CIGRE-379 **2020 CIGRE Canada Conference**
Toronto, Ontario, October 19-22, 2020

SMRs-A Solution to Climate Change

Michael D.N. Dang
School of Engineering Practice and Technology
McMaster University
Hamilton, ON, Canada
e-mail: dangmi@mcmaster.ca

Hugo Sanchez-Reategui
Station, Design - Distributed Energy Resources (DER)
Alectra Utilities Corporation
Woodbridge, ON, Canada
e-mail: hugo.sanchez@alectrautilities.com

SUMMARY

All Regions across Canada are already experiencing the impacts of climate change. Environmentalists, activists, scientists, politicians, and ordinary people (you and I) worry about climate change and want to fix it. Serious damages are already underway and there is enough carbon dioxide in the atmosphere to ensure more damages to come, and if carbon emissions continue unchecked, increases in temperature will likely increase our energy demand and our ability to deliver it reliably. Shifting rainfall patterns and droughts are shrinking river flows and draining lakes leading to decreased in hydro-electric power generation; transmission line conductors sag beyond its maximum limit resulting in reduced power flows; and power system equipment such as motors and transformers need to operate at reduced ratings to avoid overheating.

Wind and solar generation are expanding globally. Recent SMR (Small Modular Reactor) [1] innovation and development could mean cheap electricity for transportation, construction and manufacturing industries. The shift to electric cars and buses; emission-free heating and cooling systems in our homes and businesses; and energy-intensive factories using more clean power to make products will be our goals and solutions to climate change. By converting the national grid into a microgrid power network system, we will provide a carbon-free atmosphere and a better future for future generations.

KEYWORDS
Climate Change; Generation Planning; Transmission and Distribution; Wind and Solar Power; Small Modular Reactors; Microgrid; Decentralization

hugo.sanchez@alectrautilities.com/dangmi@mcmaster.ca

I. INTRODUCTION

Climate change is here, and it will affect virtually every man, woman and child on planet Earth. Its impact on the energy sector [2 – 4] is explicitly discussed by prominent scientists, in research papers, government reports and utility documents. Their common themes are that energy plays an important role in all aspects of our lives and increases in temperature mean that there will be an increase in energy demand due to running more air-conditioning units in homes and businesses, accommodating more cold storage and refrigerated warehousing of perishables, and having more cooling fans running in place of air conditioners.

Hydroelectric power accounts for more than one-third of all the energy demand in Ontario since the beginning of the 20th century. Ontario Power Generation (OPG) has approximately 66 hydraulic hydroelectric stations harnessing water flowing from a higher to a lower elevation to turn turbines. However, if climate change is to bring about droughts, tight water flows and shifting rainfall patterns that cause water levels to drop to below the statistical average, then hydro generation would be drastically reduced during high energy demand.

Ontario's electricity grid [5] is made up of about 29,000 km of HV transmission lines that deliver power to large industrial customers and municipal utilities. Global warming means higher ambient temperatures and power deliveries during high energy demand would have to be curtailed due to conductors attaining their continuous ampacity rating limits. Continued operation beyond the conductor's maximum operating temperature will result in excessive sag and suffer irreparable damage due to annealing.

Global warming is causing more extreme weather as cyclonic winds are known to topple and collapse transmission towers. Strong updrafts and strong horizontal winds could bring down multiple transmission lines within a single corridor causing (N-2) contingency [6] and cutting off power supplies to major load centers. It is time to downsize the national grid to a microgrid that can be operated in "islanded" mode and still stay connected to the main power grid for synchronization and support.

II. MICROGRID POWER NETWORK SYSTEMS

A. The Concept

The concept of a microgrid is not new. What is new is the transformation of a national grid back to a regional network system in the face of emerging technology: falling cost of renewables such as wind turbines and solar panels, and the introduction of Small Modular Reactor (SMR). The current development makes it possible. SMR has a generating capacity from about 5 to 272 MWe which is much smaller in size than conventional nuclear reactors and therefore will have lower up-front capital costs, and with enhanced safety features, it will overcome the public's fear mindset of nuclear power plants.

A microgrid refers to distributed energy resources and loads that can be operated in a controlled, coordinated way with other local distribution companies (LDCs). With the existing electrical infrastructure set up by Ontario Power Generation (OPG) and Hydro One Networks Inc., it could operate in an "islanded" mode, however it will stay connected to the main power grid for synchronization, for peak-shaving during high load demand, for power import during emergency shut-down of the SMR including during station servicing and maintenance, and for power export to neighboring LDCs.

B. Decentralization

Ontario is ideally set up for establishing a microgrid power network system. The IESO (7) has created 21 energy planning regions with around 60 LDCs owned by municipalities. Their primary roles are to distribute power radially from the grid to transformer stations (TSs) and deliver power to customers within their regional areas as shown in Fig. 1.

Fig. 1: GTA West Region Transmission Diagram

As an example, figure 1 depicts the GTA West Region encompassing roughly nine Regional Municipalities and six LDCs. This region has more than 2,600 MW of load (which is about 10% of the Province's total load) with an integrated 230 kV power network supplied by 500/230 kV auto transformers from the transmission grid. The distribution and sub-transmission system is at 44 kV and 27.6 kV and the region has two gas fired plants totalling 1850 MW. The three scenarios in which power is transferred from the grid may be summarized in Table 1 below:

Scenarios	Power from Local Generation (MW)	Power from Transmission Grid (MW)
1	0 MW	2600 MW
2	600 MW	2000 MW
3	1250 MW	1350 MW
4	1850 MW	750 MW

Table 1: Power Transfers from the Grid

To illustrate the relationship between generating capacity requirements and load in GTA West region, the load duration curve shown in Fig. 2 can best be used to reflect the activity of this Region with respect to power consumption over a given day. It also helps to explain economic dispatching, system planning and reliability evaluation.

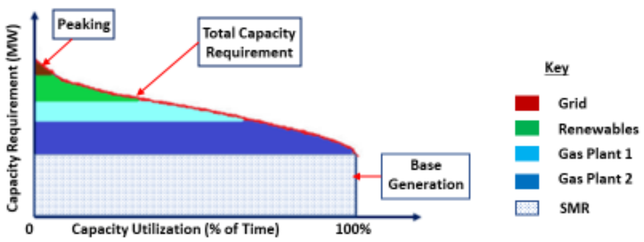


Fig. 2: Daily Load Duration Curve

C. Load Duration Curve

GTA West Region's residential, commercial and industrial loads may be represented as a load duration curve over a period of 24 hours. This characteristic shows a high load demand early in the morning, remains constant for most of the morning, falls gradually in the evening as industries start shutting down and the load attaining a minimum by midnight. This process is repeated over a 24-hour period.

To consistently meet this load, power production is classified into four categories:

- base generation – power needed throughout the year
- committed generation – power dispatched locally to meet the variability in power demand

- renewable generation - solar and wind power generation with limited predictability and reliability, and
- peak generation – power from transmission grid to meet random fluctuation and unforeseen changes in either demand or supply.

III. SMR and Renewables

A. Small Modular Reactor

Small Modular Reactor (SMR) can play a very significant long-term role for meeting the GTA West Region's base generation requirement, while simultaneously addressing challenges associated with global climate and environmental impact. There are five different types of SMRs to choose from (1) and they are:

- Water Cooled Reactors: in which all components for steam generation and heat exchange are assembled into a single integrated unit called "NuScale Power Module" (NPM) (8).
- High Temperature Gas-Cooled Reactors: is a small, modular, graphite-moderated and helium-cooled, high-temperature nuclear reactor being developed for industrial process heat, hydrogen production, and electricity generation. This is based on Framatome's Antares (9) concept.
- Liquid Metal Fast Neutron Reactors: uses sodium instead of water allowing the reactor to operate at ambient pressure. The ARC-100 (10) design ensures that the reactor will never melt down even in a disaster and that it can be fueled with the nuclear waste produced by traditional reactors.
- Molten Salt Reactor (11): uses molten salt rather than solid fuel to carry uranium fluoride for capturing and dissipating heat from the fission process. It uses low-enriched uranium (less than 5 percent 235U) fuel.
- Heat Pipe Micro-Reactors (12): develops by Westinghouse having a solid core and advanced heat pipes. The core encapsulates fuel and heat pipes enable passive core heat extraction and power regulation.

One of the advantages of the SMR design is that it is based on factory fabrication and testing of modular components that can be shipped for rapid site assembly. It is also based on a "walk away" passive safety system that ensures the reactor will never melt down even in a disaster that causes a complete loss of power to the plant site. In addition, it can be fueled with the nuclear waste produced by traditional reactors.
Pro

These SMRs come in different sizes (13) allowing municipality LDCs to plan their base generation as given in Table 2 below:

No.	SMR Types	Size of Reactor Unit
1	Water-cooled reactor	200 MWt / 60 MWe
2	High Temperature Gas-Cooled Reactors	625 MWt / 272 MWe
3	Liquid Metal Fast Neutron Reactors	260 MWt / 100 MWe
4	Molten Salt Reactor	400 MWt / 190 MWe
5	Heat Pipe Micro-Reactors	20 MWt / 5 MWe

Table 2: SMR Reactor Sizes

<u>Note</u>: MWt / MWe – Megawatt thermal / Megawatt electric

B. Renewables

The microFIT Program (14) was established in 2009 and open to individuals, homeowners, farmers and municipalities to develop projects 10 kW or less in size. Suppliers were paid a guaranteed price over a 20-year term for the electricity they produce and deliver to the province's electricity grid.

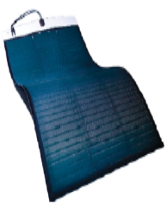
However, the microFIT Program could be modified to encourage customers to take a more active role in managing their own energy consumption, by choosing how much power they use, and when. By staying connected to the grid and automatically switch over to the grid in the absence of power generation from renewables, customers are ensured continued power supply. Existing smart meters not need to be replaced by bi-directional meters as a result. Renewables could produce significant amounts of electricity to offset power demand in the GTA West Region.

Under this model, customers will have three options to choose from and they are:

- Solar PV system – from 350 Watts to 1050 Watts
- Wind turbine system – from 300 Watts to 900 Watts, and
- Hybrid wind and solar system – from 650 Watts to 1950 Watts.

1. Solar PV System

The heart of this PV system is the MiaSolé FLEX-02 350W solar module (15) as shown in Fig. 3. It is based on thin film technology in which these lightweight (5.1 Kg) PV panels can be directly bonded to both metal and membrane system roofs, eliminating the need for solar racking, concrete ballasts, and roof penetrations. The reduced weight load makes it ideal for low weight bearing building structures and lower labor costs and installation times.



MiaSole CIGS Flexible Solar	
Power(Pmax)	350W
IMPP	11.72A (in Pmax)
Isc	13.55A
VMPP	29.9V
Voc	37.9V
Length / Width	2589mm / 1000mm
Thickness, Weight	2.5mm, 5.1kg
Certification	UL 1703, IEC

Fig.3: MiaSolé FLEX-02 350W Solar PV Panel and Specifications

2. Vertical-Axis Wind Turbine

The wind turbine system is the MALEV 300W vertical-axis wind turbines (16), standing at a height of about 1.09 m and weighing 31 Kg as shown in Fig. 4. These are vertical axis wind turbines which manufacturers claim to be quiet, efficient, economical and perfect for residential energy production, especially in urban environments. They can be mounted on roof tops, or close to, or on the ground making it easier access and maintenance.

TECHNICAL SPECIFICATIONS		
No.	Description	Specification
1	Rated Output	300W
2	Type of Alternator	3-Phase, AC
3	Start-up Wind Speed	1.3 m/S
4	Working Wind Speed	3.0—15 m/S
5	Height	1.09 m
6	Rotating Diameter	1.24 m
7	Weight	31 Kg
8	Output Voltage(Controller)	DC 24V
9	Braking System(Controller)	Over Speed Braking by 3-Phase Short-Circuit
10	Limited Temperature	-40ºC to 120ºC

Fig. 4: MALEV 300W Vertical-Axis Wind Turbine

The hybrid wind-solar package will be a mix of solar PV and wind turbine systems. This option permits customers to harness energy 24-hours a day, in most weather conditions and at most times of the year.

3. *Energy Storage*

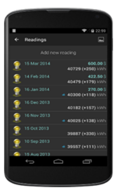
KEYS	*DESCRIPTION*
Storage Capacity	8 kWh
Operating temperature ranges	▪ - 20ºC to 65ºC for discharging ▪ 0ºC to 65ºC for charging
Battery Configuration	16s2P, 100 Ah pack
Dimensions	$32\frac{7}{8}$ " (L); $20\frac{7}{8}$ " (W); $10\frac{3}{4}$ " (H)
Weight	294 lbs

Fig. 5: Residential Li-ion Energy Storage Units

Without selling the excess energy to the grid, energy storage system allows households and businesses to store renewable energy during daytime when energy demand is low for later consumption.

Lithium-ion batteries [17] (see Fig. 5) are preferable to lead-acid ones given their similar cost but much better performance. The number and size of these battery packs are determined by the capacity of the renewable system and the home's energy consumption levels and usage patterns. Multiple units can be set up in parallel to add more capacity.

4. *Renewable Energy Meter Reader*



Functional Specifications

- Measure when, and how much energy is produced, used, sold or banked
- Display in real-time kWh power produced including cost
- Keep track of previous month and current month readings
- Send meter readings automatically via wireless technology to the CEB
- Eliminate the need for a bi-directional watt-hour meter
- Enable two-way communication between the meter and the central system; and
- Alert or remind monthly bill payment in English or French.

Fig. 6: Renewable Energy Meter Reader

Renewable Energy Meter Reader shown in Fig 6, is part of the renewable package allowing LDCs and their customers to monitor and measure how much power renewables are producing. Measurement data are displayed in real-time kWh and saved in the cloud allowing for easy access of previous and current hour/day/month meter readings to be used for planning and scheduling purposes, or simply for record keeping. This unit is menu driven and its app can be personalized to fit individuals.

III. Power Plant Cost Analysis

A. Capital and Levelized Costs

The traditional approach to estimating the cost of power is to establish capital cost which decides the type of power plant to invest in, and levelized cost which determines which technology might offer the best future performance. A thorough cost analysis that factors all the costs and benefits associated with this project will not be covered here. The aim is to compare the cost of SMR investment with other conventional base load investments. This will determine whether conversion to microgrids is financially feasible or if municipalities should pursue another alternative for base generation.

B. Investment Cost Comparison

- The cost of a simple gas turbine power plant may be as low as $600/kW [18] or as high as $1,810/kW. This includes the cost of installation and all the ancillary equipment. The actual gas turbine itself probably costs much less than this. There is unsupported evidence that large frame gas turbines for combined cycle plants may be purchased for less than $200/kW.

  However, if the focus is on highly efficient, flexible and cleaner conventional power plants, then the capital cost estimate for an F Class, 240 MW simple cycle combustion turbine [19] is $713/kW.
- At the other end of the scale, a modern nuclear plant is likely to cost over $6,000/kW (some current estimates suggest $12,000/kW due to cost over-runs).

  With relatively few nuclear plants constructed in North America and Western Europe over the past two decades, the amount of information on the costs of building modern nuclear plants is somewhat limited. However, the capital cost estimate for an advanced nuclear facility with a nominal capacity of 2,156MW is $6,041/kW.

- SMRs are projected [20] to cost less than a coal fired plant (between $3,500/kW and $5,000/kW) after SMRs are mass produced in volume in the factory and assemble on site.

  Since no such reactor has yet been built, there is not much reliable information related to the costs of these technologies besides the vendor estimates and a few research reports. The capital cost estimate for SMR of 250MW Small Modular Reactor is $6,191/kW.

- Among the advanced and renewable technologies, wind turbines are probably the cheapest at around $1,677 /kW, with solar photovoltaic power plants close behind at $1,313/kW.

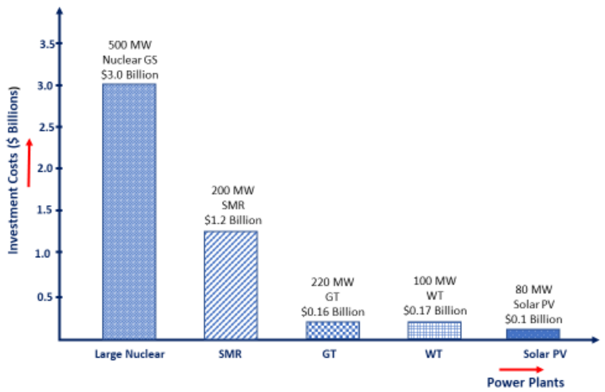


Fig. 7: Power Plant Investment Cost Comparison

Figure 7 provides a simplified illustration of investment costs by comparing the size of an SMR investment with other conventional base load investments. This allows OPG, municipalities, hence

LDCs, to evaluate potential costs and revenues that a microgrid might generate by adopting this model.

IV. Conclusions

The solution to climate change is finding a clean energy solution such as SMRs and adopt a microgrid network system. Electric vehicles alone will not stop climate change.

Small Modular Reactor (SMR) technology is becoming more attractive and the possibility of commercial deployment within the next 10 years is feasible. Meanwhile, renewables such as wind turbines and solar photovoltaic systems continue to advance, and with energy storage growing rapidly too, investing in a new microgrid power infrastructure would result in cheap electricity prices. We would see a reduction in greenhouse gas emissions through electrification of energy services such as a carbon-free transportation network, industries that would not burn fossil fuels for energy, and businesses and homes that would cease burning fossil fuels for heat.

Fortunately, climate change is solvable. We have the technologies. We have the science. We now need OPG, municipalities and LDCs to have the foresight to change course and build a better future for future generations.

BIBLIOGRAPHY

[1] “*Small Modular Reactors: Regulatory Strategy, Approaches and Challenges*”, Discussion paper DIS-16-04, Canadian Nuclear Safety Commission, Ottawa, Ontario, 2016.

[2] “Climate Data: A Sectoral Perspective”, Prepared for the Pew Center on Global Climate Change, Kevin Baumert Timothy Herzog Jonathan Pershing, World Resource Institute, August 2005.

[3] “*Canada's Changing Climate Report”,* Elizabeth Bush, Climate Research Division, and Donald S. Lemmen, Climate Change Impacts and Adaptation Division, Government of Canada, Ottawa, ON.

[4] “*The Impact of Climate Change on the Electricity Market: a Review”,* Torben K. Mideksa and Steffen Kallbekken, Center for International Climate and Environmental Research, Oslo, Norway, 2010.

[5] *“Ontario's Electricity System”,* prepared by IESO, http://www.ieso.ca/localContent/ontarioenergymap/index.html

[6] *“Reliability Guideline – Reactive Power Plannin”*, NERC, December 2016.

[7] “*GTA West – Regional Infrastructure Plan* “, Report prepared by Hydro One Networks Inc., January 25, 2016

[8] “*SMR Technologies: Water Cooled Reactors - NuScalePower (USA)”*, https://www.nuscalepower.com.

[9] “*SMR Technologies: High Temperature Gas Reactors FramatomeSC-HTGR (USA)*”, http://www.framatome.com/EN/us_platform-3225/framatomehtgr.html.

[10] *" SMR Technologies: Liquid Metal Fast Neutron Reactors ACR-100 (USA) ",* https://www.arcnuclear.com/technology

[11] *“SMR Technologies: Molten Salt Reactor Terrestrial Energy IMSR-400 (CAN)”* https://www.terrestrialenergy.com

[12] *“SMR Technologies: Heat Pipe Micro-Reactors Westinghouse eVinci (USA).”* http://www.westinghousenuclear.com/new-plants/evinci-microreactor

[13] “*Small Modular Reactors* – Innovation in the Nuclear Industry”, prepared by Paul Acchione, OSPE's (Ontario Society of Professional Engineers) Energy Task Force, June 2019.

[14] “*Ontario's MicroFIT Program - Overview”,* prepared by IESO, http://www.ieso.ca/en/Get-Involved/microfit/news-overview

[15] “Miasolé FLEX -02 series”, https://energig.com/shop/power-production/solar/flexible-solar-panels/miasole-flex-02-series

[16] “Maglev 300W Vertical Axis Wind Turbine System CXF-300*”,* https://www.emarineinc.com/Maglev-300W-Vertical-Axis-Wind-Turbine-System-CXF-300.

[17] “*Home Energy Storage System -* ePOWER4810*”,* https://www.elitepowersolutions.com/home-energy-storage-system

[18] “*Small Modular Reactors – Key to Future Nuclear Power Generation in the U.S.”,* Robert Rosner and Stephen Goldberg, Energy Policy Institute at Chicago, the University of Chicago.

[19] “*Capital Cost Estimates for Utility Scale Electricity Generating Plants*” https://www.eia.gov/analysis/studies/powerplants/capitalcost/

[20] “The Economics of Cery Small Modular Reactors in the North”, M. Moore, 4th International Technical Meeting on Small Reactors (ITMSR-4) CW-120200-CONF-012 Ottawa, Ontario, Canada, November 2-4, 2016.