u^*(Q_{k,j}) = \sqrt{\left[\frac{Q_{k,\mathrm{CT}}}{\hat{Q}_{k,j}} u^*(Q_{k,\mathrm{CT}})\right]^2 + \sum_{i \neq j}\left[\frac{Q_{k,i}}{\hat{Q}_{k,j}} u^*(Q_{k,i})\right]^2} \qquad \textbf{(2)}$$

It is clear from equation (2) that the uncertainty of well j increases when the value of $Q_{k,j}$ is small compared to the other wells. In specific applica-tions, this method may be appropriate, e.g. in systems where the well with significantly larger flow rate is reconciled and the smaller flow rates are unaltered. In general, the method requires knowledge about the measurements and expected performance. Moreover, for a system as depicted in Figure 2 2 the redundancy is equal to zero, resulting in the assumption that the measurement of all wells, except well j, are exact.

2.2 Allocation Pro rata

The Pro-Rata (PR) allocation method divides the imbalance of the allocation system to each well proportional to the value of $Q_{k,j}$ and can be mathematically expressed as

$$I = Q_{k,\mathrm{CT}} - \sum_i \hat{Q}_{k,i}, \quad \alpha_j = \frac{\hat{Q}_{k,j}}{\sum_i \hat{Q}_{k,i}} \qquad (3)$$

$$Q_{k,j} = \hat{Q}_{k,j} + \alpha_j I,$$

where I is the allocation imbalance and is the allocation factor of well j. The resulting relative uncertainty of the measurement of well j is given by

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$$u^*(Q_{k,j}) = \sqrt{u^*(Q_{k,\mathrm{CT}})^2 + \left[\left(1 - \frac{\hat{Q}_{k,j}}{\hat{Q}_{k,t}}\right) u^*(\hat{Q}_{k,\mathrm{j}})\right]^2 + \sum_{i \neq j}\left[-\frac{\hat{Q}_{k,i}}{\hat{Q}_{k,t}} u^*(\hat{Q}_{k,\mathrm{i}})\right]^2}, \quad \hat{Q}_{k,t} = \sum_i \hat{Q}_{k,i} \qquad (4)$$

The PR method distributes the imbalance over all measurements and treats all measurements similarly. Therefore, PR allocation assumes that the measurement uncertainties and biases are equal. It also requires that all input streams are measured.

2.3 Allocation based on uncertainty

To account for the differences in measurement uncertainty, the Uncertainty-Based (UB) allocation can be applied. The method relies on proper estimates of the absolute uncertainties, denoted by $u(\hat{Q}_{k,j}) = \hat{Q}_{k,j} u^*(\hat{Q}_{k,j})$ of the measurements in terms of their variance, i.e. $u(\hat{Q}_{k,j})^2$. The allocation method has a similar structure as equation (3), however the allocation factor is evaluated as

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$$\alpha_j = \frac{u(\hat{Q}_{k,j})^2}{u(Q_{k,t})^2 + \sum_i u(\hat{Q}_{k,i})^2} + \frac{\hat{Q}_{k,j}}{\hat{Q}_{k,t}} \frac{u(Q_{k,t})^2}{u(Q_{k,t})^2 + \sum_i u(\hat{Q}_{k,i})^2} \qquad (5)$$

The UB method distinguishes the reconciliation factor based on the absolute uncertainties. Since the absolute uncertainty is proportional to the measured value and its relative uncertainty, the UB method can be considered as a relative uncertainty scaled PR allocation. For a two-stage allocation system the method can be implemented as outlined in equation (5), however, the application to a multistage allocation system as depicted in Figure 2-1 is not straightforward [1]. The UB method does not consider the dependencies of the streams between the different stages and therefore at the intermediate stage, the combined stream is not corrected.

3. Data Validation and Reconcilliation

The Data Validation and Reconciliation (DVR) method is based on a minimization condition that corrects the initial measured mass flows $\hat{\dot{m}}_{k,j}$ to an allocated value $\dot{m}_{k,j}$ taking into account the measurement uncertainty of $\hat{\dot{m}}_{k,j}$, see e.g. [6]. The absolute measurement uncertainty is often written in terms of the standard deviation, denoted as $\sigma_{k,j}$ DVR minimizes the total required scaled correction to the original measured value that is still able to compensate the imbalance of the allocation system. Mathematically, this results in the minimization of the cost function by means of the least squares method

$$F(\hat{\dot{\mathbf{m}}}_k, \dot{\mathbf{m}}_k, \boldsymbol{\sigma}_k) = \sum_j \left(\frac{\dot{m}_{k,j} - \hat{\dot{m}}_{k,j}}{\sigma_j}\right)^2 \qquad \textbf{(6)}$$

Subject to the balance condition:

$$\dot{m}_{k,\mathrm{CT}} = \sum_j f_j \dot{m}_{k,j} \qquad \textbf{(7)}$$

The bold symbols in equation (6) represent the vector notation of all measurements, i.e. $\dot{\mathbf{m}}_k = (\dot{m}_{k,1}, \dot{m}_{k,2}, \ldots, \dot{m}_{k,N})^{\mathrm{T}}$ The parameter accounts for the interphase mass transfer from well j and its interaction with the other wells that feed into the same CT stream. As an example, in a gas allocation system k=g, part of the gas flow at the CT location can be attributed to degassing of condensate produced from well j. Also, the composition of other wells may influence the mass flow of well j that arrives at the CT location. Formally, this can be expressed as:

$$f_j = 1 + \frac{\sum_j \dot{m}_{p \leftrightarrow k, i \to j}}{\dot{m}_{k,j}} \qquad \textbf{(8)}$$

where p is the phase which is in interaction with phase k, typically these are the gas and oil/condensate phases. In a multi-stage allocation process, multiple mass balance conditions may be present. Solving equations (7) and (8) simultaneously results in the solution for the allocated mass flow rates.
In the DVR analysis, the well measurements can be assessed by means of the so-called penalty factor, defined by

$$\boldsymbol{z_j} = \frac{|\dot{\boldsymbol{m}}_{\boldsymbol{k,j}} - \hat{\dot{\boldsymbol{m}}}_{\boldsymbol{k,j}}|}{\boldsymbol{\sigma_j}} < \mathbf{1.98} \qquad (9)$$

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where the factor 1.98 is related to the 95% confidence interval. Using the definition of the reconciliation factor r_j leads to the equivalent expression for the penalty factor

$$z_j = \frac{|r_j - 1|}{\sigma_j^*}, \quad r_j = \frac{\dot{m}_{k,j}}{\hat{\dot{m}}_{k,j}} \qquad \textbf{(10)}$$

where σ_j^* is the relative standard deviation of measurement j.

4. Process modelling

The schematic allocation system in Figure 2 1 is modelled in the process simulation tool HYSYS [2]. This tool calculates the mass balance on component level, i.e. for each individual species in the flow and is used widely in the oil and gas industry. The mass flow of each phase is not conserved since the condensate phase may evaporate or the gas may condensate due to changes in external conditions. To account for this, HYSYS solves the phase equilibrium problem by a multi-stage flash calculation for each stream from the conditions at the well, $\left(p_j, T_j\right)$, to the custody transfer location, $\left(p_{\mathrm{CT}}, T_{\mathrm{CT}}\right)$.
At each well the gas, oil and water phases are in equilibrium at the measurement location. The input from the field may be limited or partly incorrect. Errors in the composition will directly lead to interphase mass transfer, causing an imbalance in the simulation. Therefore, it is mandatory to pre-condition the gas, oil and water flow rates.
The use of HYSYS has the advantage that all PVT data is available at all stages in the allocation system and can be checked with the configuration of the metering systems.

5 Application to wet gas allocation system

The DVR allocation method combined with the process modelling was employed to assess a large wet gas allocation system in the Malaysia-Thai Joint Development Area, see Figure 5 1. This wet gas allocation system is operated by Carigali Hess and consists of 12 different fields with more than 120 wells connected to 6 well head platforms. The total gas allocation process of these fields is based on BD and PR allocation methods and is described in the Production Measurement and Allocation Procedure (PMAP), see [3]. A BD allocation is performed between the custody transfer measurement and the well head platforms, the subsequent well allocation is done by means of PR allocation. The measurements on the wells are performed by Venturi flow meters with a wet gas correction algorithm.

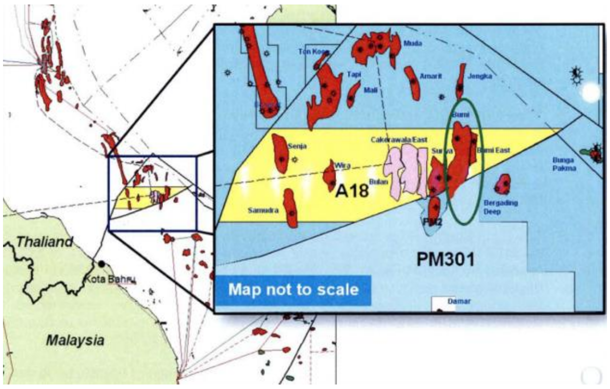

Figure 5-1: Malaysia-Thai joint development area.

The agreement between the different stakeholders demands a global reconciliation factor of the gas production between 0.9 and 1.1, see equation (7). This also means that in the current allocation procedure the BD allocation of the well head platforms could be well outside this specification, however, no requirement has been defined per well.
The application of the DVR methodology requires the definition of the uncertainties of the wet gas Venturi measurements. The uncertainty of these wet gas measurements depends on the choice of correction model, calibration uncertainty of the measurements, range of operation, fluid composition and wetness conditions. These conditions differed greatly per well, resulting in estimated relative uncertainties of the well measurements between 2 and 9%.

5.1 Results

The anonymized results for the reconciliation factors of the DVR allocation and the current allocation method for each well are shown in Figure 5 2 for a one-month period in October and November 2017.

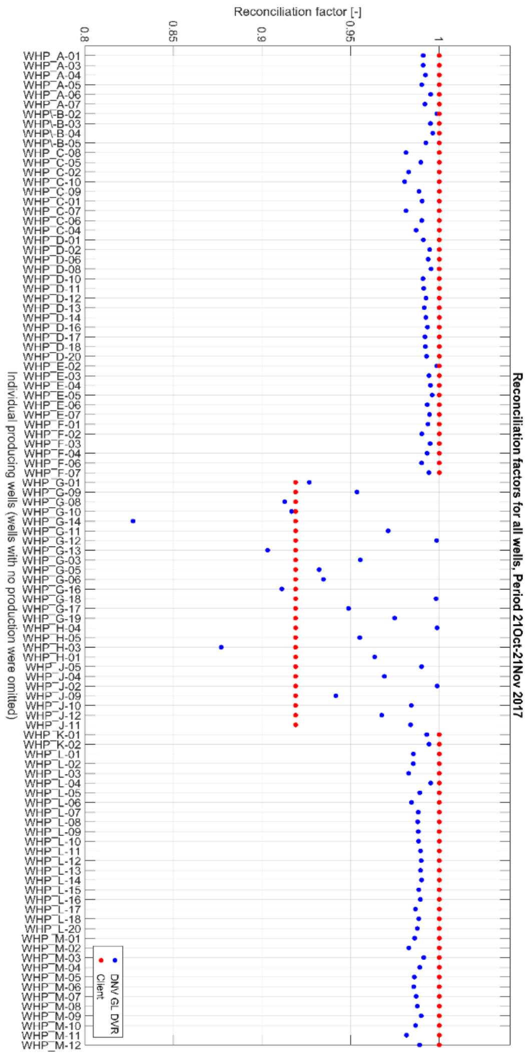

Figure 5-2 : Anonymized results of the gas reconciliation factors: Current allocation method (red) and DVR method (blue)

It is observed that the wet gas Venturi measurements over-predict the total flow leading to a negative imbalance. The current method produces, by definition, a reconciliation factor of 1 for the well head platforms that are unaffected by the BD allocation procedure. Also, the wells that are corrected (WHP_G/H/J) all have the same reconciliation factor.

The solution of the DVR allocation method shows that most wells, that were assigned a reconciliation factor of 1 in the current allocation method, have a DVR reconciliation factor of within 2% to their original value.

The wells connected to the WHP_G/H/J platforms show more variability. This is mainly due to the differences in the combination of the production rate and relative uncertainty of the measurement. Since DVR is an uncertainty-based allocation method, the absolute uncertainty of the measurement determines the reconciliation factor. In general, the wells with high production volumes have a higher reconciliation factor, and therefore more of the imbalance of the allocation system is assigned to these wells. The sources of uncertainty differ per well as state in the introduction of Section 5.

To isolate the effect of the flow rate, the reconciliation factor can be plotted as a function of the relative sensitivity factor. This parameter is defined as

$$S_j = \frac{\dot{m}_{g,j}}{\dot{m}_{g,\mathrm{CT}}} \frac{\partial \dot{m}_{g,\mathrm{CT}}}{\partial \dot{m}_{g,j}} = f_j \frac{\dot{m}_{g,j}}{\dot{m}_{g,\mathrm{CT}}} \quad . \qquad (11)$$

The results are given in Figure 5 3. If the relative uncertainties of all the wells would be equal, the graph would show all dots on a straight line where the value of the relative uncertainty determines the slope. The clear outliers are the malperforming wells in the allocation system and it is observed that some of the wells will be reconciled with a lower factor than others. However, this does not directly imply that these well measurement are performing out of specification. This depends on the estimated uncertainty and wells with a reconciliation factor that differs significantly from 1 could still be within their expected uncertainty. On the other hand, these wells are bringing imbalance to the allocation system and therefore should be addressed, although they could perform according to specification. Therefore, Figure 5 3 indicates which measurements to improve to minimize the gas imbalance of the allocation system.

To assess the well measurements the penalty factor can be plotted for the wells that do not satisfy equation (9), see Figure 5 4. Some of the wells that distort the balance in the allocation system also show a large penalty factor, e.g. WHP_G-14. Other wells perform relatively well in the allocation system, e.g. WHP_J-09 compared to WHP_G-05/06, whilst the penalty factor of WHP_J-09 is higher than WHP_G-05/06. Therefore, Figure 5 4 indicates which well measurements are not performing according to its specification and need further investigation.

It is clear from this case study that WHP_G-14 and WHP_H-03 are both malperforming in the allocation system and the cause can be related to a malperforming wet gas flow meter.

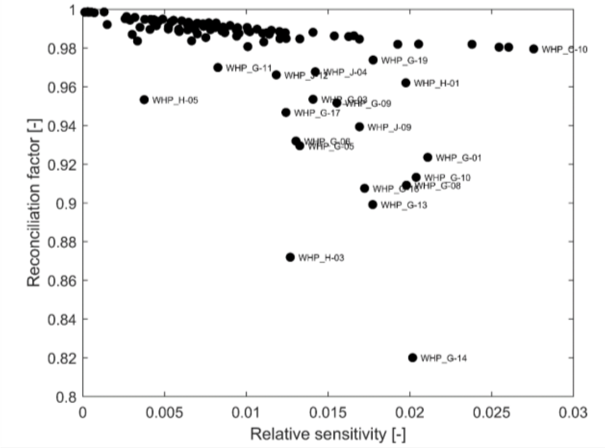

Figure 0-1 : Reconciliation factor of each well as function of the sensitivity parameter

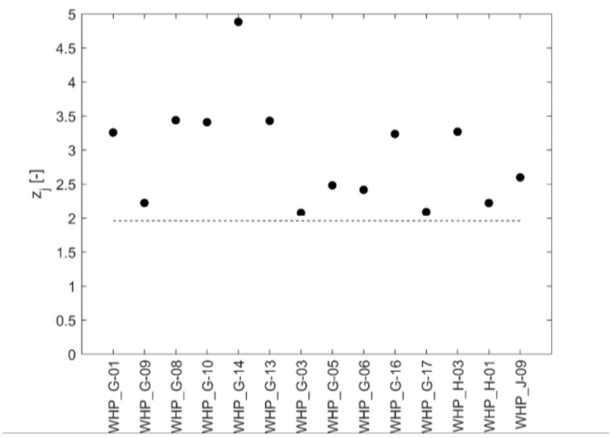

Figure 0-2 : Penalty factor of well measurements with a value not complying with equation Error! Reference source not found.

6. Conclusion

An assessment was carried out on a large wet gas allocation system of Carigali Hess containing more than 120 wells. The assessment was based on an approach that combines the Data Validation and Reconciliation (DVR) methodology and process simulations in HYSYS to accurately calculate the reconciliation factors applied to each well. It was found that the current imbalance and the allocation method complies with requirements stated in the agreement between stakeholders.

The DVR calculation indicated that the imbalance of the allocation system can be improved by further investigating the well measurements on two specific wells. The method also provided penalty factors on the well measurements that indicate that the wet gas Venturi meters are not performing according to their specification.

The assessment of the allocation system provided much insight in the sensitivity of the overall gas balance and provides prioritization of the improvements to minimize the imbalance. A more balanced allocation system leads to a fairer division of the accrued revenues from the Malaysia-Thai Joint Development Area.

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