ASSET AND SYSTEM PERFORMANCE ANALYSIS: LAGGING INDICATORS THAT MATTER

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1. Abstract

Utilities today are required to report to regulators, investors and authorities upon their performance using a few key performance indicators. Most organizations also only use these performance indicators for reporting purposes as their regulated revenues are linked to these KPI's through incentives and penalty schemes. We at Tenaga Nasional Berhad and Elia System Operator are convinced that performance indicators should also be used on a broader sense and contribute more to make decisions and enable value creation from an asset management perspective.

Elia and TNB have therefore decided to join forces and define those indicators that matter to Transmission System Operators and that are able to draw the most realistic image of the condition and performances of the grid they aim at reflecting. The approach of the paper consists of reviewing the lagging indicators used today within our organizations and benchmark these practices with the common practices with leading TSO in the world. Subsequently, the paper will develop on the different issues arising from the current indicators that prevent the TSO to make asset management decisions that make a difference. The main drivers for developing indicators should be making better-informed decisions to balance cost, risk and system performance. Lastly, this paper will provide the reader with useful insights in the way forward for System Operators with regards to lagging indicators. An implementation approach, as well as success factors, is provided in this last section.

This paper aims at initiating a debate on the use of lagging indicators, whether for asset management or reporting purposes. Elia and TNB do not intend to fix or impose lagging indicators, rather providing paths of development and leading discussion with their peers.

2. Introduction

All organizations in today's utility sector are focused on improving the quality of the services they provide, whether for regulatory compliance, continuous improvement or for revenue. The basic assumption for this paper is that utilities tend to maximize the benefits for the overall community and therefore maximize reliability and availability of their network at an acceptable cost and risk level. Continuous improvement is at the core of all organizations seeking to develop themselves in an evolving world with ever-increasing expectations.

All companies are investing in monitoring their systems' performance, but the majority among them uses the monitoring results mainly for benchmarking, reporting and transparency purposes. In many cases, the performance of the assets and system is analyzed through well-established indicators that do not allow the organizations to make sharp decisions, while the final aim of those indicators should also allow the asset managing organizations to make the right decision, while balancing cost, performance and risk.

Lagging indicators are developed to analyze and act upon the causes discovered once incidents have occurred, while system operators mainly use or publish nation-wide indicators that do not allow the asset managers to make decisions related to specific circuits or assets with the aim to optimize the risk, performance and cost. This paper therefore complements the studies performed by IEEE and other organizations[1] on this matter. The paper specifically focuses on service quality, availability and reliability indicators.

The Elia Group (Elia) and Tenaga Nasional Berhad (TNB) have over 30 years of experience in analyzing events and disturbances on the medium and high-voltage electrical grid with the aim to improve their performance. In that sense, they have developed mechanisms, governance and methodologies to master and implement the right lagging and leading indicators.

TNB is the Transmission System Operator in Malaysia and has developed methodologies that enable it to monitor and act upon the performance of its assets and systems. By doing so it secures the asset management objectives and targets, aligned with the organization's strategy.

Elia System Operator is the High Voltage grid owner and operator in Belgium. The Elia Group also includes 50Hertz Transmission, the German transmission system operators, owning and operating the High Voltage Grid ranging from North to South in the East of Germany, including Berlin. The Elia Group has been a front-runner in developing the High Voltage grid's asset maintenance and reliability.

3. Abbreviations

AIT	Average Interruption Time
APA	Asset Performance Analysis
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
EGI	Elia Grid International
ENS	Energy Not Supplied
ESO	Elia System Operator
MAIFI	Momentary Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SARI	System Average Restoration Index
TNB	Tenaga Nasional Berhad

[1] CEER, 2016; IEC-61000

4. The current situation: framing the problem

4.1. Lagging indicator: our definition

Before entering the core of this paper, Elia and TNB would like to propose a common definition of lagging indicators. Indicators are considered to be those parameters that provide the organization and its stakeholders with the performance of the organization, optimally against the defined objectives and targets. Lagging indicators are the indicators that reflect the performance of the organization by measuring the outcomes or the result of a process or an activity. These indicators are subsequent to an event or series of events.

If a lagging indicator provides poor results, it means that the measured performance has been bad, but does not provide any information on the expected performance of the upcoming events. These indicators are easy to measure as data is available and provide leverages to improve the performance visibly.

4.2. The situation at Elia System Operator

4.2.1. Organizational Structure at Elia

Elia is Belgium's high-voltage transmission system operator (30 kV to 380 kV), operating over 8,000 km of lines and underground cables and managing 800 substations throughout Belgium.

Elia System Operator has a single department responsible for analyzing the performance of the assets and systems. More specifically, a separate division is responsible for analyzing and solving all incidents that impact the electrical grid (30kV up to 380kV) and following-up the recommendations it developed to avoid reoccurrence of these incidents. It also provides operational assistance to the Maintenance and Operations teams during incidents for normalizing the system. The Asset Performance Analysis division (APA) is responsible for analyzing performance trends through the computation of long-term data. Lastly, APA calculates the lagging indicators to ensure the organization as a whole achieves the targets that have been defined with the regulator.

Nevertheless, it is not the ambition of this division to concentrate all expertise about all assets of the Belgian high voltage grid. The division works together with over 100 engineers and asset managers. The division itself is composed of analysts, engineers, coaches and a division manager. Each role has its own responsibilities to meet the division's objectives.

4.2.2. Lagging indicators at Elia

The main lagging indicators used at Elia System Operator are:

- Energy Not Supplied (ENS)
- Average Interruption Time (AIT);

The ENS is defined as the sum of the energy not supplied to Elia customers during interruptions which lasted more than 3 minutes and were caused by internal Elia problems. Any interruptions caused by "force majeure" events, customer errors or intrinsic risks (thunderstorms, third parties, birds, etc.) are not considered in the calculation of ENS. This KPI is expressed in MWh.

The AIT is expressed in minutes and is defined as the ENS multiplied by 60 and divided by the Yearly Average Power (YAP).

Those indicators have been chosen because they reflect the continuity of the supply provided to Elia customers. They allow Elia and the regulators to check that the performance of the grid meets the end customer's expectations.

They are calculated and expressed on a yearly basis but Elia monitors their evolution on a monthly basis. They are used for external reporting to the regulators, for benchmarking purposes and for internal steering of the assets related strategies/decisions.

A reward system is used by the regulator to incentivize the performance of the TSO during the present regulatory period:

$$Bonus = \min\left(2M€, 1.2 + \log(\frac{AITref}{AIT(y)}) * \text{AITref} * \text{IR(y)}\right)$$

Where :

AITref is the reference AIT (set at 2.55)

IR(y) is the incentive rate and is calculated based on the yearly average power and the value of lost load

And AIT(y) is the AIT measured on year y

Other indicators, which are not related directly to reliability, quality of services or availability of the system complete the above indicators. As an example, Elia Group has targets with regards to project execution time.

4.3. The situation at Tenaga Nasional Berhad

4.3.1. Organizational Structure at TNB

Grid Division plans, operates and develops TNB's 132kV, 275kV and 500kV transmission network, which transports electricity in bulk from power generators to distributors and in some cases transports directly, to large industrial customers.

Its primary business activities include operating the grid on a 24/7 basis by monitoring electricity flow across the system, monitoring all network components and replacing those that are no longer functioning optimally, and further developing the network to meet the ever growing electricity demand.

Each department in TNB Grid plays vital roles to drive the Division to achieve its aspiration. Grid Strategy Department (GS) is responsible to facilitate a safe and reliable grid through utilization of technology and innovation. The department strategizes the investment of capital expenditure and optimizes the operational expenditure required. GS also governs all asset related policies and guidelines.

4.3.2. Lagging indicators at TNB

The main lagging indicators used at TNB Grid are:

- System Minutes
- System Availability

System Minutes is defined as the energy in Megawatt Minutes not supplied from the system to customers divided by the Annual System Peak in Megawatts for the year. The Megawatt Minutes not supplied is measured from all unplanned transmission outages affecting the customers, for 1 minute or more. "One System Minute" indicates that an equivalent interruption of total system for 1 minutes at the time of annual system peak. This is one of the reliability indices by IEEE and also known as Delivery Point Unreliability Index (DPUI), which is based on the interruption time

System Minutes in TNB Grid is calculated by the following formula.

$$System\ Minutes = \frac{Total\ unsupplied\ energy\ (MW.\min)}{Annual\ System\ Peak(MW)}$$

The unplanned outages of 132/33kV, 132/22kV, and 132/11kV power transformers that resulted in loss of load to customers are also taken into consideration for calculating the System Minutes.

The System Minutes is reduced by ensuring that maintenance activities are conducted as planned in an effective manner according to the established procedures. This applies to both preventive and corrective maintenance.

System Availability is defined as the probability of equipment being available for operation in a year. System Availability is calculated based on the total length of planned and unplanned availability durations and the total

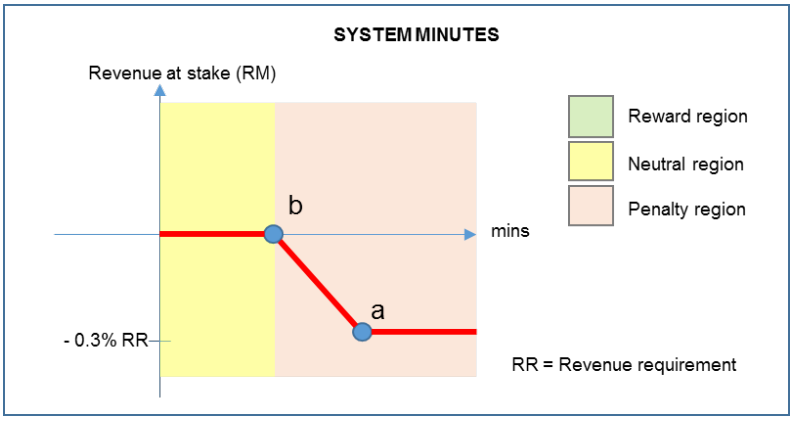
hours the circuit should have been available in a given period (in this case annually). The availability of the system measures the increased reliability of the system and is important in the case of unplanned event. High availability provides fewer opportunities and less compromising situations in the event of failure when back up (redundant circuits) are in service (available).

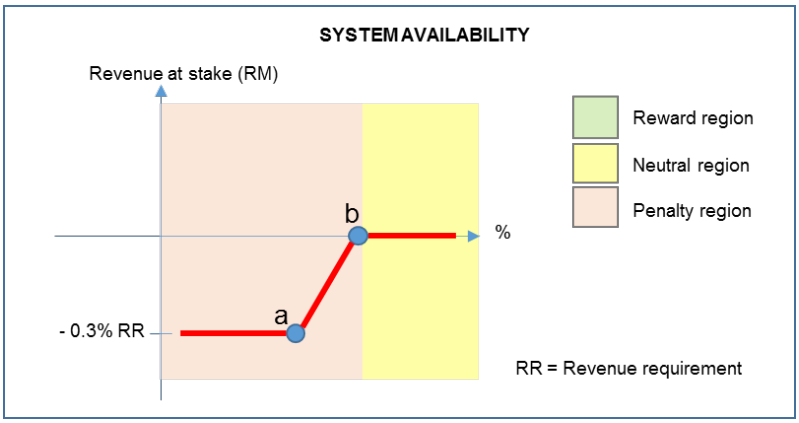
System Availability is calculated by the following formula.

$$System\ Availability = \frac{The\ sum\ for\ all\ circuits\ of\ hours\ available}{(No.\ of\ circuits).\ (no\ of\ hours\ in\ period)}$$

In order to maintain high level of availability, all circuits are returned to service as quickly as possible in the event of unplanned unavailability due to failures of related asset. In the case of planned unavailability, all circuits are returned to service quickly after completion of maintenance work to avoid any extended outages. An increase in live maintenance work will further improve the indicators.

Both System Minutes and System Availability are the performance indicators that being monitored by the Energy Commission of Malaysia under the Incentive Based Regulation (IBR) since Regulatory Period 1 in 2015. Starting from Regulatory Period 2 (2018-2020), both indicators are based on asymmetrical target i.e. penalty only as follows:-





4.4. Similarities and differences between our indicators

From the above sections the main *similarity* between Elia's and TNB's lagging indicators is that the System Minutes Lost indicator used by TNB and the ENS and AIT indicators used by Elia have the same purpose: monitoring the quality of supply towards the customers.

The following *differences* can also be identified:

1. The System Minutes Lost indicator used by TNB and the ENS and AIT indicators used by Elia do not use the same basis for power demand. TNB uses the maximum power demand, while Elia uses the yearly average power demand.
2. Elia considers the interruptions of less than 3 minutes as power quality issues, and other indicators (than the ones above) are used to monitor issues. In TNB, the threshold is set at 1 minute.
3. Elia considers the interruptions of which the causes can be acted upon by Elia (e.g. not considering force majeure, but considering material failure, direct or latent human error, etc.), while TNB considers all causes.
4. While TNB reports on system availability, Elia has no reported indicator on system availability. The aim of this indicator is to provide an indication of the quality of services not only at customer level, but also at system level.

4.5. Lagging indicators: benchmarking worldwide TSO's

Most System Operators use and calculate lagging indicators[2]. Although some differences can be highlighted in the indicators adopted, most of those indicators are compliant with international standards, such as e.g. IEEE Std. 1366-2003 or IEC-61000.

Three main categories of indicators can be derived[3] [4]:

1. Service Quality Indicators: "minutes lost per year" (e.g. SAIDI, CAIDI, SARI)
2. Reliability indicators: "incidents occurred per year" (e.g. SAIFI, CAIFI)
3. Availability indicators: "power or minutes without power" (e.g. ENS and AIT)

In Europe the most commonly used indicators are SAIDI and SAIFI within the System Operators, where AIT and ENS are mostly used only by the Transmission System Operators. In South East Asia, the same indicators appear as top of the list. In sub-Saharan Africa, the most common indicators are the same and concern MWh per year not supplied, number of outages per year and time of interruption per year, and Latin American System Operators seem to assess their performance similarly[5]. As our colleagues from OETC (Oman Electricity Transmission Company) have described it in 2009, the same KPI are used in the Middle East[6], and there is a tendency to converge on the same KPI to enable benchmarking. Other, frequent KPI include e.g. MAIFI.

[2] Elia Grid International internal research
[3] CEER, 2016
[4] CIGRE, 2004
[5] World Bank, 2009
[6] World Bank Group, 2018

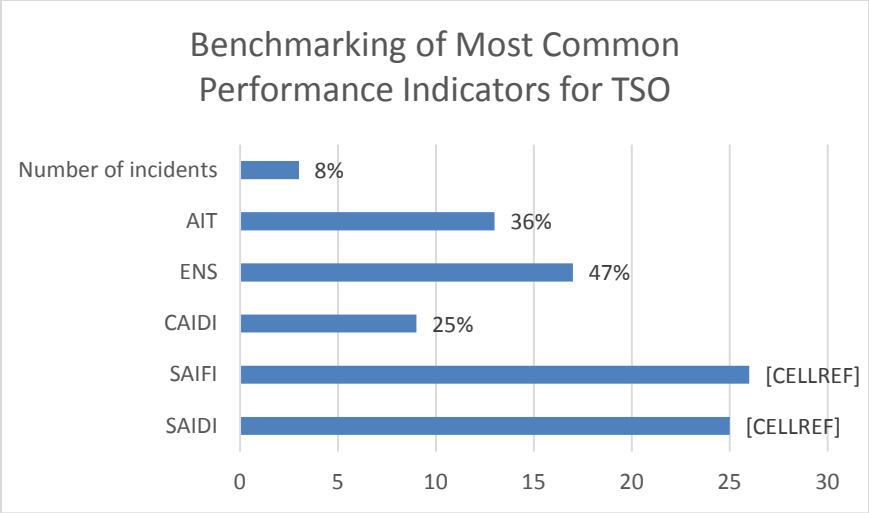


Figure 1 Most common KPI used by TSO, based on an EGI research of 36 TSO[7]

Fewer Transmission System Operators tend to analyze the system's availability as a whole, accounting the down times of the systems' circuits, whether due to planned or unplanned events. Some of the Transmission System Operators tend to take into account other parameters in the monitoring of their system's performance such as the customers that experience multiple interruptions or the best- and worst-served customers (Sweden)[8]. In general terms, there are two tendencies that appear, the System Operators that focus on the customer's satisfaction and those that focus on the power transmitted.

What appears from the analysis is also that operators that operate at Low Voltage levels in the calculation of their KPI will perform worse than the operators that do not operate at those levels or that separate KPI per voltage level.

Lastly, the regulatory regimes differ from country to country where rewards and penalties are applied, or a combination of both, to the achievement of the set targets[9].

4.6. Lagging indicators: room for improvement

The current lagging indicators and their current usages leave room for improvement. TNB and Elia have identified through this paper a variety of shortcomings to the indicators used today, based on the purposes they are used for:

1. Benchmarking:
    - Calculation methods are different between organizations and events taken into account differ, even though the indicators are called the same, which leads to erroneous benchmarking and performance target setting.
    - Weighting is mostly not used by the System Operators, and therefore does not allow proper comparison between System Operators.
    - Voltage levels are not taken into account when calculating or comparing the calculated KPI, which can lead to major discrepancies and deduction of erroneous recommendations.
    - Definition of the KPI calculation method is important, but also the scope and definition of an incident, event, interruption or fault.
2. Transparency:

[7] EGI market analysis
[8] CEER, 2016
[9] CEER, 2016

- Remuneration, penalties or reward system is broadly based on existing KPI, driving the TSO to optimize the value of the KPI rather than optimizing the overall system or specific assets, prioritizing the most critical points.
- The performance indicators that are suitable for reporting and transparency purposes do not allow proper decision-making. The current lagging indicators are influenced by a large number of factors and they are therefore difficult to use on a daily basis to make sound assets-related decisions.

3. Holistic approach:

- Current lagging indicators don't allow monitoring the performance of the whole grid. They are very well suited for the monitoring of the areas of the grid where customers are connected but they don't allow following the performance of the assets of highly meshed transmission grids, where failures rarely lead to customer interruptions.
- Today, utilities use performance indicators that do not focus on the performance of the systems, rather than the performance of individual assets or the full grid's availability. This approach does not allow to take the required measures on those systems, as the system approach is increasingly encouraged by asset management.
- Clear methodologies are not always used to set targets for performance indicators. Historical performances are used to calculate the targets, instead of deducing them from the level of service required by the community and the price the community is willing to pay for an additional improvement of its quality of supply.

5. Lagging Indicators: Thinking ahead

5.1. Redefining the objective of using indicators

We at Elia Group and Tenaga Nasional Berhad tend to believe that Key Performance Indicators should:

- Be **reflecting the strategy** of the organization through the targets of those performance indicators. The chosen performance indicators need to reflect the country's and TSO's reality at a certain point in time. If, e.g. the availability of cross-border capacity is critical to the performance of the grid, this could be monitored through a specific KPI.
- Enable better **decision-making** by the operational staff.
- Allow organizations to compare and **benchmark** their performance with their peers, whether they have similar systems or asset bases.
- Assure to **comply** with **regulatory** and legal requirements.

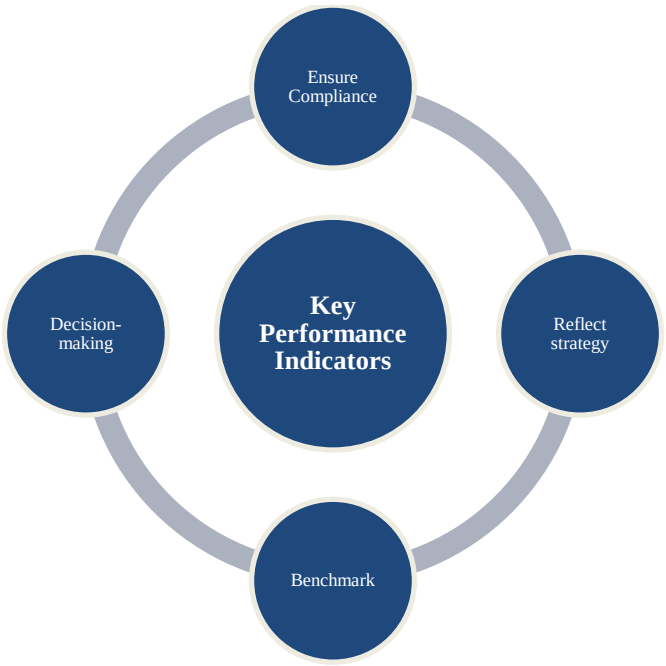


Figure 2: The objectives of Key Performance Indicators for Electrical Utilities

The 4 dimensions need to be addressed to obtain Key Performance Indicators with value for the organization, especially as asset manager.

5.2. Conclusion and reflection paths

In conclusion to this paper, Elia and TNB would like to provide some reflection paths which should guide system operators towards improved lagging indicators, with the aim to initiate a common and shared approach in the sector:

1. The first consideration is that the performance indicators chosen should **reflect performance and events on which the TSO have action leverages**. In any case, performance that cannot be improved can be monitored but should also be reported as such. As of today, there is still a disconnection between the lagging indicators implemented and the corporate strategies.
2. Rather than only harmonizing the indicators, the TSO should develop specific indicators that enable the asset managers to make **the right decision based on the trade-off between risk, performance and cost**, rather than driven by remuneration schemes.
3. The **impact of investment decisions** which result from the monitoring of KPI to improve the quality of provided services should be **monitored**. If the investment decisions do not render the expected value, strategy should be adapted .
4. The most **common indicators should be complemented** with performance indicators that are customer-focused, voltage-dependent and allow to drill down to the assets level.
5. Lagging indicators should enable to monitor the performance of the grid not only towards the **demand-side, but also the generation-side**. ENS only enables TSO to assess the quality of their service towards the consumer, while the producer's service level is not monitored.
6. Lagging indicators consider that all users of the grid have the same **expectations with regards to quality**. In the future, system operators could differentiate the needs and expectations of the different users, considering possible implications on the applied tariffs for the different levels of services. One solution could be to apply weighting of the lagging indicators :
    a. per customer or customer type
    b. per amount of users affected

c. per delivered point

d. by the power affected

e. by annual energy consumption

Targets for the KPI should be defined **taking into account the expectations of the customers connected** to the grid, in order to reach a technical-economic optimum and to **avoid overinvesting or underinvesting** in the performances of the grid

7. As a heavily regulated industry, there is always an increasing cost pressure in utilities to keep electricity qualitative and affordable at all times. As the assets age, the cost of maintenance of the assets rises. It is therefore crucial to ensure all the assets continue to operate at optimum cost for the required level of service and consistent with commercial and risk management strategies.

   Limitation in both capital and operational expenditure requires utilities to look for new approaches to for cost optimization Therefore, it's important for utilities to know their relative cost position with reference to the others in the same industry. Among the objective of KPI's is to **measure performance and benchmark them with similar sized utility** to assess the performance improvement attained. By introducing a KPI on cost efficiency, utilities can not only benchmark on its reliability performance but also on cost.

8. As stated by our colleagues: "Improvement of maintenance performance is an issue that is being actively pursued by most utilities" and "at the present time, there are no internationally recognized indicators for measuring the effectiveness and efficiency with which maintenance is performed. Although some international measures are available, they are not widely used in the context of **measuring the efficiency and effectiveness of maintenance"**[10].

5.3. Recommendation: The approach to realize the ambition

The Elia Group and Tenaga Nasional Berhad strongly believe that redefining the way lagging indicators are used in utilities will greatly contribute to the way performance is monitored, managed and achieved. Therefore, it proposes a simple multi-stage plan to develop these practices in similar organizations:

1. Develop Asset Management Objectives based on the corporate strategy

Defining Asset Management objectives is crucial to make sure that the targets and corresponding indicators measure what matters to the organization. Without agreeing initially on these topics, the organization would in other words be defining performance of inexistent or inappropriate objectives. In other words, it would mean calculating the time to get somewhere, when 'somewhere' is not defined.

2. Develop governance to manage asset and system performance

After having defined the objectives, the organization will have to develop the framework and governance that will enable the execution and implementation of the defined objectives. This involves managing the data that will enable to calculate precise and correct performance indicators.

3. Develop performance indicators that enable decision-making

Monitoring the implementation of the objectives is the next logical step, to ensure the organization has taken the right actions towards the achievement of the defined objectives. As has been addressed along this paper, the monitoring can best be done through lagging and leading indicators. These indicators should make sure that the organization is able to react if the agreed objectives are not achieved.

4. Monitor and audit performance indicators to assure these indicators provide the required outcomes

Organizations should engage in a process of continuous improvement. Elia and TNB have decided to improve the way their asset performance is managed a long time ago, but still continue to question their current methodologies. This is part of a broader benchmarking exercise that operators should engage in.

[10] Cigré, 2004

The **key success factors** for developing and using performance indicators at their right value are summarized below:

- Lagging indicators are part of a more complete set of asset management practices to be initiated in the organization.
- The organization and its management recognize and commit to applying the indicators' results as guidance for allocating resources and priorities.
- In order to obtain acceptance, there must be a direct link between the indicator and the performance it measures.
- Lagging indicators of the assets' and system's performance need to be directly linked to the organization's targets, and derived in specific objectives for personnel

Elia System Operator and Tenaga Nasional Berhad have also developed an approach in order to **complement their lagging indicators with leading indicators**. The latter indicators enable the organizations to **act** upon the reliability of the grid even **before the disturbances** have affected the grid. Leading indicators enable decision making, while lagging indicators are focused more on reporting and analytics.

Today, these leading indicators are mainly applied in the nuclear sector, where disturbances and incidents are risks that these plants cannot afford taking. But **imagine** that in the future, due to increasing regulatory requirements, environmental laws and public image, **incidents and disturbances are no longer accepted** on the electrical grids. The solution would be to use these **leading indicators** to act upon the same parameters as the lagging indicators but prior to the occurrence of the disturbance.

Most utilities consider leading indicators **only those indicators related to their assets**, such as condition monitoring. **Many other indicators** can be used to predict that an event will affect the grid's reliability or availability

- The indicators shall allow the organization to compare trends between different performance objectives.
- Lagging indicators are nothing without the actions triggered by the indicators' threshold values.
- Lagging indicators shall monitor internal and external influences.
- Leading indicators require a lot of data for reflecting what they should measure. Organizations shall, in order to use leading indicators, first develop a data model that supports the needs of such leading indicators.

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