ETN White Paper

Industrial Internet: the next age of productivity for European GT based plants (Revision 1)

Contents

1   Executive summary

In recent years, there has been a lot of discussion on how Industry 4.0 and the industrial internet is challenging traditional business models and processes and how it provides new opportunities to gain competitive advantage. Industry 4.0 refers to the 4th industrial revolution enabled by the Industrial Internet of Things (IIoT). Connectivity of all assets to a single platform and real-time access to this consolidated data, combined with advanced analytics, will provide insights required to go closer to the limits of the equipment, eliminate inefficiencies and enhance the human work experience.

The energy sector as well as the Oil&Gas sector have been early adopters of digital technologies to improve their processes [4]. Since the 70's, digital techniques were introduced for decision support and process improvement and have been commonly used for well over a decade now. We are all familiar with remote monitoring centres, on-line performance decks and other digital support systems. So, what is all the fuss around digitalisation, the industrial internet and industry 4.0 all about? Is it just a new buzzword for more of the same or are we really at the start of a new age of productivity? In a series of workshops, the ETN Technical Committees 4 and 5 have been reviewing this question and the latest status has been summarised in this paper.

The first part of the analysis quickly showed that a lot of the digital initiatives in the past got stuck in the information generation phase, without really providing the insights required to improve the business result. Many of the causes for this were related to IT infrastructure and data handling issues. Reasons included missing data, bad quality data, issues in accessing data, insufficient resolution because of data compression, different disconnected data pools, incompatible formats and disputes on data ownership.

A look to other industries, and to customer experiences we make in our private lives, showed that advances in IT technologies in the last decade have provided a lot of the answers to deal with above mentioned roadblocks. New developments such as improved connectivity, cloud data storage, software as a service, advanced and self-learning algorithms, improved sensors, etc. were identified. It quickly became clear that industrial IT has completely re-invented itself and now provides us with the means to address most of the historic roadblocks. In addition, it offers new opportunities to increase competitiveness. However, any new development, also comes with new risks. Risks to industrial IT projects, such as cyber security, new skill requirements and unclear governance and purpose were identified and need to be considered in implementation projects.

Unlocking the full value of the data involves more than just an IT project, it requires a transformation of value creation processes within the company. The last chapters of this paper are therefore looking into a self-assessment model for digital maturity and some best practices related to the implementation of digital capabilities.

2   About this paper

The objective of this paper is to provide support and guidance to the ETN members on Industry 4.0 and the Industrial Internet. The content was developed during the regular ETN workshops in a joint effort between Technical Committees (TC) 4 and 5, in 2016 and 2017

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

2

and published in February 2018. A first revision was made after a further working session at the 2018 ETN annual general meeting in Bucharest. This revision includes, besides some corrections, additional detail on how to assess digital maturity and recommendations on the implementation

Authors:

- Chris Dagnall (DNV GL)
- Pascal Decoussemaker (General Electric)
- Based on the inputs of the members of ETN TC4 and TC5
  Contributors included participants from Mälardalen University (Sweden), Roma Tre University (Italy), Cranfield University (UK), University of Genoa (Italy), University of Stavanger (Norway), Enel (Italy), German Aerospace Centre (DLR) (Germany), DNV GL (UK), Ansaldo Energia (Italy), Siemens (Germany), GE Power (USA, France, Switzerland), VBR Turbine Partners (Netherlands), Fogale Nanotech (France), Frazer-Nash Consultancy (UK), National Instruments (Italy), ADGAS (UAE).

Publication dates:

- First published: February 2018
- Revision 1: November 2018

3   About ETN

ETN is a non-profit membership association, bringing together the entire value chain of turbomachinery technology worldwide. ETN currently has 114 members.

ETN addresses the main challenges and concerns of gas turbine (GT) users in committees and individual projects, composed of experts across the entire value chain: power generation and oil & gas companies, OEMs, R&D institutes, suppliers and service providers and technology consultancies. ETN believes a common strategy and research effort between all stakeholders, along with supportive energy and research policies, will enable growth and increased competitiveness of the gas turbine sector globally.

For more information: http://etn.global/

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

3

4 Introduction

Improving plant hardware to improve plant performance has made a huge leap forward in recent years and is reaching an area of diminishing returns. The next big opportunity to further improve plant performance is to accelerate productivity, reduce inefficiency and waste in equipment operation, and enhance the human work experience through digital technologies.

Information and communication technology (ICT) has been mentioned several times in the 2016 update of the Project Board R&D Recommendation Report issued by ETN [2]. In several sections of the report, ICT was highlighted as an enabler to achieve some of the targets of the European stationary gas turbine industry. Specifically mentioned are for example predictive performance algorithms, use of analysis of operation conditions to manage sub-system lifetime, risk based maintenance approaches, use of "grey box models" for monitoring purposes, merging sensor based information with inspection and off-line monitoring results, advanced instrumentation, fault detection systems and big data storage and management.

Other organisations are also looking into using the industrial internet to improve business results. For example, in 2014, the Industrial internet consortium® (IIC) has been founded to bring together some of the main industry players, to promote the accelerated growth of the industrial internet of things (IIoT). Also EPRI, the electric power research institute in the USA, has started a project to setup a physical and virtual host test site to test the industrial internet. The name of the project is I4Gen [5], which stands for insight through integration of information for intelligent generation.

As we have seen elsewhere in other industries, the digital transformation is challenging traditional business models and presents new opportunities. Players who are quick to embrace this transition will gain a unique competitive advantage as they will increase income through a better control of their operations and will keep costs down in an increasingly demanding industry.

This paper will review what new opportunities the IIoT provide, associated risks and how GT based plants in the Oil&Gas and the power generation industry may benefit from the adoption of the industrial internet.

Unlocking the full value of the data involves more than just an IT project, it requires a transformation of value creation processes within the company. The final chapters of this paper therefore describe a methodology to assess the digital maturity of an organisation covering both the technical as well as the organizational dimension. Finally, the paper shares some recommendations on how to successfully master the digital transformation in your organisation.

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

4

5 Industry 4.0 and the industrial internet

Industry 4.0 (see Figure 1) refers to the 4th industrial revolution. In the first revolution, the world changed from a society depending mainly on agriculture to create value, to a society that relied on industrial production, driven by water and steam. In the second revolution, electricity was introduced as a driving force, and assembly lines were created to increase productivity. Later, in a 3rd industrial revolution, assembly lines were automated, supported by electronics and IT systems. In Industry 4.0 all steps of the lifecycle of a product will be connected by a single digital thread, operated through a single platform. Sustainability becomes a key factor, together with the integration of smart systems for control and monitoring. A major part of the digital journey is based on data and connectivity. Connecting all machines to the internet and consolidating all data sources on a single platform are stepping stones to creating the insights required to improve processes and go closer to the limits of the equipment. A key enabler for all of this is the introduction of Cloud Computing technology which helps to provide a safe, central repository, available through the Internet.
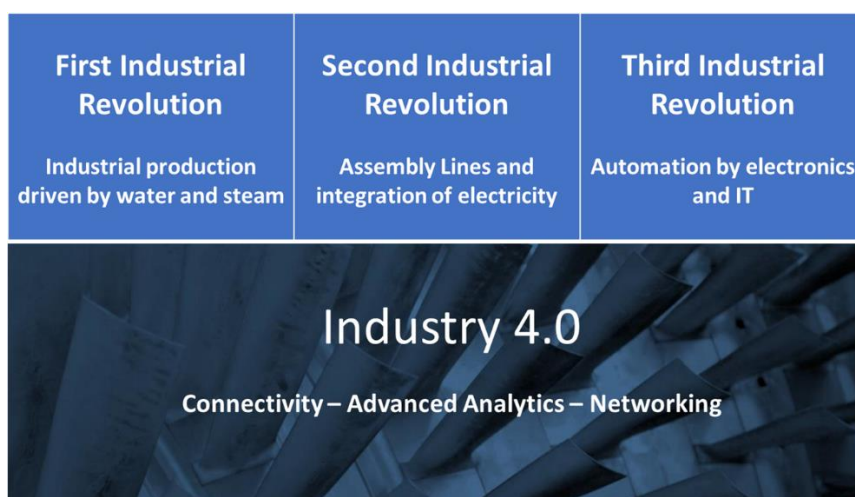
Figure 1: Industry 4.0

The most important pillar in the breakthrough of industry 4.0 is Internet of Things, or Industrial Internet of Things (IIoT) [9]. The concept is to connect all hardware and software components within an industrial environment, providing complete visibility into operations at any time, at any location. The IIoT is not really a new technology, but it refers to the mixing of the industry with the open computing and communication systems developed as part of the Internet Revolution. The convergence of machinery and smart data allows for constant and real-time adjustments and provides insights required for smarter business decisions. The aim of this integration is to open up new frontiers to accelerate productivity, reduce inefficiency and waste, and enhance the human work experience.

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

5

The IIoT brings together:

- Intelligent machines with embedded technology to sense and interact with their environment (advanced sensors, better models and controls);
- Advanced analytics (physics based, predictive, …) and machine learning;
- Networking of people at work through discussion groups.
- Faster decision making and improved interaction, thanks to new generation HMI solutions in both work or domestic environments.

6 Review session at ETN Annual General Meeting

6.1 Historic Roadblocks

The graph (Figure 2) below is a typical graph used for introduction of knowledge management. Starting from data extracted from activities and processes, data becomes information when put into context and made accessible. This information in turn becomes knowledge when adding insight gained through understanding. The real value only comes from the actions or decisions taken based on these insights, which ensure long term sustainable and profitable operation.
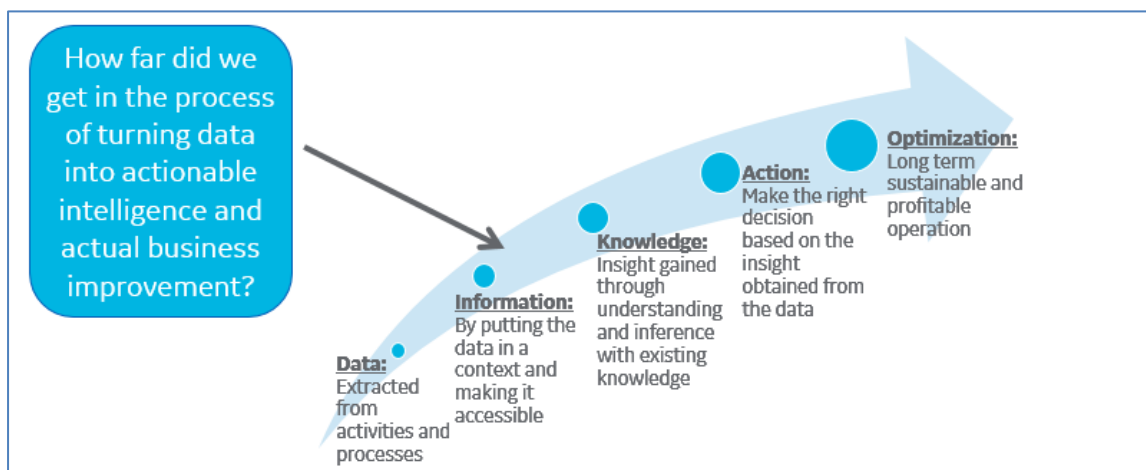
Figure 2: Knowledge Management

The gas turbine based industry has started implementing remote M&D, performance models, neural networks and condition monitoring for several decades. But when asked in which stage of implementation most plants are, the ETN Technical Committee members agreed that it is usually somewhere between "information and knowledge". Similar feedback was received at similar discussions organised by EPRI in 2016 in the USA.

What are the historic reasons we did not get any further and have not been able to create a breakthrough in creating added value? Below is a list of reasons from a brainstorming, held at the ETN Annual General Meetings in 2016 (Prague) and in 2017 (Oberhausen):

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

6

- **Data access and connectivity:**

  - Data islands:
  Missing inference with other data / information sources or lack of bridges between data islands: e.g. no access to maintenance history, subsystems of different suppliers often use different data loggers or control systems, … Decision support only works when all inputs are available. Historically, most of the effort in problem solving is related to finding the required data.

  - Time continuity of data:
  Moving of assets to other locations, so no data continuity over the history of the equipment.

  - Incomplete data model:
  Many influence factors are often not considered in the design and therefore not monitored (e.g. chemistry, previous inspection results and fleet experience).

  - Data resolution:
  Sampling is too slow to make transient analysis, e.g. for real-time monitoring of fatigue supported by FE. This is often caused by storage limitations or lack of effective data compression techniques.

  - Data browsing limitations:
  Navigating through large amounts of data and finding the right extract is often a challenge, both because of the lack of possibility to effectively zoom out and because of processing capacity limitations.

  - Physical limitations to access the data:
  Stand-alone systems in the control room can only be accessed when physically going there. This makes data use of the generated data by specialists inside and outside of the company less efficient. In addition, internet access to remote oil&gas or power generation facilities may be limited or non-existent.

  - Disputes over data ownership.
  Unclear situation regarding final data ownership and other IPR related issues.

- **System / platform management and maintenance:**

  - Hardware or software update issues:
  Issues related to hardware obsolescence, missing software updates, regular data back-up, software/hardware interface protocol changes, etc. With the lean staffing on power generation or oil&gas facilities, the access to professional IT management staff is limited.

  - Hardware limitations:
  Limited storage place or processing capabilities require compromises in data storage or analysis.

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

7

- Different data formats:
  Difficulty to transfer and automate analysis of data other than simple time series, e.g. FFT, pictures, heat maps.

- **Data management and maintenance:**

  - Incomplete data:
    If the data is not used pro-actively, but only looked at when there is an issue, it is often discovered that part of the data is missing, disturbed or not available.

  - Data validation:
    Limited data plausibility checking or validation capabilities.

- **Data security:**

  - Access limitations because of security requirements:
    It is often time consuming or impossible to give all stakeholders access to the data, especially if they are part of a different organisation, such as OEM's or other service providers.

  - Risk related to 3rd part access to critical infrastructure control platforms.

- **Analysis and analytics:**

  - Modelling limits:
    Limitations of models to mirror future reality, and all possible future degradation schemes, transferability between sites, individual site characterisation.

  - Effort / cost involved with the maintenance of the models:
    Keeping models up to date is important to avoid false positives or false negatives, but often requires a lot of effort.

  - Expertise:
    Lack of access to the knowledge required to interpret the data and establish the necessary relationships.

  - Risk management:
    How much risk is acceptable. Lack of acceptance by deterministically educated engineers for risk based decision making. Lack of acceptable ways to quantify risk make it difficult to accept risk.

  - Economical evaluation and market models:
    Lack of maturity of such models to be used on an industrial level. It is however important to integrate these models in the decision-making process in order to generate useful insights.

  - Human factors:
    Organisational barriers, such as fear for job loss or unwillingness to share information. There is often not enough focus on creating a win-win situation.

ETN a.i.s.b.l.   8
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

– Uncertainties related to the pay back / cost-benefit:
What will be the "real cost"? How much effort is justified to invest for "non-noble parts"? What is really needed and what is "nice to have"?

6.2   What has changed in the last 10 years

The on-set of the IIoT has provided a number of new features that will help to deal with many of the historical challenges discussed in the previous chapter. This was reviewed in the ETN Workshop held in Genoa (Italy) in October 2017 [1].

- **Data access and connectivity through use of the cloud:**

    – Single source access to data from different data sources, such as operational data, plant floor technical data, financial data, supply chain / ERP, maintenance planning system (CMMS) and maintenance history, dispatcher/grid system, weather data, smart metering, information on volatile / distributed generation resources, control systems, sensors, configuration data, lab results, inspection results, design information, instruction manuals. The possibility to query and combine data from different sources as if it is in a single data pool is also often referred to as **big data**. All the data is "just there".

    – Possible to integrate data islands related to older, legacy systems or data in different formats.

    – Different connection/access technologies are available (e.g. 4G/5G at locations with limited wired internet, WLAN, LoRa, …).

    – Access through mobile and remote devices, from various locations inside and outside of the plant.

- **System / platform management and maintenance:**

    – Software as a service (SaaS) moves away the system responsibility from the end user. Responsibility for hardware and software maintenance and updates is transferred to a professional IT service provider with latest state of the art hardware and software.

    – Improved reliability by moving away from individual machines that may fail. Disaster recovery is now managed through a professional organization and supported by redundant systems.

    – Possibility to store and handle different data types, including higher resolution data. Not just time series data but also other types of data can be handled, such as patterns, pictures, compressed data, aggregated data etc.

    – Handling of data streaming from control systems, SCADA systems, energy management systems, equipment sensors, plant historians, and many other sources. This different data sources must be organised, combined and made available to many end users to get an effective optimisation.

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

9

- Scalability is designed into cloud based systems. It is easy to scale number of users, applications, storage or processing capacity.

- Technology (cloud) is not "GT industry" specific, leading to economies of scale, and rapid technology advancement.

- Open platform, can receive applications from different developers (3rd party apps).

- Reduced cost because it is no longer necessary to purchase and maintain your own IT infrastructure. But also in general, IT hardware costs have gone down in the last decade.

- Cost of edge (on-premise) devices has reduced, and processing power has improved. This helps to connect additional local devices and also enables local control as well as remote control and updates through local control devices.

- **Data management and maintenance:**

  - Improved data quality because it is easier to maintain the data if it is all at a single location. Data from different sources also provides more validation options, e.g. through comparison with other data, or with virtual or soft sensors.

  - Short term storage on edge computing devices (see chapter 11) allows dealing with periods when connectivity is temporarily interrupted.

  - Improved HMI solutions to navigate through the data history and visualise data in different ways. This also includes capabilities to effectively sort through large amounts of data and zoom into specific areas of interest.

- **Data security:**

  - Oil and Gas facilities and Power plants are strategical assets: if data is transported away from the plant, into the cloud, it reduces the risk of direct access to the plant and therefore reduces the need for access restrictions.

  - Secure data storage through central identity management in the cloud by means of the use of a "single" cooperate identity (SSO).

  - Secure data transfer through encryption techniques.

  - Data diode to protect undesired external access to the plant strategic assets.

  - Making data or information available through links is more secure than distributing documents and other files by (e-) mail. Centrally stored information can be better monitored compared to data on private disks or folders.

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

10

- Central version control of updates ensures the implementation of the latest security patches.

- A downside remains however that all data is stored at a single location, so if someone gets in, the consequences may be larger.

- **Analysis and analytics:**

  - Advanced analytic techniques and self-learning systems have become more available, more effective and user friendly. Maintenance efforts have been reduced through self-learning systems.

  - Code sharing and standards help to reduce programming effort and cost.

  - Virtual plant or digital twin models can be used for different applications, e.g. project validation, new controls testing before installation, but also to monitor existing installations for deviations.

  - Increased amount of visualisation options, e.g. through cockpit charts that allow to drill down to more detailed KPI's.

  - Ease to provide data access to different users and user groups. This does not only facilitate user management, but even more important is that it helps to break down organisational silos (e.g. EHS, different plants of the same owner, reliability team, operations, maintenance, trading, …), through sharing of experience and expertise in a common system. It also becomes possible to give access to specialised companies to help the end user with the interpretation and effective usage of the data.

  - Hybrid Plant Networks allow to manage Virtual Power Plants (VPP).

  - Faster fault analysis and efficient disaster recovery solutions, combining remote access to plant data and virtualisation & simulation of the plant network.

- **Sensors:**

  - Improved sensors: better accuracy, higher temperature resistance, longer life, more robust and versatile.

  - Better and faster processing technologies leading to faster measurements and processing, e.g. surge detection, flame monitoring, 3D exhaust flow monitoring.

  - Lower cost, or improved functionality such as smart transmitters with on-board diagnostic features.

  - Wireless technologies make it easier to integrate new sensors in existing systems.

ETN a.i.s.b.l.   11
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

6.3 Pitfalls / risks

Regarding the loss of business continuity, the risk perimeter increase is the common factor when connecting hardware and software components within an industrial environment (IIoT).

Below is a listing of some of the risks that need to be considered when implementing the IIoT:

- **Cyber Security:**

  - Hackers who want to harm the IT system, or the plant:
    Hacking a professionally maintained system is more difficult, but in case a hacker does get through, there is potentially access to a lot of data. However, value of plant data is usually less interesting to criminals, assuming that other market players will not engage in criminal activities. In addition, by moving data away from the plant into the cloud, the threat of sabotage to plant equipment is reduced.

  - The convergence of OT and IT systems:
    The introduction of internet capable control and supervisory systems, makes OT systems more vulnerable to malware and external interference, potentially leading to acts of sabotage.

  - Competitors who get insight in your business to get competitive advantage:
    This may happen through internal data leaks and misuse or external unauthorised access. As discussed in the previous chapter, it is easier to control data and information in the cloud compared to uncontrolled (e) mail or hardcopies.

  - Privacy concerns:
    Are less of an issue for "machine" related data.

- **Skills:**

  - IT skills:
    This requirement is reduced through SaaS.

  - OT skills:
    Power plant reliability is the driving need for these requirements. In fact OT skills are driven by the stability and interoperability demands to correctly use and maintain still working legacy systems (e.g.: Windows XP) as well as to effectively protect more modern internet enabled OT technologies. Remote support helps to address this challenge.

  - User skills:
    Some training and internal promotion will be required when introducing new systems and technologies, especially with older generations. However, millennials that have grown up in the digital environment will expect this as well in their "new" work environment.

ETN a.i.s.b.l.   12
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

- **Abundant data by itself solves nothing:**

  – It is important that leadership and process know how carriers are part of the implementation project teams and that their expertise and requirements are leveraged. A pre-condition to generating useful insights is to connect all the right data sources to the processes that need them and that there are no gaps that need to be filled with individual "work arounds".

  – However, to some extent, it may proof useful to pool more data than strictly needed by the application. It may help to deal more easily with future requirements.

- **Ownership:**

  – Data access and property conflicts related to historic data: Data is owned by the organization that generates the data. A contractual license agreement needs to be in place to arrange the usage of the data by 3rd parties.

  – In IIoT, the software is provided as a service, therefore ownership of the software and the system remains with the service provider. The software is provided on a subscription basis.

6.4 Value

How can the industrial internet create tangible value to the end-users? Three (3) areas of value were identified in the definition (see chapter 5):

- **Accelerate productivity (increase income):**

  – Go closer to the limits of the equipment (e.g. surge protection, lean combustion, life consumption, adaptive control approaches) through better sensors and models. This will improve capacity or flexibility (e.g. reduced minimum load, better response time).

  – Better short and medium-term demand forecasting based on complex interaction of many parameters (weather, time of the day, season, end-consumer behaviour, etc.) to better anticipate load / operation management and provide a better service to the customer (grid).

  – Trade-offs between market opportunities and cost / life consumption.

- **Reduce inefficiency and waste (reduce spending):**

  – "Off design" tuning (e.g. part load, ambient fluctuations, duct burner use) for optimum efficiency.

  – Predict and avoid defects and unplanned breakdowns through early warning, lifetime monitoring or more effective maintenance planning.

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

13

- – Reduce life cycle cost (investment, maintenance, consumables, …) through risk and condition based maintenance, based on better insights from the available data on condition and business impact (risk).

  - – Fleet level comparison to optimise operations, benchmarking between plants (e.g. fuel consumptions, maintenance tasks).

  - – Better alignment between internal organizations through better visibility of priorities.

- **Enhance the human work experience:**

  - – Mobile worker becomes more efficient through easy access to all required information and reduced reporting efforts.

  - – Robotic inspection technologies reduce costs and outage time and often also provide better data.

  - – Learning with the aid of virtualization minimize risks related of possible damages to physical equipment and downtime.

7 Maturity model

Industry 4.0 or the smart factory concept relies upon cyber-physical systems (CPS), which link the physical and virtual worlds by communicating through an IT infrastructure, the Internet of Things. The good implementation of Industry 4.0 enables distributed, highly automated production. Differently from traditional production, smart factories will control and monitor the production process and, in the final mature phase, will guide themselves autonomously through production. The smart factory is a production environment in which the production systems and logistics systems largely organise themselves without human intervention. This is what happens in the smart factory environment. Industry 4.0 also involves digital modelling through the smart gathering, storage, and processing of data. In this way, the smart factory concept ensures that information is delivered and resources are used more efficiently. This requires a real-time, cross-enterprise collaboration among production systems, information systems, and people. These integrated systems produce large amounts of data that are processed, analysed, and integrated into decision-making models.

Most companies will not start from zero. To get started in the digital transformation journey, it is important to understand where a particular organisation stands in terms of digital maturity. Digital mastery does not only require the right technology, but also requires the right governance to manage the transformation. This topic was extensively review at the ETN Annual General Meeting in Bucharest in 2018. Assessing the Industry 4.0 maturity level can be done according to the following two main dimensions:

- Digital capabilities [4]:
  - o Data:
    How good is data collected, stored and made available? How much of the process is reflected in the data, e.g. do we use advanced sensors, do we

ETN a.i.s.b.l.   14
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

collect diagnostic information from local instruments and controllers? Is the infrastructure scalable, performant and safe?

- o Connectivity:
  How effective and efficient is the infrastructure in connecting the devices and the users of the date.
- o Analytics:
  Are digital twin models in place to perform analytics? Does the organisation also use prediction or optimization algorithms?

- Leadership and organisational aspects [8]:
  - o Management:
    Is there a clear vision, plan and KPI's linked to the expected business outcomes.
  - o Organisation and implementation of digital capabilities:
    How is the adoption? How is the relationship with the IT department? How is training for users organised?

For each of these dimensions, a list of questions has been developed to perform a self-assessment (see chapter 13). Questions should be answered on a scale of 1 to 5:

- 1 strongly disagree / not at all;
- 3: neutral / partly;
- 5: strongly agree / fully in place.

Results can then be average in each category.

Finally, the results of the different categories can be averaged according to the two main dimensions on plotted on a XY graph (see Figure 3) [8].
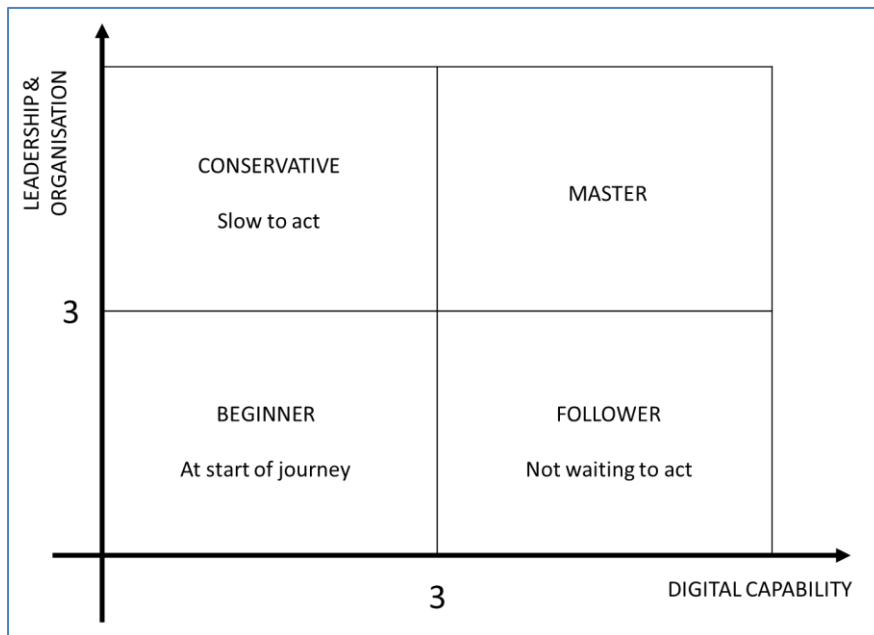

Figure 3: Result of self-assessment

ETN a.i.s.b.l.   15
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

Companies in the "follower" quadrant are quick to take up and experiment with new technologies, but may lack governance to get the full value out of their investment. Companies in the "conservative" quadrant have a good control of the development of their capabilities and the required investments but may be too slow to adapt. In the "master" quadrant, companies have mastered to find the right trade-off between implementation of new technologies and improving their processes and capabilities in-line with the opportunities the new technologies provide.

8 Implementation model

In order to implement an Industry 4.0 model, new technologies and organisational methods need to be merged with existing technologies and processes. A successful implementation requires that an organisation goes through a number of steps and considers both the technology development, leadership aspects and the issues related to sustainable organisational development.

Whereas traditional IT infrastructure projects depended on clear design and well-structured plans, more recent IT projects often engage in test-and-learn strategies, based on experiments. However, doing major implementations of new technology in a learning-by-doing approach could be dangerous. It may increase rework, waste money and introduce security risks [9]. A two-speed approach that does not work around systematically addressing any IT issues is therefore recommended:

- Start by building up a digital backbone with interfaces to legacy systems. It is important that in parallel, any of the old IT processes continue to receive full support. This project has to be performed in a careful and systematic manner in order to avoid any security issues and re-work.
- Once this digital backbone is on place, various capabilities can be developed in a fast, agile and flexible manner. The continuous deployment ensures a rapid feedback of users and business and the effectiveness of the implementations.

A best practice implementation process consists out of four phases:

1) Create a Digital Vision:
   At the start of the process, it is important to create management awareness of the importance and an associated sense of urgency. It is also important to know the starting point or the digital maturity or the organisation. The self-assessment proposed in the previous chapter is a good tool for this. Once this is clear, company transformative vision around its strategic assets needs to be defined, together with a clear business expected business outcome.
2) Project planning:
   In this phase, goals need to be defined, an implementation plan needs to be developed and the budget for the transformation process and the subsequent operation needs to be defined. Part of this effort is also the return on investment calculation.
3) Implementation project:
   The IT backbone needs to be implemented and first applications need to be

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

16

developed. These pilot projects should represent quick wins to gain acceptance. Try out different alternatives and adapt the organisation to support this.

4) Consolidation:
Expand, learn, check progress and compare to planned resource attribution. Correct where needed to achieve sustainable processes. Training and building up of the required digital skills is important in this phase.

9   Success story

A large US power utility was faced with the challenge of providing economic and reliable power as demand and fuel prices fluctuate. At the same time, the leadership recognised the value of leveraging data from their plants to make more informed decisions about operations and market opportunities.

To achieve this, they worked with GE's team of experts to implement GE's Predix based Asset Performance Management application at a pilot plant. The system captures data from machine sensors and applies analytics to create insights that drive more profitable decisions. A centralised monitoring centre was created to help drive the key performance indicators for system availability, thermal performance and operational flexibility.

This resulted in an integrated view that puts the plant manager and their trading counterpart on the same page. Automatic notifications alert the plant manager about any operational anomalies in order to prevent risky operations. Cloud-based visibility, insights and actions keep leadership focused on achieving their continuous improvement initiatives including identifying opportunities to improve thermal performance, increase operational flexibility and reliability. Because of this digital power plant initiative, the plant reached the top quartile for heat rate, reduced fuel costs during start-up and achieved 1% improved reliability. It allowed this older combined cycle plant to remain competitive even after newer, more efficient plants began operations in an already very competitive regional market. The company has since decided to extend the system to its other fossil plants and future plans also include the nuclear fleet [7].

10 Requirements from the user community and next steps

A number of items have come up during the discussions that require further investigation and feedback to the user community.

- Experience feedback on the execution of the maturity model self-assessment described in this paper (chapter 7).
- Recommendation on how much a company should count on suppliers and how much should a company invest in internal capabilities on the Digital knowledge, there could be difference approaches, this has an effect on the organisation, costs, sustainability etc.
- Define best practices for analytics. As for analytics development the agnostic, physics based or hybrid approach can be followed and this has an implication on role and responsibility of OEM and on market penetration as well. In the recent PHM conference in the Netherlands the Hybrid approach was shown as a best practice.

ETN a.i.s.b.l.   17
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

- Virtual reality is just mentioned in the paper but together with augmented reality it could have an important role in maintenance optimisation.
- Provide some examples of best practices and more technical detail related to the actual implementation. General Electric (GE) has provided a number of publications to provide guidance to the users [3].
- Further requirements from the user community and next steps will be mainly dominated by AI tools for proficient modelling. Some specific detail on how AI has been applied in gas turbines (e.g. for diagnostic or control) and ideas for further improvement should be summarised.
- An important topic is the standardisation of control interfaces to different proprietary systems, especially against the background of the increase of decentralized power generation and even household CHP infrastructure.
- The remote data transfer today is mainly applied to monitor the asset rather than to operate it, in the short future unmanned plants would change the situation and IIoT will be key to even operate remotely.

11 Glossary

Analytic:
Algorithm used for examining big data to uncover hidden patterns, unknown correlations and other useful information that can be used to make better decisions

Edge computing:
The part of the system at the edge of the network, where IIoT connects to the physical world. Edge devices collect, pre-process and perform local computing tasks in addition to providing a seamless link between the IIoT and the cloud. In addition to connectivity, edge computing provides privacy, reduces latency (delay) for applications where network delays cannot be tolerated and provides additional connectivity robustness.

12 Abbreviations

AI	Artificial intelligence, the field of computer science dedicated to solving cognitive problems commonly associated with human intelligence, such as learning, problem solving and pattern recognition [6].
CHP	Combined heat and power
CMMS	Computerised Maintenance Management System
CPS	Cyber-physical systems, mechanism that is controlled or monitored by computer-based algorithms, tightly integrated with the Internet and its users. In cyber-physical systems, physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioural modalities, and interacting with each other in a myriad of ways that change with context [12].

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

18

EHS	Environment, health and safety
EPRI	Electric Power Research Institute
ERP	Enterprise Resource Planning (business management software)
ETN	European Turbine Network
FFT	Fast Fourier transformation, e.g. used for vibration spectrum analysis
FE	Finite elements
GT	Gas turbine
HMI	Human machine interface
ICT	Information and communication technology
IIC	Industrial internet consortium[®]
IIoT	Industrial internet of things
IPR	Intellectual property rights
LoRa	Long range, low power wireless platform, based on the unlicensed radio spectrum.
KPI	Key performance indicator, metric that characterises the process performance, used for high level tracking (e.g. plant efficiency). When it deviates, drilling down to sub-KPI's is needed to diagnose the reason.
M&D	Monitoring and diagnostics
OaaS	Outcome as a Service, an offering where products and services are bundled as required to guarantee a desired business outcome.
OT	Operational technology, hardware and software used to monitor and control physical devices, as used in industrial control systems. Traditionally, often not networked because either mechanical or based on proprietary protocols.
SaaS	Software as a Service, software license and delivery model in which software is licensed on a subscription basis and is centrally hosted. Also referred to as "on-demand software" [10].
SCADA	Supervisory control and data acquisition, a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management, but uses other peripheral devices such as programmable logic controllers and discrete PID controllers to interface to the process plant or machinery [11].

ETN a.i.s.b.l.   19
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

SSO	Single Sign On
TC	Technical Committee. ETN TC4 covers "condition monitoring and instrumentation" and TC5 covers "asset management".
VPP	Virtual Power Plant, a cluster of distributed, usually small-scale, generation installations that are collectively managed as a single facility through a central control entity.
WLAN	Wireless local area network is a wireless computer network that links two or more devices using wireless communication within a limited area.

ETN a.i.s.b.l.   20
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

13 Self-Assessment

Questions should be answered on a scale of 1 to 5:

- 1 strongly disagree / not at all;
- 3: neutral / partly;
- 5: strongly agree / fully in place.

13.1 Digital capabilities: data

QUESTION	ANSWER
We systematically collect and store operational data in a commonly accessible system.	
We systematically collect all required data for all critical equipment of the plant.	
We have the right resolution of data available. This requires the use of some level of intelligent data reduction algorithms for operational data collection, where needed.	
Data plausibility and validity is systematically checked.	
We have more sensors for operational data collection than what is strictly required for controls.	
We use advanced additional instrumentation and/or measurements.	
We systematically collect and store results from inspection and measurements on all critical equipment of the plant. This data is accessible to all stakeholders.	
We have easy access to all documentation, such as O&M manuals.	
TOTAL	
AVERAGE	

13.2 Digital capabilities: connectivity

QUESTION	ANSWER
We share data through a cloud solution.	
We can access all data for a plant (operational, inspections, manuals, maintenance information) through a single system.	
We have common systems to cover our whole fleet.	

ETN a.i.s.b.l.
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

21

QUESTION	ANSWER
The cloud solution we use is open to applications from different providers and we also use applications from different providers.	
System level security measures are in place (access management and control, encrypted data transfer, backups) and we are comfortable with it.	
TOTAL	
AVERAGE	

13.3 Digital capabilities: analytics

QUESTION	ANSWER
We have a good understanding of the correlation between our high level KPI's and the data we collect.	
We have KPI cockpit charts, that we can use to drill down.	
We have an HMI that is easy to use and that highlights the right information.	
We have a central team analysing the data (remote monitoring centre) in a systematic manner.	
We use physical models or a "non-model based data driven approach" to analyse the data. These models are connected to the measured data to provide the outputs required. We use warning level that evolve with operating mode or age of the assets.	
We use the above-mentioned models to make decisions that improve our business result in a significant manner.	
We have direct inputs into the control system to optimize the operation of the plant.	
We use knowledge management approaches, such as fault trees, discussion forum, experience response system.	
TOTAL	
AVERAGE	

13.4 Leadership

QUESTION	ANSWER
There is a clear top-down vision and commitment in regard to digitalisation.	
Business objectives and expected benefits of digitalisation and associated	

ETN a.i.s.b.l.   22
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global

QUESTION	ANSWER
KPI's defined. The return on investment been evaluated.	
There is a clear contract and division of responsibility with the software service provider.	
The budget for IT infrastructure set up and maintenance as well as for the data analysis capability build up and execution is available.	
Any sourcing needs are defined and reliable.	
TOTAL	
AVERAGE	

13.5 Organisation and capability development

QUESTION	ANSWER
The system is in general use and accepted across the complete organisation.	
Users have been sufficiently trained. Any new digital skill requirements have been developed.	
The digital system is integrated in the business processes.	
Roles and responsibilities to maintain and use digital systems are clear. The role of the "company IT department" is well defined and has evolved in line with the new requirements.	
Our business model has evolved / changed since the digital technologies have been introduced.	
The business performance of the digital system is monitored and in line with the expectations.	
TOTAL	
AVERAGE	

14 References

[1] Decoussemaeker, Pascal. , "The European Turbine Network (ETN) met in Genoa to discuss digitalisation in Oil&Gas and Power", LinkedIn, October 2017, https://www.linkedin.com/pulse/european-turbine-network-etn-met-genoa-discuss-oilgas-decoussemaeker/ .

[2] European Turbine Network (ETN), "R&D recommendation report 2016", Brussels, Belgium, 2016, http://etn.global/ .

[3] GE Power Digital Solutions, "GE Digital Twin, Analytic Engine for the Digital Power Plant", 2016, https://www.ge.com/digital/industries/power-utility/power-generation

[4] International Energy Agency (IEA), "Digitalization and Energy", Paris, France, 2017, http://www.iea.org/digital/ .

[5] Maley, Susan / Espinoza, Neva, "The Future of Generation: Intelligent, Integrated", EPRI Journal, July/August 2016, http://eprijournal.com/wp-content/uploads/2016/08/The-Future-of-Generation.pdf

[6] Marr, Bernard, "The key definitions of artificial intelligence that explain its importance", Forbes, February 2018.

[7] Overton, Thomas W., " TOP PLANT: Linden Generating Station, Linden, New Jersey", POWER Journal, September 2016, https://www.powermag.com/linden-generating-station-linden-new-jersey-4/?pagenum=1

[8] Westerman, George / Bonnet, Didier / McAfee, Andrew, "Leading Digital, Turning Technology into Business Transformation", Harvard Business Press, Boston, Massachusetts, USA, 2014.

[9] Wikipedia, "Internet of Things", https://en.wikipedia.org/wiki/Internet_of_things

[10] Wikipedia, "Software as a service, https://en.wikipedia.org/wiki/Software_as_a_service .

[11] Wikipedia, "Scada", https://en.wikipedia.org/wiki/SCADA .

[12] Wikipedia, "Cyber-physical system", https://en.wikipedia.org/wiki/Cyber-physical_system .

ETN a.i.s.b.l.   24
Chaussée de Charleroi 146-148, 1060, Brussels, Belgium
Telephone: +32 (0)2 646 15 77   www.etn.global   info@etn.global