Power
Transmission
& Distribution
Systems

Spotlight on Smart and Strong Power T&D Infrastructure

Case Book - version 2.0

Summaries

ISGAN Annex 6

Disclaimer

Acknowledgments

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Table of Contents

Introduction

This document contains summaries of the 13 cases included in the second edition of ISGAN (International Smart Grid Action Network) Annex 6´s case study *Spotlight on Smart and Strong Power T&D Infrastructure*. This case study highlights the experiences of countries in different parts of the world, as they performed transmission and distribution projects on their electrical systems. The projects illustrate a wide range of applications, solutions, and technologies that were used to meet the challenges that various countries were facing. Many of the projects focused on the need to manage the integration of large amounts of renewable and often intermittent energy sources.

The first edition of the case study was published in the spring of 2015. It included eight cases, based on information collected from 2014 to 2015.

Table 1. The eight cases included in the first edition of the case book

Country	Case
Ireland	HVDC interconnector enables integration of wind power and improves electricity market
Sweden	Optimal combination of transmission technologies solves transmission congestion
The United States	Wide-area measurement systems used to avoid large-scale outages
Italy	Wide-area measurement enhances the Italian power system
South Africa	Grid situational awareness proof-of-concept
France	Smart Substation
Austria	Maximizing the DER hosting capacity of low- and medium-voltage networks
Italy	Impact of the enforcement of a time-of-use tariff on residential customers in Italy

Five new cases and an updated version of the case from the United States were added in the second edition. The second edition was finalized in the spring of 2016.

Table 2. The five cases added to the second edition

Country	Case
China	Multi terminal system demonstrates that true networks can be built with HVDC
Germany	Superconductivity enables increased capacity in congested urban area
Belgium	Increased hosting capacity by intelligent control of PV inverters
Canada	Energy Storage and Demand Response for improved supply reliability
Denmark	More efficient energy system by combining electricity and heat

The full case book, containing all of the studies, can be accessed using the ISGAN web page: http://www.iea-isgan.org.

1 IRELAND

HVDC interconnector enables integration of wind power and improves electricity market

What is the project about?

The East-West Interconnector (EWIC) is a voltage source conversion high-voltage direct current (HVDC-VSC) link connecting the electricity transmission grids of Ireland and Great Britain. It is 264 km long, 187 km of which is beneath the Irish Sea, and has a capacity of 500 MW (equivalent to approximately 10% of Ireland's peak electricity demand). EWIC also provides a range of ancillary services, such as frequency response and reactive power provision, and includes the capability to "black start" the electrical transmission systems of either Ireland or Great Britain in the event of a major system-wide outage.

Main goals

The EWIC project had three key objectives:

- Improve the security of supply by providing additional capacity.
- Exert downward pressure on wholesale electricity prices in Ireland by providing direct access to Great Britain's larger electricity market.
- Allow the export of excess power from Ireland at times of oversupply to the Irish network.

Current status/timeline

EirGrid commenced work on EWIC in 2007, and it went into commercial operation in December 2012.

What is the result/expected benefits of the project?

Analysis completed in 2014 after one year of full commercial operation demonstrated that the load-weighted average system marginal price (SMP) in the Single Electricity Market of Ireland and Northern Ireland was reduced by 9% compared to if EWIC was not present. Increased competition and pressure is narrowing the gap in the cost of electricity between the islands of Ireland and Great Britain, facilitated by generators located elsewhere in the EU, particularly in Great Britain.

EWIC is also facilitating the development of the indigenous renewable energy market and provides export potential to help Ireland achieve its European 2020 40% renewable energy target. EirGrid has been reducing RES curtailment through the use of EWIC system operator trades recording priority dispatch trade volumes of 300 GWh in the six-month period between July and December 2013.

What is next?

Following the success of the EWIC project, further future interconnection between the island of Ireland and the wider European power system is being considered.

2 SWEDEN

Optimal combination of transmission technologies solves transmission congestion

What is the project about?

The South West Link is a combined alternating current (AC) and voltage source converter high-voltage direct current (HVDC-VSC) link totalling 427 km in length, reinforcing the transmission grid between mid- and southern Sweden. The northern part of the link is a 176 km 400 kV AC overhead line (OHL) and the southern part is a 251 km DC transmission line divided into a 61 km OHL and a 190 km underground cable. Commissioning is planned in 2015, and will increase the capacity in the congested intersection in the southern part of the transmission grid by approximately 25%.

Main goals

The South West Link project has four key objectives:

- Improve the reliability of the transmission grid in the southern part of Sweden.
- Enhance the security of supply to the southern part of Sweden after the decommissioning of the Barsebäck nuclear power plant located far south in Sweden.
- Increase the transfer capacity to the south of Sweden to reduce the price differences between bidding areas in Sweden and also increasing the possibilities to export power.
- Enable the ability to connect and transfer power from renewable energy sources.

Current status/timeline

The project is working hard to achieve results and ensure the connection will begin operation in 2015. The AC stations are in operation, and the cable project is almost finished. Work is still ongoing on the OHL parts and the HVDC stations.

What is the result/expected benefits of the project?

The project has many drivers and will yield considerable benefits to Sweden, especially to the southern parts. From the beginning, the main drivers were to increase the reliability and improve the security of supply to the south of Sweden. Increasing the capacity to the south part of

Sweden has also become a main driver, especially after the decommissioning of the nuclear power plant in Barsebäck (located at the coast west of Hurva), which led to increased capacity limitations in the south of Sweden due to voltage instability problems. The South West Link is also an important part in the necessary development of the national grid, which is required to enable the introduction of renewable energy planned in accordance with Swedish and EU energy policy objectives.

What is next?

Less than a year after the connection is made operational, a second large HVDC-VSC project will commence operation. The NordBalt link, a 300 kV 700 MW interconnector between Sweden and Lithuania, will link the Nordic power market with the emerging Baltic power market.

3 CHINA

Multi terminal system demonstrates that true networks can be built with HVDC

What is the project about?

Zhoushan multi-terminal flexible DC transmission connection is the world's first five-terminal flexible DC transmission project with a voltage level of ± 200 kV. The connection establishes an important link between the mainland and 5 isolated islands, enabling power flows and enhancing grid reliability and security of electricity supplies. It delivers power to these islands and can export surplus electricity to the mainland when required. Moreover it provides support to economic development and significant improves the daily life of local populace. It also helps to protect the environment by facilitating wind power generation.

Main goals

- Improve the reliability of the transmission grid in the Zhoushan archipelago preventing significant electric power shortages in the future
- Enhance the stability of integrating large-scale wind power
- Maintain voltage stability
- Utilize the line corridor effectively to reduce the dependence on AC submarine cables.

Current status/timeline

The Zhoushan DC project was officially approved by Zhejiang Development and Reform Commission on December 14, 2012 and began construction on March 15, 2013. Five convertor stations of Zhouding, Zhoudai, Zhouqu, Zhousi and Zhouyang were constructed with a total capacity of 1 GW. A 141.5 km ± 200 kV DC transmission line was built. On July 4, 2014 the project was officially put into operation.

What is the result/expected benefits of the project?

The project has many drivers and will yield considerable benefits to China, especially to the Zhoushan archipelago. Firstly, the flexible DC transmission technology has strong advantages in improving power system stability, dynamic reactive power provision, power quality, facilitation of renewable energy, and distribution grid's reliability and flexibility. It is also environmental friendly with less land use and little environmental impact. Secondly, the multi-terminal flexible DC transmission is a significant technological breakthrough on the basis of double-terminal flexible DC transmission technology. It can get power from multiple sources and supply power to multiple places by constructing a multi-terminal flexible DC system, adopting 3 convertor stations or more and connecting them using various methods. Thirdly, it will also allow large-scale access to renewable energy supplies, such as onshore and offshore wind power.

What is next?

Following the success of the Zhoushan DC project, a HVDC VSC-based regional DC power grid with the voltage class of ≥ 200 kV is being considered in the near future.

4 GERMANY

Superconductivity enables increased capacity in congested urban area

What is the project about?

The AmpaCity project, located in Essen, Germany, features a system consisting of a 40 MVA high-temperature superconducting (HTS) power cable and fault current limiter. The system was installed to connect two substations in downtown Essen, replacing a conventional high voltage system.

Main goals

The project seeks to demonstrate both the technical and economic viability of HTS technologies as solutions to upgrade electric power systems in congested urban areas where space and other constraints limit the feasibility of expanding current high voltage delivery systems.

Current status/timeline

The project became operational in spring 2014; the demonstration and evaluation phase will last at least for two years.

What is the result/expected benefits of the project?

HTS technologies, such as the power cable and fault current limiter featured in the AmpaCity project, provide several benefits when compared to conventional high voltage systems in dense urban environments:

- Less space required for power cables and substation equipment
- Enables lower voltage in distribution system
- Reduced power losses
- Lower overall system cost
- Negligible thermal impact on the environment
- No outer magnetic field during normal operation
- Improved power quality and reliability due to fault current limiting capability

What is next?

Next steps regarding the Essen installation will be determined after the two-year demonstration period concludes in 2016. This project provides operational experience and data about new HTS technologies and thus enables further development of these devices.

5 THE UNITED STATES

Wide-area measurement systems used to avoid large-scale outages

What is the project about?

The Bonneville Power Administration (BPA) is a federal power marketing authority based in the northwestern part of the United States. In 2013, BPA completed installation of an unparalleled synchrophasor network, part of a three-year, $30 million investment. The BPA synchrophasor project combines the latest synchrophasor technology with a more robust telecommunications system to give transmission operators a much clearer view of the entire system in the West. With all the measurements synchronized by GPS, BPA can see precisely how the interconnected power systems in the West are responding to changes or disturbances.

Main goals

The project provides grid operators and reliability coordinators with more frequent and time-synchronized system information. Better system visibility will help system operators avoid large-scale regional outages, better utilize existing system capacity, and enable greater utilization of intermittent renewable generation resources.

Current status/timeline

The agency is receiving data from 126 Phasor Measurement Units (PMUs) at 50 key substations and large wind-generation sites throughout the Northwest. In addition, BPA developed an application capable of assessing the dynamic performance of its generating fleet within minutes of a power grid disturbance.

What is the result/expected benefits of the project?

The wide-area synchrophasor measurements are used for wide-area controls. The synchrophasor-based controls will use wide-area synchronized measurements to determine voltage stability risks and will initiate corrective actions in less than one second. Also, four real-time analytical applications are in use in the BPA control center together with operational displays.

Another important benefit is that the collected data is used to validate the system models leading to more accurate models, which are essential for reliable and economical grid operation.

The data gives a better understanding of power grid performance, which, in turns, leads to possibilities to optimize the capital investment. It is also expected that the synchrophasor data will lead to large-scale outage avoidance and early detection of equipment problems.

What's next?

BPA will continue to solicit ideas for research and development projects. The agency is collaborating with wind power plant operators in the region to expand PMU coverage, and PMU data will help address large-scale wind integration challenges. To facilitate coordinated operation of the interconnection, BPA exchanges PMU data with 11 key partners in the region and will be expanding the exchange in the future. Another important area for future growth is the development and refinement of advanced applications.

6 ITALY

Wide-area measurement enhances the Italian power system

What is the project about?

The development of wide-area measurement system (WAMS) technology, combined with phasor measurement unit (PMU) devices, offers new, valuable solutions for power system analysis, monitoring, and control. This case study describes the architecture, monitoring functions, and operational experiences of the WAMS realised by TERNA, the Italian transmission system operator, for the synchronised monitoring of the Italian power grid interconnected with the Continental European system.

Main goals

The development of the Italian WAMS allows a deeper and more straightforward understanding of system conditions and provides considerable support to control actions and manoeuvring.

Current status/timeline

The first synchronised measurements in the Italian system were performed in the early 2000s, during preliminary tests of different commercial PMUs. Currently, 55 substations are monitored by PMUs, mainly on the 400 kV level, but also on the 220 kV level. Substations at 150 kV have been equipped with PMUs too, especially in areas with limited coverage of 400 kV and in view of testing Dynamic Line Rating applications. Functions have been developed for oscillatory stability analysis, network separation detection, load shedding intervention evaluation, and line thermal estimation. The development of real-time functions is still ongoing, potentially to include wide-area control systems/wide-area protection systems.

What is the result/expected benefits of the project?

The WAMS platform provides valuable information to support operators in the control room. Real-time plots and charts of system quantities, such as phase angle differences, and the output of monitoring functions, such as oscillation identification, enable operators to better track system stress and dynamic phenomena and evaluate viability of responses. Cooperation with other countries of the same synchronous area, in the form of real-time PMU data exchange, proved particularly useful.

What is next?

More PMUs are expected to be installed in the near future, for a total of about 100 units. Future PMU deployment will address critical interfaces of the grid. When each border is fully monitored, estimation of the state “by areas” may be investigated as a new monitoring function. Other anticipated activities include the design of WACS/WAPS solutions, coordinated and integrated with the existing Italian defence plans and shedding schemes. The central processing system will be enhanced with a distributed architecture that will ensure higher reliability and allow the system to manage the increased amount of data that will result from further PMU deployment.

7 SOUTH AFRICA

Grid situational awareness proof-of-concept

What is the project about?

The project is about grid situational awareness (i.e., the combination of the electrical interconnected power system with environmental conditions in order to accurately anticipate future problems to enable effective mitigation actions). Grid situational awareness provides real-time support for intelligent decision making based on real-time event management, forecasting, power stability, and management through dynamic system sources.

The proof-of-concept focuses on integrating various data sources in order for Eskom, the South African utility, to be able to make intelligent decisions regarding situational awareness based on experience built up through the implementation process.

Main goals

The main goal is to improve the situational awareness in the Eskom system, and the described proof-of-concept aims at investigating the feasibility, requirements, and development of a visualization server stack for the grid situational awareness concept.

Current status/timeline

The physical integration process was completed in three months. Most of the project's one-year timeline was spent collaborating with different providers of data, possible users of the data throughout the business, and system architects in order to establish a roadmap for future implementations regarding the integration and visualisation of data from disparate sources. Feedback was provided by the system operators regarding the transfer of developed capabilities into a maintained production environment during the closing phase of the 2013/14 financial year.

What is the result/expected benefits of the project?

Some benefits to grid situational awareness include the following:

- Improved maintenance scheduling
- Ability to perform preventative maintenance
- Fault finding
- Warnings of impending danger
- Shortened downtime
- Immediate feedback based on data

What is next?

The focus of the continued research on grid situational awareness is on integrating data and implementing models related to forecasting future renewable generation capacity and informing the system operator of drastic changes. Other data sources include pollution data and plant growth and vegetation. There are also plans to expand on visualisation and alerting rules.

8 FRANCE

Smart Substation

What is the project about?

The Smart Substation project aims at developing new, digitalised functionalities of the electrical substation, focusing on the ultra-high-voltage grid while considering the interface with the distribution grid. This is an industrial pilot project with experimentation of a new technological package including new advanced control functionalities in the French electrical grid.

The demonstrations will be set in the north of France, where there is significant wind power and where several new parks are planned. Two types of substations will be developed and tested: a transmission substation and a distribution substation that represent the interface between the transmission system and the distribution system. The innovative digitalised architecture will be deployed on existing substations.

Main goals

The Smart Substation project aims to design, build, test, and operate two fully digital smart substations by 2015 in the northern area of France. The project will assess the benefits provided by these solutions, such as a lower environmental impact, better integration of the renewable energy sources (RES), improved transmission capacities, and optimal use of the existing assets.

Current status/timeline

This is a four-year project that began in 2013. Three years will be dedicated to development and one to experimentation. Currently (as of July 2014), specifications are finished and development is underway. The first results on site will come in 2016.

What is the result/expected benefits of the project?

The development of smart substations will enable the electrical power equipment to work closer to their physical limits. At a national scale, a transmission system using smart substations carries more energy than a traditional grid. The development of digitalisation will, also looking at a national scale, enable optimisation of the grid's reinforcement works. The digitisation of all substations is also a technological solution that will contribute to reaching the European commitment to increase RES integration.

What is next?

The project will continue to 2017, with the first results coming from the site in 2016. The project results will be examined and the new functionalities will be further developed. The project results will be investigated based on experiment feedback on the advantages (from the operator's point of view) resulting from digital technologies and advanced functions.

If the outcome is positive, the project will enable the transmission system operator to start drawing up methodologies for the implementation process on site, work on the graphical user interface (which should assist the operators on smart substations management), and prepare for the crafts evolution.

9 AUSTRIA

Maximising the DER hosting capacity of low- and medium-voltage networks

What is the project about?

The main challenge of integrating distributed energy resources (DER) in rural distribution networks is keeping the voltage within the specified limits (i.e., in compliance with EN 50160). This study considers how to maximise the hosting capacity of DER in low-voltage (LV) and medium-voltage (MV) networks through the use of smart planning, smart monitoring, and smart control.

Main goals

The main goal of the project is to find an efficient way for the integration of renewable-based distributed generation (DG) with regard to optimised investment by maximising the utilisation of the existing asset base in LV and MV grids. The focus of the related projects presented in this case study is to increase the hosting capacity of LV and MV distribution networks for distributed energy resources, including DG, demand response, and electric vehicles.

Current status/timeline

The demonstrations and the evaluation of related field tests for LV networks were finalised at the end of 2014. Currently, a follow-up project on the integration of small-scale storage in the field test area is under preparation. One of the solutions for MV networks is already commercialised, and for the other solution, an enhancement of the algorithms is under preparation.

What is the result/expected benefits of the project?

Implementation of voltage control concepts in LV and MV networks can increase the hosting capacity significantly. Examples of other benefits include the possibility of lower losses and reduced greenhouse gas emissions. All smart grid applications developed and tested within the individual projects are seen as part of an overall smart grid approach, which should enable advanced services.

What is next?

One important issue is to further investigate the replicability and scalability of the developed solution in Austria. Therefore, networks where similar problems may occur should be identified and used to determine whether these solutions will be suitable. Additionally, based on the experiences in LV and MV networks, the next step will be to investigate, further develop, and demonstrate the interaction of all the controls in high voltage, MV, and LV levels and include them in the operational network management.

10 BELGIUM

Increased hosting capacity by intelligent control of PV inverters

What is the project about?

The MetaPV project aimed to resolve network constraints for large-scale deployment of photovoltaics (PV) in distribution systems.

The demonstration project was developed to test controllable PV inverters and determine their ability to increase the hosting capacity of distribution grids for distributed generation. It covered residential-scale PV installations with controllable inverters of 428 kilowatts (kW) peak power on low voltage (400 V), and commercial-scale installations with 2.4 megawatts (MW) on medium voltage (10 kV), with locally high concentrations of controllable PV and PV in general.

Main goals

The overall objective of MetaPV was to show how large amounts of distributed generation can be integrated in real, largely saturated, distribution networks. The project team wanted to investigate and show on a large scale how PV plants themselves can contribute to increasing the hosting capacity and thus substitute for expensive grid reinforcements.

Current status/timeline

The MetaPV demonstration ended in spring 2015. The final results and recommendations are summarized and published.

What is the result/expected benefits of the project?

The main findings from the MetaPV project are:

- Inverter-based voltage control works in real distribution grids
- Different concrete implementations vary in terms of effectiveness, efficiency, fairness and simplicity. They should therefore be evaluated according to the importance of these criteria for the individual situation.
- The requirements for active and reactive power control as required by grid codes and standards should be further harmonized; however, without harmonizing specific threshold and setpoint values.
- Voltage control by PV inverters is a viable and lower cost alternative to grid reinforcement for increasing the voltage hosting capacity of existing grids.
- Storing electricity from distributed resources for the purpose of grid voltage support is barely competitive with intelligent curtailment. In the future, the deployment of grid-connected storage on distribution systems will depend on technology costs and ability to serve multiple use cases with the same plant.

What is next?

The MetaPV inverters used in the demonstration are still in use after the project and have been set to apply the control function best suited for their particular situation.

Distribution system operators, industry and regulators are encouraged to build further on the project results for improving, replicating, and upscale the solutions presented there.

11 CANADA

Energy Storage and Demand Response for improved supply reliability

What is the project about?

A 1 MW, 6MWh battery storage is installed near a community which gets its power supplied via a long distribution feeder, prone to frequent power outages of significant duration. The energy storage increases the supply reliability and provides clean backup power. Demand response from the residents helps increasing the effect of the storage.

Main goals

The project had two key objectives:

- To enhance customer supply reliability for the community
- To provide clean backup power for the community

Current status/timeline

The project has been in operation since July 2013. The battery provides clean back-up power and performs daily peak shaving to demonstrate management of distributed energy resource.

Since 2015 approximately 20% of the residents are receiving notifications when the battery is in an islanded condition. This notification encourages them to reduce the community load during a power outage, hence maximizing the duration of the battery support.

What is the result/expected benefits of the project?

The results after the project has been an enhanced customer supply reliability during sustained power outages in the Field with clean back-up power. Also many lessons learned and best practices have been gained related to the design and construction phases which can be applied toward any future battery storage projects.

What is next?

BC Hydro will continue to monitor the performance of the battery system availability and efficiency over the life of the battery to better understand the battery system.

12 DENMARK

More efficient energy system by combining electricity and heat

What is the project about?

The "Grid connection with reduced network access"-scheme is a contract initiated by the Danish government to increase the utilization of electricity from renewable energy sources. The contract allows electric boilers in district heating to connect to the grid with a very low connection fee. The electric boilers are however limited in operation to only use the available excess capacity in the network at any given time ensuring no need for grid reinforcement due to the electric boilers.

Main goals

The objective is to receive a better balance between production and demand in the market, by giving incentive to the CHP-plants to produce heat from electricity (electrical boilers) from alternative energy sources during hours of high surplus of electric production.

Current status/timeline

The "Grid connection with reduced network access"-scheme was implemented 2006. The Danish development project CHPCOM has developed a communication solution for integration of plant SCADA with DSO SCADA using the IEC 61850 standard. This allows for a fine-grained throttling of the boilers by the DSO. The project ended January 2016.

What is the result/expected benefits of the project?

To mitigate the uneconomic electricity production during periods with high surplus of energy, it is viable to convert electricity to heat in those hours. The incentive is intended to reduce the electricity infeed by substituting heat production on CHP-units with heat production on electrical boilers, and increasing demand of electricity at the same time.

Both the DSOs and the CHP-plants benefit from the reduced network access scheme. The DSO gets an increase in revenue from network tariffs and a higher utilization of the network assets, the CHP-plant gets the opportunity to produce heat from electricity when this is cheaper than alternative energy sources and avoids paying the normal connection fee.

What is next?

The connection scheme has been expanded to also include large heat pumps in district heating system. Work is ongoing with business cases for this alternative to also be economically viable.

13 ITALY

Impact of the enforcement of a time-of-use tariff on residential customers in Italy

What is the project about?

The Italian Authority for Electricity and Gas (AEEG) approved the implementation of a mandatory Time-of-Use tariff (ToU) based on two time slots for residential customers in Italy starting July 1, 2010. The introduction of the ToU tariff is the last step of a process that was designed to progressively expose Italian customers to time-variable costs of electricity supply. The introduction of the ToU tariff for residential customers in Italy is a significant event; currently, 20 million families are paying their electricity consumption with a variable price during the day, which created an unprecedented occasion to analyse the changes of customer behaviours in response to time-variable electricity prices. In order to assess the impact of the ToU tariff on the Italian consumers in the short and medium terms, RSE ran this research project in collaboration with, and under the patronage of, AEEG.

Main goals

The main goal of the project was to evaluate the impact of a ToU tariff on residential customers in Italy. In the long run, the goal is to induce the Italian customers to adjust their consumption according to the abundance or scarcity of electricity, leading to a decreased need to reinforce the network due to high loads during peak hours.

Current status/timeline

The ToU tariff was introduced gradually, with an 18-month transition period (from July 1, 2010, to December 31, 2011) with a limited price difference between peak and off-peak hours (a transitional ToU tariff). After this period, the price difference became larger, in accordance with the competitive market price of electricity (the final ToU tariff).

What is the result/expected benefits of the project?

The results show that, even if there has been a limited shift of consumption from peak hours to off-peak hours in the period following the introduction of the mandatory ToU tariff, the change in the behaviour of the users is not negligible. The ToU tariff in Italy has been capable of shaping users' habits to a certain extent, according to price signal. Also, the mandatory ToU tariff in Italy has contributed to improving the efficiency of the whole Italian system, moving a percentage of the residential consumption from peak hours to off-peak hours. In particular, it has demonstrated the role of the customers in shaping their energy consumption as active users in order to face time-dependent electricity costs.

What is next?

The analysis has continued, with the goal of determining if the consumption shift trend persists or not. Another approach that may be used in combination with the ToU tariff is critical peak pricing, which consists of a significant increase in the electricity price during short duration periods in which the reserve margin is low. The higher price difference and the shorter duration of time intervals are the two factors that allow a significant load shift from peak hours to be achieved with respect to ToU tariffs.