Asset Management, Industry 4.0 and Maintenance in Electrical Energy Distribution

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Abstract. This article presents the effects of Industry 4.0 (I4.0) combined with Asset Management (AM) in improving the life cycle of complex systems in Electrical Energy Distribution (EED). The boom in smart networks leaves companies in this sector no choice but to move forward I4.0. The contribution of I4.0 to the progress of AM in maintenance in EED will therefore be demonstrated by a case study using simulation. The case study will concern the benefits of using Advanced Metering Infrastructure (AMI), the heart of smart grids, at Hydro-Québec Distribution (HQD), the primary supply authority in Quebec. The HQD network includes 4.3 million clients, on a territory of approximately 250,000 km2 and 680,000 overhead transformers. The results are conclusive: the number of outages will drop by 7% annually and maintenance costs will fall by at least 5% per year.

Keywords: Asset Management, Maintenance, Industry 4.0, Smart grid, Advanced Metering Infrastructure.

1 Introduction

These days, maintenance is considered an integral part of the key processes that make a company competitive and allow it to endure [1]. AM (Asset Management), which involves a balance between costs, opportunities and risks in relation to the desired performance of assets with the goal of achieving the organization's objectives, is indispensable [2]. The new revolution, known as Industry 4.0 (I4.0) is also required with the current advent of new technologies and the major challenges of the moment, which are due especially to the growing complexity of equipment. With the arrival of new sources of private energy (solar, wind, etc.), climate change, attention to social-environmental protection and safety, the EED (Electrical Energy Distribution) sector is perfectly placed in the context stated above. Globalization, labour shortages, the need for even greater network availability and the aging of facilities are other factors that contribute to the need for this transition to excellence in maintenance in EED. It is from this perspective that a good number of companies in this sector are analyzing the possibility of utilizing AM and Industry 4.0 to integrate, optimize and improve their management processes for the life cycle management of complex systems. The objective will be to demonstrate the efficiency of combining AM and I4.0 in life cycle management of complex systems in EED companies. Many authors have focused only either on the use of one or a few technologies as part of smart grids, or on AM in EED. This article therefore makes it possible to link technologies in the current context of I4.0 with AM, then show the benefits of such a connection in life cycle management of complex systems in EED. This link will first be made through a literature review of AM in EED, I4.0 and technological advances in EED. Secondly, a case study at Hydro-Québec Distribution (HQD), the EED company in Quebec, on the use of AMI (Advanced Metering Infrastructure) coupled with the development of customer voltage and consumption monitoring algorithms for the low voltage (LV) overhead network will be outlined. In this case study, maintenance without I4.0 is compared to maintenance with I4.0 through a simulation of discrete events to reveal the potential benefit of moving to I4.0.

2 Literature Review

This section describes the state of the art on the application of AM and I4.0 in life cycle management of complex systems in EED to gather the necessary information for this article.

2.1 Asset Management

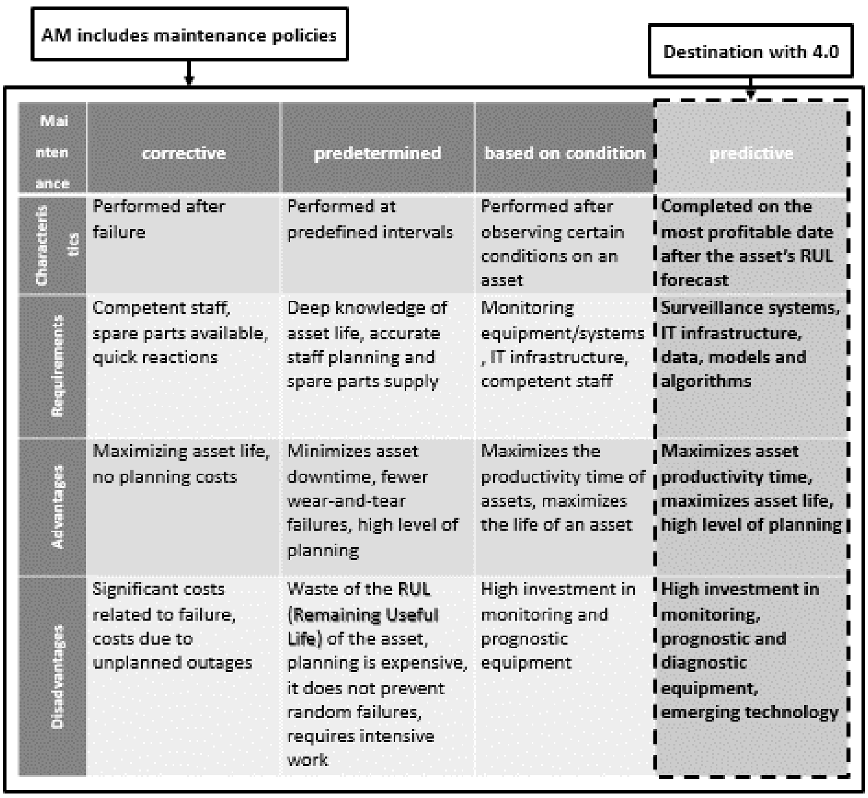
The work of Shah et al. (2017) reveals that AM is a mix between the fields of engineering and management that must be based on reliable, relevant and timely information while taking into account strategic business objectives [3]. This relation with information processing was confirmed by Khuntia et al. (2016), who link AM and data management [4]. These same authors also list the different techniques, methods and philosophies that comprise AM. They especially evoke in the EED field RCM (Reliability Centred Maintenance), CBM (Condition Based Maintenance), TBM (Time Based Maintenance), RBM (Risk Based Maintenance), and LCCA (Life Cycle Cost Analysis).

2.2 Industry 4.0 and Maintenance

Based on the literature review, the most widespread and general definition of I4.0 is the one in which Industry 4.0 would be a collective term, a revolution, grouping technologies and value chain organization concepts [1, 5]. Just as for AM, data processing is essential in I4.0. Bengtsson et al. (2018) observe that the new challenge for engineers is data processing in the current fourth industrial revolution [6]. Maintenance systems in the current framework must be sustainable, agile and interoperable. It is essential that these systems also possess the ability to manage disparate data in real time thanks particularly to I4.0 tools such as e-maintenance, smart sensors, IOT, Big Data and augmented reality. These tools are associated with AM best practices such as CBM and LCCA. Smart predictive maintenance, which is simply the improvement of CBM, is a key element in the new industrial revolution [7, 8]. Dąbrowski et al. (2018) emphasize that smart predictive maintenance makes it possible to predict the risk of failure in real time while taking into account the RUL (Remaining Useful Life) and relying on efficient data collection [7]. Wang (2016) continues along the same lines and adds that this type of maintenance uses the tools of I4.0 [CPS (Cyber Physical Systems), IOT (Internet Of Things), Big Data and Data Mining, IOS (Internet Of Service) or Cloud Computing] to detect signs of failure, predict the future behaviour of an asset and thereby optimize operation of the asset [5]. Nonetheless, Bengtsson et al. (2018) recall that the basic concepts and techniques of maintenance (lubrication, cleaning, inspection, etc.) should not be neglected in the current context of the fourth industrial revolution [6]. They propose combining the old maintenance methods with the new emerging technologies of Industry 4.0 for a more efficient maintenance process.

2.3 Link between AM and I4.0

In general, AM includes acquisition, operation, maintenance and decommission. I4.0 allows to be proactive in context of AM. One of the links that can be established between AM and I4.0 is that AM encompasses the various maintenance policies [4, 9], while I4.0 makes it possible to move toward predictive maintenance and, thus, to maximize an asset's productivity time and life span [7]. This section is summarized in **Fig. 1**; the table below is taken from Dąbrowski et al. (2018) [7].



Maintenance	corrective	predetermined	based on condition	predictive
Characteristics	Performed after failure	Performed at predefined intervals	Performed after observing certain conditions on an asset	**Completed on the most profitable date after the asset's RUL forecast**
Requirements	Competent staff, spare parts available, quick reactions	Deep knowledge of asset life, accurate staff planning and spare parts supply	Monitoring equipment/systems, IT infrastructure, competent staff	**Surveillance systems, IT infrastructure, data, models and algorithms**
Advantages	Maximizing asset life, no planning costs	Minimizes asset downtime, fewer wear-and-tear failures, high level of planning	Maximizes the productivity time of assets, maximizes the life of an asset	**Maximizes asset productivity time, maximizes asset life, high level of planning**
Disadvantages	Significant costs related to failure, costs due to unplanned outages	Waste of the RUL (Remaining Useful Life) of the asset, planning is expensive, it does not prevent random failures, requires intensive work	High investment in monitoring and prognostic equipment	**High investment in monitoring, prognostic and diagnostic equipment, emerging technology**

Fig. 1. Link between AM and I4.0

3 Case Study: Use of AMI

3.1 General Information on AMI

In general, I4.0 makes it possible, in almost real time, to collect and analyze a large volume of data and develop models for predictive maintenance. The EED-specific framework is that the data to collect comes from AMI that measure consumption at customer premises. AMI are considered the backbone of smart grid [10, 11]. Compared to a traditional grid where only the electrical flow circulates, this new type of grid disseminates not only the electrical flow but also the bidirectional information flow between EED companies and clients through AMI [11, 12]. HQD's benefit is that AMI is already installed and, therefore, no installation costs are incurred (**Fig. 2**).

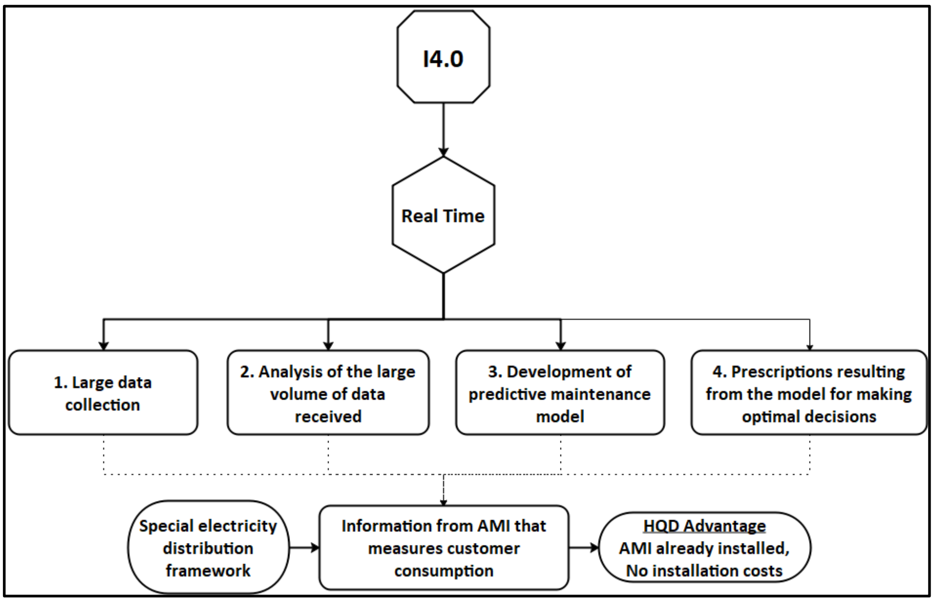


Fig. 2. HQD advantage with regard to evolution to 4.0

In the 2010s, HQD replaced electrical meters used to measure the consumption of all its customers with AMI. This infrastructure could make it possible to detect the deterioration of a transformer (**Fig. 3**). Damage to a transformer after lightening passes can also be detected by AMI (**Fig. 4**). They can also serve in identifying an overloaded transformer (**Fig. 5**) and customer/transformer mismatch (**Fig. 6**).

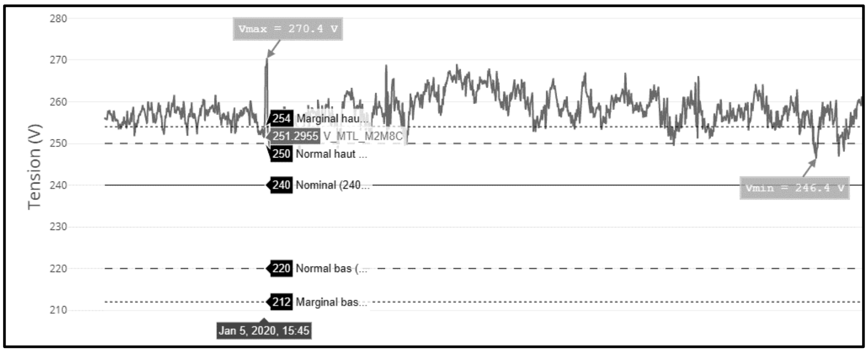


Fig. 3. Detection of a degraded transformer with AMI

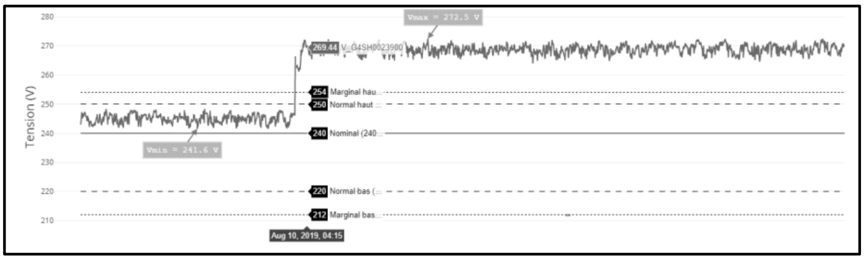


Fig. 4. Detection of a transformer damaged by lightning with AMI

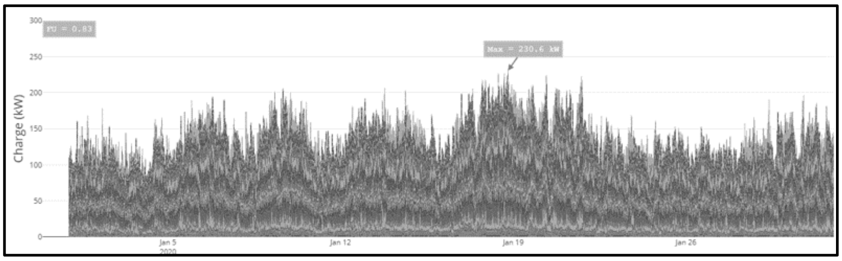


Fig. 5. Detection of an overloaded transformer with AMI

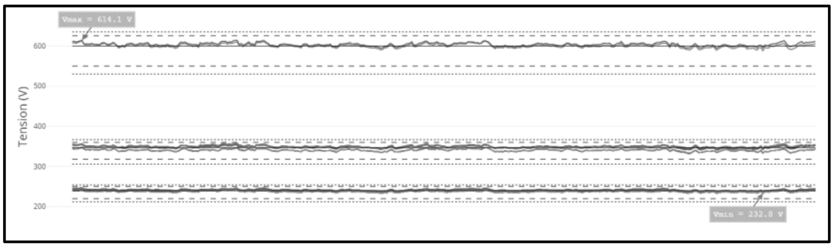


Fig. 6. Detection of customer/transformer mismatch

Given these functionalities offered by AMI, the study will make it possible to establish the profitability of their use coupled with the development of Artificial Intelligence (AI) algorithms to monitor customer voltage and consumption. This will help to identify the problems listed above before outages and breakages and will constitute the I4.0 maintenance case.

3.2 Case Study

The project that consists in demonstrating the benefits of implementing I4.0 for the HQD electrical grid was the result of need combined with opportunity. The need is the necessity in the current context of AM to migrate toward predictive maintenance. The opportunity is that the data permitting this migration are available thanks to AMI installed at customer premises.

As explained above, it consists in comparing maintenance without I4.0 to maintenance I4.0 by simulating a concrete example. The simulation consists in replacing an existing system by a simpler computer model with similar behaviour. The existing system is HQD's overhead low voltage (LV) distribution system. It was selected because it is more convenient to estimate the parameters to consider such as the number of customers interrupted (CI) following an outage. The computer models were created on the Rockwell Arena simulation software. Maintenance without I4.0 is represented by an initial model illustrating the current LV overhead network, with the presence of AMI only. The maintenance 4.0 model integrates the AI algorithms discussed above. Outages as well as customers interrupted, repair time based on the type of day when the outage occurred and the costs resulting from these outages are taken into account. The two models are compared to reveal which is most beneficial as well as the scale of the benefits.

3.3 Building the Simulation Model

Historical data from 2015 to 2019 provided by HQD were used as the basis for developing the models. The period from 2020 to 2024 is the predictive part of the models. The data has been fitted to statistical distributions. Given a data non-disclosure agreement with HQD, we cannot give further details on the distributions used, model logic and what-if scenarios.

The effect of maintenance 4.0 was considered on LV cables, fuses and transformers. Maintenance with I4.0 would make it possible to reduce a certain number of outages on fuses and to convert a certain number of outages on transformers and LV cables into planned outages. AI algorithms would make it possible to identify transformer overload and to replace it preventatively (which would result in a planned outage) before failure occurred. A few irregularities in LV cables due to overload could also be resolved in planned interruptions before they result in breakages. Fuses very often blow because of transformer overload and prevent an outage. They can therefore blow several times and each time be replaced as a corrective measure before it becomes clear that these repetitive breakages on the fuses originate from the transformer's overload. By detecting earlier, the transformer overload, these repetitive outages on the fuses can be avoided.

3.4 Steady State and Validation

As simulation models are finite horizon, the steady state is implemented from the beginning of the simulation. The main outcomes (number of outages, number of CI, costs) are incremented every year. The number of replications was set at 30. With these 30 replications, the percentage of error (half width interval) in the outcomes was cumulatively less than 1% at the end of 2019 (**Table 1**). The models were configured to roll from 2015 to 2024. The period from 2015 to 2019 made it possible to verify that the program indeed behaves like HQD's actual LV overhead network. The Real/Simulated relationship is presented in **Table 2** for the cumulative outcome values from 2015 to 2019. We note that it is very close to 1 for the number of outages and the number of customers interrupted. Regarding costs, the values and distributions selected were estimated based on equipment samples. These estimates are supposedly representative of reality, as are the costs resulting from the models.

Table 1. Percentage of error in quantitative outcome

Quantitative outcome	Error (Half width)/Average(%)
Total number of outages	0%
Total CI	0.001%
Costs	0.116%

Table 2. Real/Simulated Relationship

Quantitative outcome	Real/Simulated Relationship
Outages	0.982
Customers interrupted	1.016
Costs	The values and distributions selected were estimated based on equipment samples that are representative of reality

3.5 Results

The main outcomes quantified were the number of outages, the number of customers interrupted and maintenance costs. **Fig. 7, Fig. 8, Fig. 9** present these outcomes for maintenance without I4.0 and maintenance with I4.0. For the figures, the y-axes are not filled in and the results are presented as a percentage, still in the context of the non-disclosure of data.

The simulation shows that with I4.0, outages would be reduced by an average of 7% per year (**Fig. 7**). The number of customers interrupted also fell by an average of 7% annually (**Fig. 8**), which is because the number of outages and customers interrupted are correlated [1 outage corresponds to a triangular distribution of parameters 7.5 (minimum), 7.7 (equiprobable), and 8.1 (maximum) of customers interrupted].

Costs would be reduced by 5% per year on average with I4.0 (**Fig. 9**). In fact, for LV cables and transformers, with I4.0, replacement of the equipment for which failure can be predicted should be planned. Maintenance would therefore be performed on a regular basis and would make it possible to avoid costs related to overtime for corrective maintenance. Regarding fuses, a proportion of outages would be totally avoided with I4.0. Maintenance activities that could result in this proportion of outages would therefore be avoided along with the related costs.

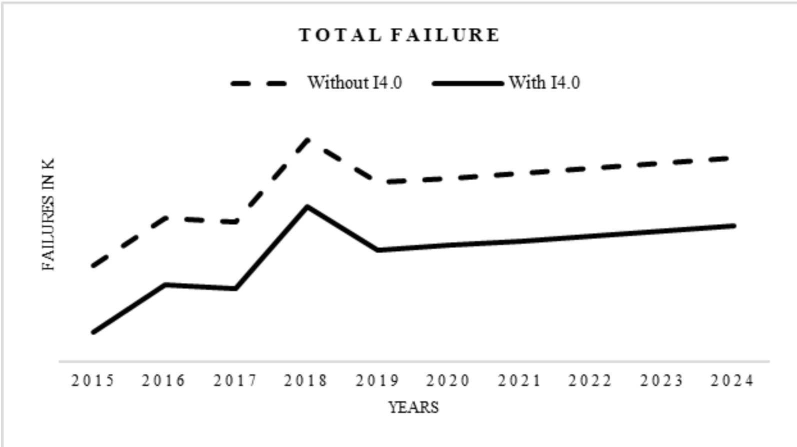


Fig. 7. Comparison between Maintenance without and with I4.0 in term of outages

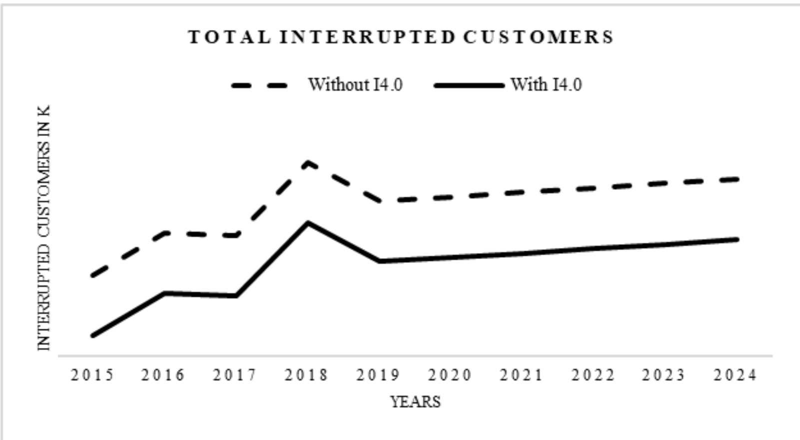


Fig. 8. Comparison between Maintenance without and with I4.0 in term of customers interrupted

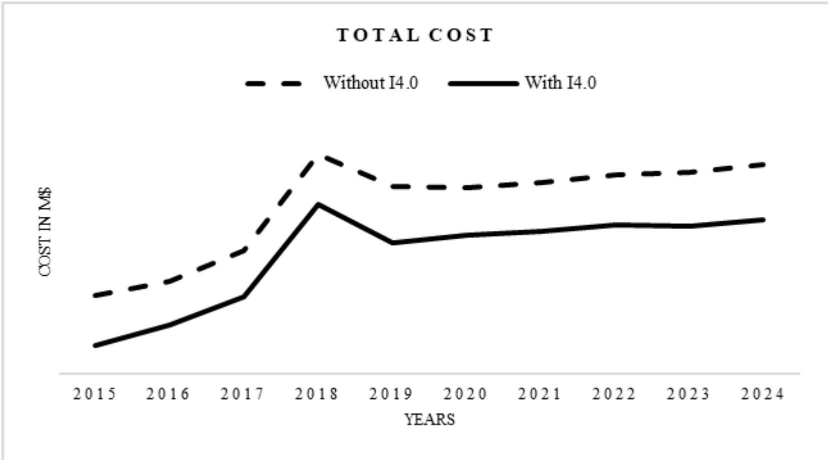


Fig. 9. Comparison between Maintenance without and with I4.0 in monetary term

3.6 Discussion

The scenario presented in this paper is conservative but the reductions determined, although appearing to be quite low in percentage, represent thousands of failures avoided, tens of thousands of customers who will be able to benefit from greater continuity of service, and a decrease of maintenance costs in order of millions of dollars CAD.

The case of maintenance I4.0 focused on fuses, transformers and LV cables in the study. Furthermore, the database used takes into account only the primary volumes of outages on equipment and their causes. If the effect of I4.0 on other equipment and volumes beyond the primary ones had been considered, a greater benefits would have been found. Furthermore, the benefits resulting from detecting customer/transformer mismatch, transformers not connected to at least one client could be explored in a later study. A next step resulting from this analysis would be to develop the AI algorithms required considering the potential benefits.

4 Conclusion

Firstly, the literature review reveals the link between AM and I4.0. AM includes the various maintenance policies and I4.0 will make it possible to move toward predictive maintenance. Data collection was one of the biggest tasks for the case study. Through the simulation, the relevance and benefits of matching I4.0 with AM in the EED sector were demonstrated for customer satisfaction, resource optimization and in monetary terms. I4.0 and AM therefore become indispensable for improving life cycle management of complex systems in EED. To the best of our knowledge, this study is the first to show the profitability of using I4.0 with AMI for an electrical grid.

Funding

This research was funded by HQ, and by the NSERC, Natural Sciences and Engineering Council of Research of Canada Grant: CRSNG-RDCPJ-530543-18.

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