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Applicability of performance measures for production performance analysis in oil and gas industries including lower carbon activities

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Production performance analysis includes methods for predicting production availability, to identify bottlenecks and assess different alternatives in design. Such methods have a tradition for use in the oil and gas industry and are recently also considered for use in renewable energy industries. However, despite principles generally being transferable across different industries, some methods might need adjustment to be applicable for the range of renewable energy. The need for adjustment is also reflected in the extended scope of ISO 20815, where the next revision then will aim at giving guidance to production assurance and reliability management in oil and gas industry including lower carbon energy.
Some of the relevant performance measures for various lower carbon activities are addressed in this paper. The objective is to consider the applicability of existing measures outlined in ISO 20815 (2018), by discussing practical implications and attempts to establish definitions that can be applied across all industries, while addressing nuances needed to reflect unique aspects of each industry. For example, production availability is generally defined with reference to planned or potential production. In the oil and gas industry, the reference has typically been given by production profiles. Production profiles as a reference would also be meaningful in industries like wind and solar, but they are more volatile and must be handled somewhat differently, indicating a need to calculate production availability differently from the current standard.
Selected industry cases are used as examples to demonstrate the feasibility and coherence of performance measures in production assurance analyses within various energy industries.

Keywords: Performance measures; Production availability; Standardization; Renewable energy.

1. Introduction

Production performance is defined in the international standard ISO 20815 (2018) on production assurance and reliability management as: "*capacity of a system to meet demand for deliveries or performance.*" In the oil and gas industry, production performance analysis has long been instrumental to ensure efficient and reliable operations (Poston et al. 2019). These analyses have a key role in predicting production availability, to identify bottlenecks, and to assess various design alternatives. Several scholars such as Barabady et al. (2010) and Qarahasanlounce et al. (2017), point to the need for quality in production performance calculations, for effective production assurance management and for improvement of production plant performance.

Recently, the scope of methods traditionally used in the oil and gas industry has expanded to include renewable energy industries, reflecting a broader shift towards lower carbon activities. This transition necessitates adjustments to some of the traditional methods to accommodate the unique characteristics of renewable energy sources. See e.g. discussions related to wind energy in Bougoüin et al. (2024). This transition should as such be reflected in the next revision of ISO 20815, which should then provide comprehensive guidance on production assurance and reliability management, not only for the oil and gas sector but also for lower carbon activities. To maintain quality and succeed in the transition there is a need to focus on the practical implications and the need for industry-specific adjustments. This paper contributes to this aim by exploring the applicability of some of the existing performance measures outlined in the current edition of ISO 20815 (2018).

As indicated in this international standard, there is a variety of measures that can be used to express production assurance, where some focus on past and some on future performance. Clearly, there is a need for consistency in analysis, however it is not obvious that the conceptual understanding of the measure is the same across industries. One such measure, where this might be the situation, is the production availability measure. There are already different ways to understand this measure conceptually. It's typically referenced against production profiles in the oil and gas industry, representing a way that is challenging for renewable energy areas such as wind and solar that exhibit a greater degree of volatility. This might require some sort of differentiation or a different approach in how to calculate the production availability, ensuring that the measures remain relevant and accurate across diverse energy sectors.

For use of performance measures, there is a need to test applicability against relevant cases. Through selected industry cases, this paper aims to demonstrate the feasibility and coherence of performance measures in production assurance analyses, highlighting the importance of tailored approaches to meet the distinct needs of various energy industries.

2. Production availability as performance measure

As a concept, availability refers to the ability to function at time t. In reliability terms this is the probability that the item works at time *t*, often denoted *A*(*t*). IEC 60050-192 (2015) and ISO 14224 (2016) defines availability as "*ability to be in a state to perform as required*". This would correspond to an instantaneous measure of availability. When calculating this availability, usually a period is considered instead of the time *t*, making it more appropriate to focus on the mean availability over the period considered (see e.g. Brissaud et al., 2012). This mean value can then be calculated either based on time or volume. For time-based calculations, it is then the mean proportion of time where the system is operational or functional, depending on whether focus is on technical (inherent) or operational availability. When the measure is volume-based, the availability is to be measured against some reference volume (e.g. contracted volume) and the ISO 20815 (2018) refers to this as the production availability, i.e. "*ratio of production to planned production, or any other reference level, over a specified period of time*."

The time-based availability is directly applicable in any industry. This may be measured on item or system level, but considers only the state and not the product, and can thus be specifically defined regardless of the industry. Production availability depends on the production of a certain product, which may differ depending on the industry. Regardless of the product, the production can be measured or estimated with specific units in a consistent way. But the reference level is not always clear. One way to interpret this level is with respect to maximum volumes, which makes it relevant to measure the fraction produced against the production potential. The ratio of produced volume against the production potential over a specified period is in ISO/TS 3250 (2021) referred to as the production efficiency. Other references could be the planned volume, demand volume, or market potential (maximum volume rate that can be received by the market).

We may summarize tis as illustrated in Figure 1

	Time-based	Volume-based
Actual performance	Same definitions across industries	Same definitions across industries
Reference performance	Same definitions across industries	Different definitions for different industries

Fig. 1. Consistency of availability definitions across different industries

As time-based availability refers to functionality rather than production output, it makes it simpler to define and apply given a representation is in discrete states. Normally the item will have binary states, i.e., either functioning or non-functioning, and the production availability can then be estimated with reference to the fraction of time where the item is in the functioning state. When referring to volume-based availability, it might be slightly more challenging to specify what should be the reference level. In contrast to the time-based considerations, the are several references that could be applicable. For example, in oil and gas, one might consider a planned volume or a capacity as the reference. There is a flexibility that opens up for inconsistency, both with oil and gas application, but also across industries.

For oil and gas, reference performance is typically obtained from production profiles. These are often limited by equipment and system capacities. After the plateau phase, the decrease in oil profiles may be a result of pressure drop in the reservoir, but it is also typically limited by capacity constraints in the separation or produced water systems after water breakthrough. In any case, reference production is largely given by equipment and system capacities and the gap between actual production and reference production is merely a consequence of failure of these equipment and systems. This is not necessarily the case for other industries, which is subject to discussion in the next section.

Another challenge is to make sure that we speak the same 'language' across industries. For instance, the term, production profiles, is not commonly used in the wind industry. The same concept exists, but with terms like 'wind energy production curves' or 'generation profiles.' The equivalent of 'production availability' in the wind industry is 'capacity factor' or 'energy availability', depending on the way it is defined (see discussion in the next section). These terms have arisen independently, as different standards have been developed in different industries without collaboration. The problem is that these industries cannot be regarded as fully independent of each other. Many oil companies have offshore wind projects and there are examples of projects where wind turbines are generating power to oil platforms instead of or in addition to gas turbine generators. Not speaking the same language and using different terms for equal or similar concepts may lead to confusion.

3. Performance measures in the renewable energy industries

We will now take a closer look at how production availability from an ISO 20815 perspective can be applied in renewable energy industries, wind and solar power.

3.1. *Wind power*

For many analysts in the wind energy industry, the difference from the petroleum industry is not the primary concern. Many have not worked with oil and gas and perform analyses within the framework of standards and common practice that has been established in the wind energy industry for a while now. This section therefore is primarily meant to bridge the gap that may arise when analysts in the two industries communicate, when one moves from one industry to the other, or when there are synergies that are becoming increasingly common.

In the wind energy industry, the difference between actual production and reference production at a given time is not necessarily only determined by equipment and system states. There are at least two ways to define the reference production:

(i) Wind turbine capacity, which gives the capacity factor
(ii) Wind profiles, which give the energy availability

Measuring the actual electricity generation against any of these will yield vastly different results depending on your choice. Wind turbine capacity is, unlike oil and gas production, rarely the sole constraint of electricity generation. The wind turbine can only reach its full potential when wind conditions are optimal. Hence, measuring production availability with these optimal conditions as reference, will generally yield low values and wind conditions will often make up a larger factor for the loss than the equipment availability. This is the capacity factor. The problem with this approach is that most of the production loss comes from a factor that you cannot control.

The other alternative is therefore more common as a metric in production availability studies. In fact, IEC/TS 61400-26-2:2014 defines both time-based and volume-based availability similar to ISO 20815 and includes formula (1), where production-based availability A_P is expressed with respect to the energy potential expected.

$$A_P = \frac{Energy\ actually\ produced\ (in\ kWh)}{Energy\ potential\ expected\ (in\ kWh)} \quad (1)$$

One may argue that the full capacity of the turbine cannot normally be expected and that this expectation therefore includes realistic wind profiles. Taking these into account, however, is not without challenges. Wind profiles can be built using historical wind data under the assumption that future wind speeds will be similar to historical ones. But since the wind speed is fluctuating by the minute, profiles that cover many years into the future must necessarily be expressed as averages over a period much longer than a minute. There is a problem with using averages in a non-linear relation. The relationship between wind speed and electricity generation is expressed in a power curve. An example is given in Figure 2.

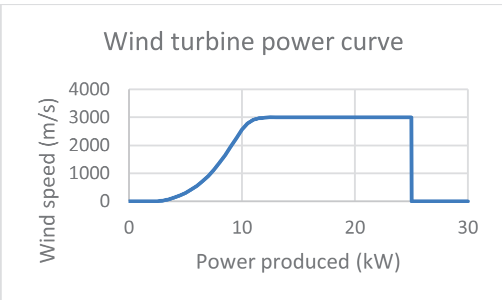

Fig. 2. Wind turbine power curve

To illustrate this problem, let us assume wind speeds for a period of one hour in 10-minute increments as given in Table 1.

Table 1. Wind speed and power for given time increments

Minute	Wind speed (m/s)	Power produced (kW)
[0,10]	6	552
[10,20]	6.2	614
[20,30]	6.5	714
[30,40]	7	906
[40,50]	7.3	1033
[50,60]	7.2	989
Average	6.7	801

If we base wind profiles on an average wind speed over an hour, we have in this example an average wind of 6.7 m/s. According to the power curve, a wind speed of 6.7 m/s yields 788 kW of power. This deviates from the 801 kW produced as an average over all 10-minute increments, because the relationship between wind and power is non-linear. The longer the time increments over which we average the wind in the profiles, the greater the potential for error. Hence, it is in our interest to reduce the time increments as much as possible. But this cannot be done in a meaningful way. Wind data cannot be used to predict the difference between 10 years and 10.0001 years into the future. Thus, wind profiles must either be arbitrary or remain constant within periods that can only be differentiated from each other with significant seasonal variations in the data. But since wind is not the product, this must be converted to electricity generation. Not knowing about the pitfalls of averages over non-linear relations as demonstrated, this may cause us to underestimate the electricity generation where the power curve is convex and overestimate it where the power curve is concave.

In production availability studies, we are interested in predicting the future production rather than measuring the historical production. In a modelling context, it is common to use smaller time-increments to draw wind speeds and associated energy generation from probability distributions, to reflect the natural fluctuations of the wind, even if the underlying distribution does not change at these smaller time-increments. Consequently, we obtain a reference production that is artificially changing in small time-increments. The model is more realistic in the sense that it captures the constantly changing nature of the wind. But unlike the oil and gas production profiles, the specific wind speeds are drawn randomly. Only the underlying wind distribution is based on historical data, but not the specific wind speed figure. This distribution can change between larger timespans, like months and seasons that may yield different wind speed distributions based on historical data. Historical data may even demonstrate a statistically significant difference between day and night due to atmospheric and thermal effects, in which case the underlying distribution of wind speed might change quite frequently in the model.

When wind speeds are generated sequentially from the same distribution, a realistic model should ensure that successive values are not independent but evolve smoothly over time. To this end, a Markov Chain Monte Carlo (MCMC) model is useful, as outlined in e.g. Papaefthymiou and Klockl (2008) and Almutairi et al. (2016).

When it comes to the small time-increments, computational speed may become a challenge. Production availability studies are often performed by modelling tools applying the discrete event simulation technique. The more events, the more computational power is needed, and each time-increment with a shift in the profile would be regarded as an event.

To summarize, when those who are used to assessing production availability in the petroleum industry attempt to do the same for wind power, there are certain complications that one needs to be aware of:

(i) Unlike oil and gas, capacity of wind turbines is usually not the primary constraint defining the potential production
(ii) Whereas oil and gas profiles can be applied directly as reference, wind profiles are not the product and cannot be applied directly, only via a relationship to the product, electricity, that is defined by a non-linear power curve
(iii) Wind is continuously fluctuating. Modelling of wind in production availability studies must be done either in short increments that are random and computationally heavy, or unrealistically long periods of static wind speeds.

3.2. *Solar power*

Many of the same aspects of wind energy in a production availability context that differ from the petroleum industry, also apply to solar power. There is no need to repeat all of those. The three points summarizing the discussion at the end of Section 2.1 also apply to solar. That is:

(i) Capacity of solar panels is usually not the primary constraint defining the potential production. Even in very sunny locations, the sun shines on the panels at different angles that are optimal only at mid-day. However, solar profiles are more predictable than wind. Clouds introduce a random element but the diurnal cycle, sunrise and sunset at different times of the year are predictable.
(ii) As for wind power, sunshine is not the product and the relation to energy generation is also non-linear, meaning that electricity generation averages over long time periods based on soar radiation averages, may yield wrong results
(iii) To capture the solar cycle with some degree of accuracy, a model needs fine granularity at least to the level of wind. Even though it is more predictable, the short time-increment may pose a challenge to computational speed. Longer computational increments coarsely assuming average solar radiation makes little sense, since there is generally much more variation e.g. within a day than between two consecutive days.

At large, solar and wind are similar in nature, and both differ more from oil and gas than from each other when it comes to definitions and calculations of production availability.

Another point to be made about solar energy is that planned maintenance has little to no impact on production since it can be scheduled at night. This reduces the difference between technical and operational availability. These are also ISO 20815 (2018) terms that distinguish between availability under ideal conditions of operation and maintenance and availability experienced under actual conditions of operation and maintenance, respectively.

4. Production availability calculation of renewable energy

With the discussion from section 2, we are prepared to model production availability of renewable energy in ISO 20815 terms, with a simple single offshore wind turbine as case example, assuming the power curve from Figure 2. Figure 3 illustrates the parameter values of the case example.

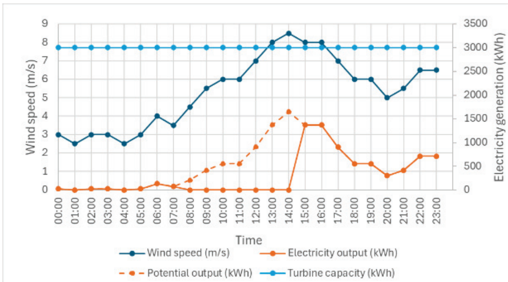

Fig. 3. Example of wind turbine data

For simplicity, we only consider a 24-hour period in this example. The time-based availability is straightforward and similar to any other industry. In this case, the turbine is in a non-functioning state during six of the 24 hours in the calculation period. Thus, the wind turbine availability is 18/24=75%. Calculating production availability according to ISO 20815 and the discussion in this paper, there are at least two options as outlined in Section 3.1:

(i) The capacity factor would be calculated as a fraction with the accumulation of electricity based on the solid orange line as the numerator and the accumulation of electricity based on the light blue line as denominator. The calculation would yield 10%

(ii) The energy availability would be calculated as a fraction with the accumulation of electricity based on the solid orange line as numerator and the accumulation of electricity based on the dotted orange line as denominator. These are always the same unless there is maintenance, but due to the maintenance period of 6 hours, the calculation yields 56%.

As we can see, there is a big difference between the time-based availability and the two versions of production availability. The time based availability will only give a different result than 100% when equipment fails. The capacity factor is impacted by the failure, but even with a turbine out 75% of the time, which would be a lot in the longer run, it is the wind conditions that contribute the most to the low value of 10%. The energy availability is the value that aligns best with the ISO 20815 definition of production availability. 56% would be regarded as low, but this is a consequence of adding maintenance to this specific day in our case example. In the long run, availability would be calculated the same way but with most of the days maintenance free, yielding higher availability.

In this example, turbine repair is unplanned and happens when wind conditions are reasonably favorable compared with the rest of the day. This is why we end up with a lower energy availability than the time-based turbine availability of 75%. In case of planned maintenance, wind energy has an advantage over the petroleum industry, at least if there is some flexibility in short term planning. Weather forecasts can be utilized to identify times when wind speed is low and little is lost during repair. Such strategies would lead to higher energy production availability than time-based availability, as opposed to this example.

At this point, it is important to note the difference between availability measurements backward in time and predictions forward in time. Production availability can be applied to both but we go about them very differently. Figure 3 is presented as historical data and measurements with post hoc availability calculations. In the prediction model that we briefly discussed in Section 3.1, a similar figure would be based on computer generated numbers from a wind distribution and a power curve. Like a similar case from the petroleum industry, equipment failure and repair times are generated from distributions based on equipment reliability data. Unlike the petroleum industry, wind at a given time increment is also generated from a distribution based on historical data relevant for a certain time or season. The resulting produced electricity is then derived from that via the power curve.

5. Concluding remarks

ISO 20815 is part of WG4 in ISO/TC67, where the scope has been extended from petroleum and petrochemical industries to also include lower carbon industries. The question that has been addressed in this paper is whether a metric like production availability is valid in these industries as defined. The definition is general and broad and can therefore easily encompass other industries like wind and solar, but the somewhat vague term, “planned production or any other reference level” in the definition must be specified to avoid confusion. The petroleum industry has traditionally applied production profiles, at least for the upstream business category, as this reference. It is not intuitively clear what this reference is for wind and solar, but based on the discussion in this paper, we conclude that this reference should be the electricity production based on a power curve for wind speeds obtained from a distribution based on historical data and knowledge about certain patterns (like e.g. no sun at nighttime). To create accurate calculations of historical data or realistic predictions of future performance, this reference must vary with time increments that are typically much smaller than what is necessary in the petroleum industry, due to the volatile nature of wind and sun. All things considered, the wind and solar industries complicate the production availability concept a bit but is still manageable.

‘Lower carbon’ is a general term that of certainly involves more than just wind and solar. These were used as examples to address the issue, as this paper was not intended to be an exhaustive treatise of all possible lower carbon industries within the framework of production availability. Still, we could briefly mention carbon capture and storage (CCS). This is an interesting case that deviates somewhat from the norm, since it is not an industry in its own right, but reliability and availability is still relevant. Production availability in this case would even be a misleading term, since production is not relevant, as CCS is aimed at getting rid of something rather than to produce.

Acknowledgment

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