MiGen Project – Empowering the transformation at the grid edge

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SUMMARY

During the next few years, the utilities will experience huge changes at the grid edge. The availability of affordable domestic generation and energy storage, plus intelligent appliances will impact the way electrical utilities operate their system. These transformations will impact the load and power profile at the substation and on transmission lines. Many utilities, with large penetration of domestic generation experience a drastically different and worrisome load peak shape at the transmission, substation, distribution line and distribution transformer levels. To address these challenges, Hydro Ottawa launched the MiGen project to leverage new technologies for optimizing the load profile, reduce generation costs and provide customers greater value for their bill.

The paper describes the MiGen project, its architecture and use cases. Hydro Ottawa is completing the first phase of the project that resulted in a 20% load shaping capability without even optimizing load and generation interaction. With the success to date of this first phase, Hydro Ottawa is initiating a second phase to achieve an improved customer-centric offer and go further in the use of the technologies to improve and add more functionalities, such as a transactive energy shadow market, DER optimization, load prediction accuracy, customer segmentation, loyalty program, etc.

KEYWORDS

Smart Grid, Grid Edge, Data Analytic, decentralized utility model, customer-centric, prosumer, grid democratization.

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1 Introduction

Today, the choice of home smart energy devices is growing fast, triggering huge technology changes that result in major impacts to the utilities. Like many other technologies that appeared during the last one hundred years, it is expected that the grid edge technologies will grow at an exponential pace, however much faster with a tipping point expected in 2020.

At the same time, the industry is experiencing a digital transformation that will force the utilities to revise their traditional business model. Other industries were subject to such transformation and many succeeded while others failed. One good example is Kodak that missed its transformation although their research department has developed digital technologies; high-management doubted that the money flow generated from sale of rolls of film will ever end. The digital transformations have their roots not only in the internal changes but also in those that happen outside the company because their customers have their own digital evolution and expect to connect to their providers using new technologies. The customers also expect a different relationship whereby they want control, better or custom services and choice.

Grid edge technologies present a tremendous opportunity for utilities to succeed, with their digital transformation in deploying enabling infrastructure so their customers can interact with the system and redefine their overall experience. A new business model will emerge for new revenue sources from innovative services and products.

Illustrated in fig. 1 is the impact at the edge. The load pattern and peak time for the same peak summer day in the Ontario market is different at each hierarchy level, or node, from the bulk provincial market to the distribution transformer. Evident is that the peak demand at each node occurs at different times, and though the general load shapes are roughly similar, there are clear variations. The total bulk system load profile (green, top, curve) peaked at 6 p.m. However, the substation peaked (gray second top curve) at 3:30 p.m., while the feeder (blue third top curve) peaked at 8 p.m. Finally, the distribution transformer (red fourth top curve) peaked at 11 p.m. The light-blue curve (at the bottom) shows the smart solar PV generation at the edge that caused a dampening ripple change at each upstream node.

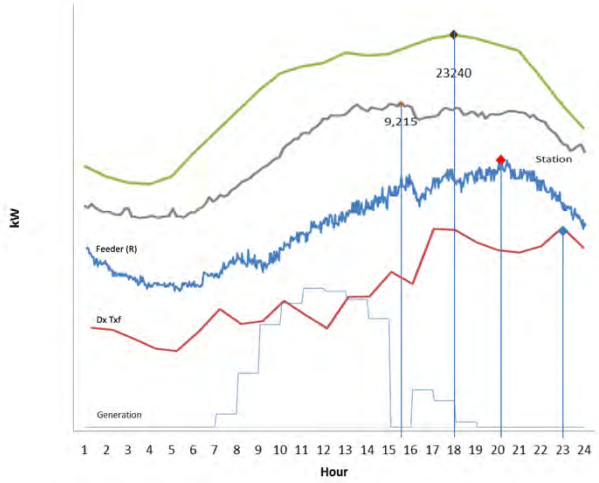

Fig.1. Ontario Market Demand (Sep 5, 2018)
and Coincident Nodal Peaks

The new business approach will define a system with more customers being integrated. The utilities will be able to work with their customers to shape the load at the edge for improving overall system reliability and performance. Furthermore, the flexibility obtained from edge control will help cost effective and more dependably support to new fast-growing energy demand applications such as electrification of fossil-based loads and electric transportation.

2 MiGen Ph I

With the MiGen project, Hydro Ottawa intends to leverage the new technologies to optimize the load profile so overall costs — generation connection, grid infrastructure, electricity bills — are reduced for each stakeholder and each of them benefits from their participation in MiGen. The goal of phase I is to control the load profile at the distribution transformer level to affect the loading at each extreme edge. MiGen negotiates with loads and energy sources to harmonize their use at the grid edge and predicts activities. MiGen is developed to be truly scalable using a largely decentralized architecture.

IEEE 2030.5 standard is used to specify the interoperability, through communication and data exchange models, between the different system elements. This protocol is built on HTTP/1.2 using RESTful profile requiring very low processing power from the IoTs. The data model is naturally compliant to the Common Information Modeling (CIM) (IEC 61968).

2.1 Architecture

Illustrated in fig. 2 are the main elements of MiGen ph I. The architecture includes software agents to monitor and manage health of critical assets. MiGen negotiates with loads and energy sources through a cybersecurity and privacy-by-design firewall, so they collaborate at the Grid Edge where all the spikey, challenging to predict activity happens. The main elements in the architecture are the utility owned Transformer Agent (TA), Customer Agent (CA), plus supporting prosumer owned Home Energy Management System Controller (HEMS-C) and the Home Energy Management System (HEMS). Each of these elements has its platform supporting software agent that monitors and surveys their environment, conducts network management and communication with the other devices and, using artificial intelligence functions, defines strategies to optimize the operation of the system under its responsibility.

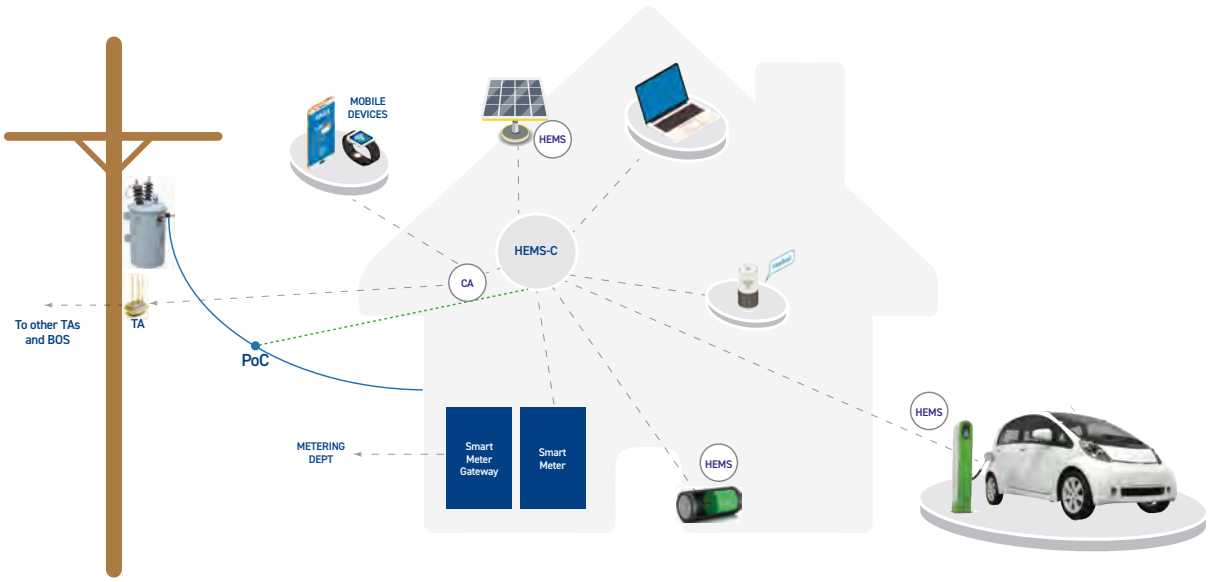

Fig. 2. MiGen ph I Architecture

The HEMS are devices or appliances that produce, store or use energy and defines the best strategies to meet the goals set by the HEMS-C. This last device coordinates the operation of all the HEMS installed in the house to meet the prosumer's requirements and to negotiate energy usage with the TA as needed. Prosumer comfort is handled with a multi-input multi-output (MIMO) fuzzy controller. The prosumer can always opt out of any transactive energy or demand response (TDR) event.

The CA serves as the firewall for privacy and cybersecurity between the prosumer and the utility. As the gateway, the CA passes function sets and sends control signals between the TA and Home

Energy Management System Controller (HEMS-C).

The TA is mounted near a distribution transformer, power transformer or a constrained point in the grid. To control the load profile, the TAs can negotiate with each other to satisfy the feeder or wider area needs. At the same time, they can determine the best strategy to meet operating objectives at the substation or market level. The loading on the stations, and the entire grid, can be managed through the Back-Office System (BOS) to meet the required power flow at the transmission nodes and thus support market and transmission needs.

The TA communicates in real-time with multiple HEMS-C to create a private autonomous distributed architecture supporting localized dynamic TDR strategies. The TA seeks to maximize the DR or DER request across the network by negotiation with each HEMS-C, subject to requirements set by each homeowner.

The Back Office System (BOS), Distribution System Operator (DSO) or the Market System Operator, (or Independent System Operator (MSO/ISO)), manages the TDR. The regulator also participates in the process through planning market renewal to support TDR. The BOS can operate in the cloud or on a corporate server for use by the System Operators, Planners or other authorized personnel.

2.2 Results

To validate the operation of MiGen ph I, field tests were done with residential customers having both generation and storage assets, in addition to diverse loads that are subject to control. Various types of electric connections were covered for testing, including single phase electrically serviced, low-income and private residential homes, and a three-phase serviced multi-unit residential building.

As shown in figure 3, the peak happens between 5 PM and 8 PM. Though the customers may have much more load or generation installed, the coincident peaking is approximately 2 kW capacity per customer. Of this, about 1.2 kW is available for TDR negotiation at the time negotiation is needed. Participation and acceptance vary depending on the level of agreement from the customer. We target for 11 kW of load reduction, and in the first round of negotiation 5 kW is offered and accepted, so 5 kW of capacity is now available for other needful purpose. The incentive offered to cooperate is reduced every negotiation cycle, to prevent gaming.

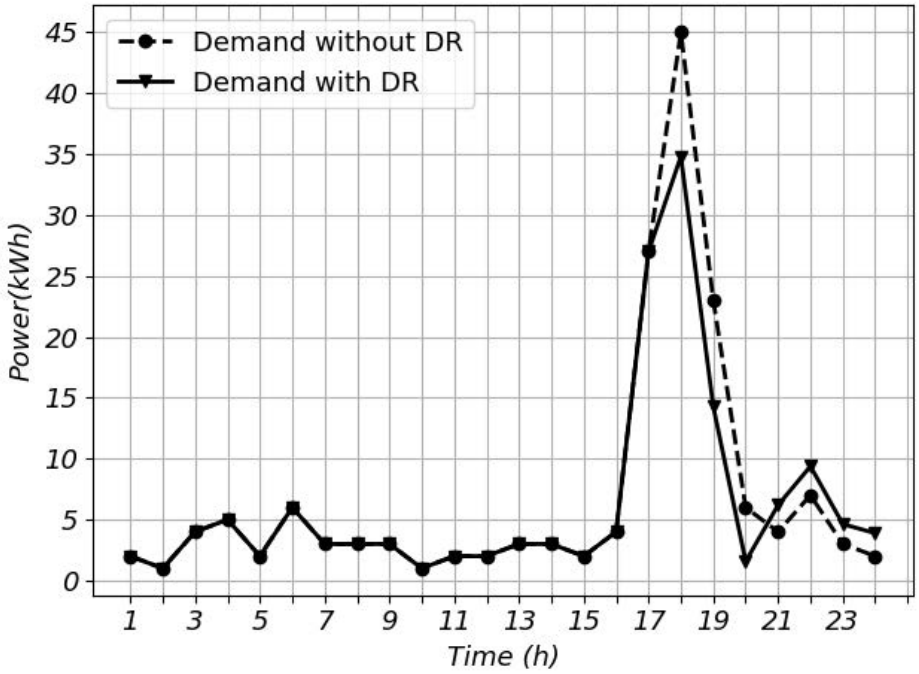

Fig. 3. Transformer Load Profile

The result of targeting a reduction in the coincident peak is a 5 kW reduction in transformer loading

or 22% diminution of the peak from 45 kW to 35 kW, followed by a time shift change in the load shape curve which in this case also helped reduce energy use. This again was achieved without optimizing the use of the load and energy sources at the same time. If that had happened, more load reduction may have been achieved.

With more loads and energy sources participating in a TDR event within a prosumer's premise, the less likely the prosumer is inconvenienced, and the more likely the desired load shape — at the transformer or first constraint level at the edge — can be guaranteed. With the scalability of MiGen for TA to TA negotiation, the objectives of guaranteeing a load shape at higher nodes away from the edge become more possible with no more inconvenience to the prosumer if any.

3 MiGen Ph II

Hydro Ottawa is launching MiGen ph II to achieve an improved customer-centric solution and go further in the use of the technologies to enhance and add more functionalities such as transactive energy, DER optimization, prediction accuracy, better customer segmentation and loyalty program. During this new phase, support functions for the DSO and the ISO will be developed. New data analytic functions will enable Hydro Ottawa to generate an important value stream from the customer's energy assets. At the same time, the prosumers will benefit from better personal value, such as lower energy costs, better resiliency to power failure and better home comfort.

In addition, the flexibility brought by this project may enable Hydro Ottawa to reduce or defer major investments in the distribution system. This project will create further opportunities in developing a better understanding of the prosumer's behavior to help anticipate their needs so the utility can better plan future investments and add greater value and more confidence for each dollar spent. Finally, the collaboration between Hydro Ottawa and its prosumer to create the optimal load profile will help reduce or eliminate the use of polluting sources of energy and so reduce the carbon footprint.

3.1 MiGen ph II Architecture

The loyalty program is an important addition to the MiGen platform. To successfully shape the load at the edge, prosumer active participation is required, and the Loyalty program is the key element to improve their engagement with confidence in an authentic, transparent and reciprocal relationship. The utility can interact in real time with prosumers to propose reward schemes in exchange for the modification of their energy consumption. This marketing tool can be used to help operate the power system and to balance generation and load. Moreover, real-time machine learning tools enable the utilities to analyze customer behavior (in group types), find patterns in data using powerful data visualization, and react faster and with greater confidence for new opportunities. Data analytics also helps predict the long-term trends in energy usage or offering and find new ways to increase customer empowerment.

Big data technologies are important in providing more accurate analysis, which leads to more concrete decision-making resulting in greater operational efficiency, cost and risk reductions for the business. Real-time analytics, based on probabilistic or heuristic modeling and machine learning, will increase business intelligence by processing disparate data for a clearer view of the grid and customer experience. This information varies from qualitative and quantitative data about the prosumer, from smart devices inside the house or from external databases like traffic or weather. This requires an infrastructure that can manage and process huge volumes of structured and unstructured data in real time while protecting the prosumer's privacy. The data sets used for the analysis has to be adapted to the changing grid and the analysis has to be at various level throughout the grid.

Illustrated in figure 4 is a high-level functional architecture of MiGen ph II that introduce a new set of functions to support customers, DSO and ISO objectives. The architecture shows different function layers beginning at the bottom with the HEMS-C installed in intelligent home, the optimal distribution transformer management installed at the transformer, the optimal feeder management installed in the substation and the upper layers installed at the back office. The two first rows at the top show the stakeholders and business function. Below, the customer loyalty management is responsible for

monitoring and forecasting customer behavior. The analysis results are used to better dispatch management signals to prosumers in various load reduction specific calls/requests and general program offerings. The loyalty system evaluates, based on the expected response of the prosumers, the optimal amount of loyalty points to grant them to reach the objectives. The reconciliation and assessment application validate at the end of a load reduction activity whether the participants met their load reduction goal. The shadow market evaluates in real-time the value of DER generation in the transactive energy market. This is the price the prosumers can get if they sell their excess energy to the distribution system. Demand-response and distributed energy response are DSO operations to influence future or real-time use of energy.

The customer participation application uses the load control objectives with transactive market values to define a range of load targets for each customer. This range is determined by the expected participation of the prosumer and choice related to desired optimization. The prosumers can decide, on a 0–10 scale, if they desire to receive more incentive or have less impact on their comfort. The optimal feeder management application will choose a value within the proposed range and send it to the HEMS-C. In deciding the value, the application verifies if the operational constraints are not violated on the feeder and that the targeted load reduction goal is met. The applications in the two bottom rows are the same as in phase I.

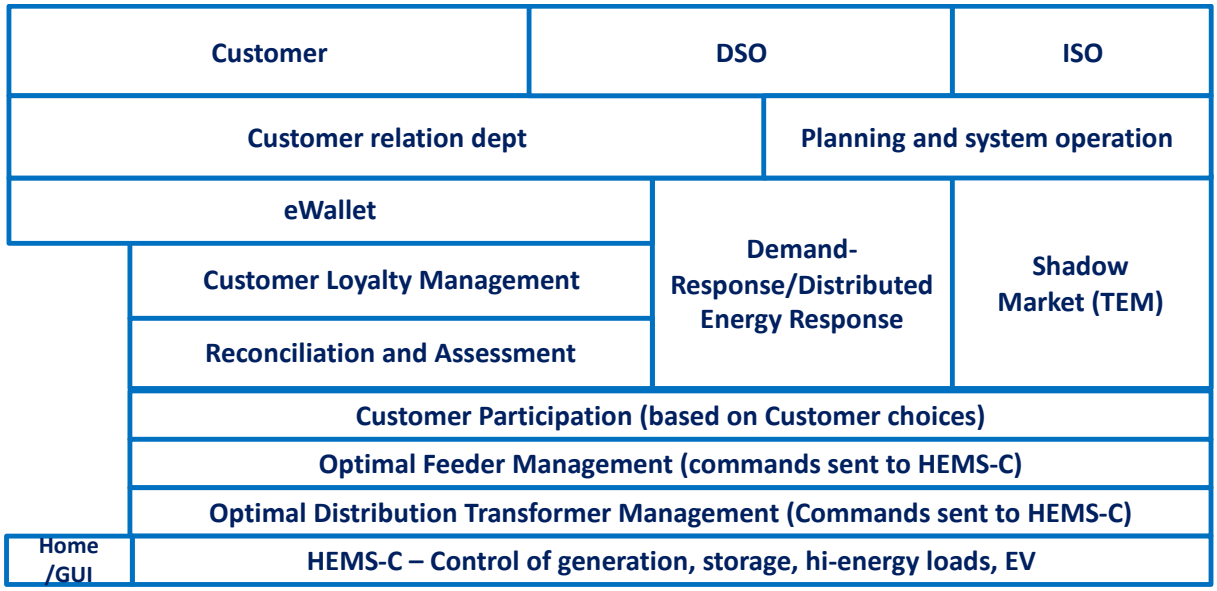

Fig 4. — MiGen ph II Functional Architecture

The eWallet application allows the prosumers to manage their loyalty portfolio, validate the status of participation and set their choice for incentive level.

3.2 Benefits of MiGen

The MiGen project will bring many benefits to the customers and to Hydro Ottawa. Intelligent management of prosumer energy assets will allow them to optimize their use of energy and reduce their energy cost according to their expected level of comfort. Intelligent appliances, electricity storage and electric vehicle charging are example of devices that can be managed. Other assets such as renewable generation, intelligent home, thermal storage or battery can be controlled for power, energy or to reduce carbon emission.

Utilities will benefit in many ways from the grid management flexibility created by the project. This can develop new value streams:

- Utility Asset Deferral: in managing the load, it will be possible to defer investments for major upgrades in costly infrastructures like substations, feeders or even distribution transformers. Better comprehension of the prosumers' habits and knowledge of their future needs will help

to better plan future investments and avoid unnecessary expenses.

- Develop new ancillary services: from aggregated domestic loads, it will be possible to support the frequency response, increase the operating reserve, implement a very accurate demand-response scheme and contribute to emergency grid management.
- Carbon Market Participation: with better load and distributed energy reserves management, use of polluting sources of energy can be avoided, contributing then to reduce the carbon footprint.
- Overall Resiliency: Having domestic generation and storage plus optimal control of smart devices, the smart homes will be more resilient to power failures. This gives the utilities the opportunity to revise downward the requirements for substation resiliency and thus reduce the capital investment in their infrastructure. A more flexible scheme in substation layout can be developed to reduce the need for redundancy in power equipment.
- Optimize future investments: the project will create great values from the aggregated and anonymized data generated by the HEMS-C to develop collective intelligence. The new system will provide the necessary information to develop new services that would be greatly appreciated by their customers.

4 Conclusion

This document has shown that disruptive technologies at the grid edge will impact power system management and operation. Load shaping will be very challenging technically, economically and socially for the utilities. MiGen ph I project has proved it can manage the load profile at the edge while comfortably guaranteeing a load shape at higher nodes away from the edge. The challenges brought up by the new technologies at the edge are transformed into benefits for both the utility and the prosumers.

In addition, the utilities can develop innovative business models based on a more customer-centric approach. Prosumers benefit from their investment in electrical load, clean generation and energy storage reduced energy bills and more control over improved life comfort, all the while becoming active participants in a transactive energy market. Data analytics is a strategic element of the project providing more accurate analysis and forecasting to improve the customer loyalty program. Thanks to the customer loyalty program, the utilities will be able to know more about the future needs of their customers and avoid investments in unpopular or inappropriate programs.

The new technologies installed in prosumers' premises will enhance the service resiliency, allowing the utilities to revise their engineering criteria and reconsider their investments. Operational costs will also be reduced because more flexibility in load management improves the efficiency of system maintenance.

5 Acknowledgments

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