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Review paper: interconnected micro energy grids

Hossam A. Gabbar

Email: Hossam.gabbar@uoit.ca

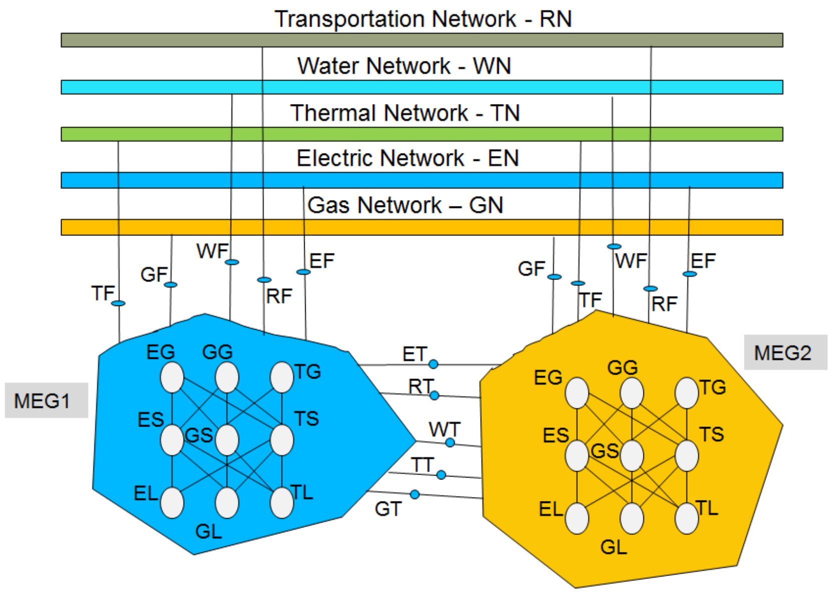
In recent years, there has been a global movement in the direction of adoption and deployment of distributed and renewable resources. Renewable energy (RE) sources differ from conventional sources in that, generally they cannot be scheduled, they are much smaller than conventional power stations and are often connected to the electricity distribution system rather than the transmission system. Smart energy grid (SEG) infrastructures will enable efficient bidirectional energy supply chains. SEG can provide distributed energy generation of electricity, thermal, and gas, that are interconnected with storage and loads. SEG includes hierarchical infrastructures with small energy grid called micro energy grids (MEGs). Interconnected MEG can provide higher performance by exchanging excess energy from one MEG to another based on local generation and loads. Interconnected MEG can allow scalable superstructure to cover energy demand and needs in local regions. To evaluate different design and operation scenarios of such dynamic superstructures of interconnected MEG, local and global performance indicators are proposed to evaluate these scenarios. Intelligent optimisation techniques are employed to identify potential scenarios of MEG design, control, and operation. Intelligent modelling and simulation tool is proposed with distributed decision-making capabilities to manage the data gathering and analysis functions and map to static and dynamic models of SEG components. As SEG is a multi-player domain, this requires collaborative decision-making and control with distributed knowledgebase to support different views. In addition, it is important to support the automatic and dynamic identification and evaluation of control and protection boundaries and operational scenarios of MEGs. Practical business models are essential to support the practical implementation of MEG and deployment of interconnected MEGs. The proposed automated MEG engineering tools will enable energy providers and utilities to negotiate profitable solutions of SEG that meet energy suppliers, end-users, technology providers, and government/regulators to achieve suitable solutions with local and global optimisation with proven low carbon and improved efficiency and reliability of the target SEG with interconnected-MEGs superstructures.

As part of the future implementation of SEG, it is important to demonstrate regional SEGs and MEGs with RE as distributed generation. This decision involves capital cost for changing infrastructure to support the target dynamic and scalable SEG. In order to achieve such target, it is essential to provide modelling and simulation environment to understand existing grid structures and support the design and evaluation of the target SEG. There is no current modelling and simulation technology that can support the dynamic micro grids with distributed generation structures as mapped to GIS, which created bottleneck to move forward in the design and implementation of true SEG. In addition, there is no technology to support the evaluation of different grid applications in different scales within the grid, such as hybrid electric vehicle (HEV). Moreover, most of the design and operation decisions should be based on safety and reliability of grid physical structures. However, current modelling and simulation technologies does not support asset integrity models as linked with power/energy modelling, which created limitations to evaluate different design and operational scenarios in terms of safety, reliability, and availability. In addition, most of current modelling tools do not provide data analysis features that are needed to tune SEG physical structure models with dynamic simulation capabilities. This will lead to limitations on performing accurate optimisation of grid performance.

This review paper is presenting a design and planning of resilient SEGs via automated and intelligent monitoring, planning, and distributed modelling and simulation to support the design and operation of SEG. The solution will support real-time modelling and simulation of the superstructure of SEG in two levels top-level grid model, and low-level component level. Distributed data management module will be developed to construct and tune the following SEG models: grid superstructure physical and asset models, power/energy models; grid asset integrity and reliability models; safety and protection models; and operation and control models.

The proposed technology will support the following business functions: multi-sensor intelligent metering design support, distributed control and operation support, dynamic peak analysis and optimisation, distributed energy generation planning and optimisation, asset degradation and upgrade scenario synthesis and verification, and design and implement security components in the component levels.

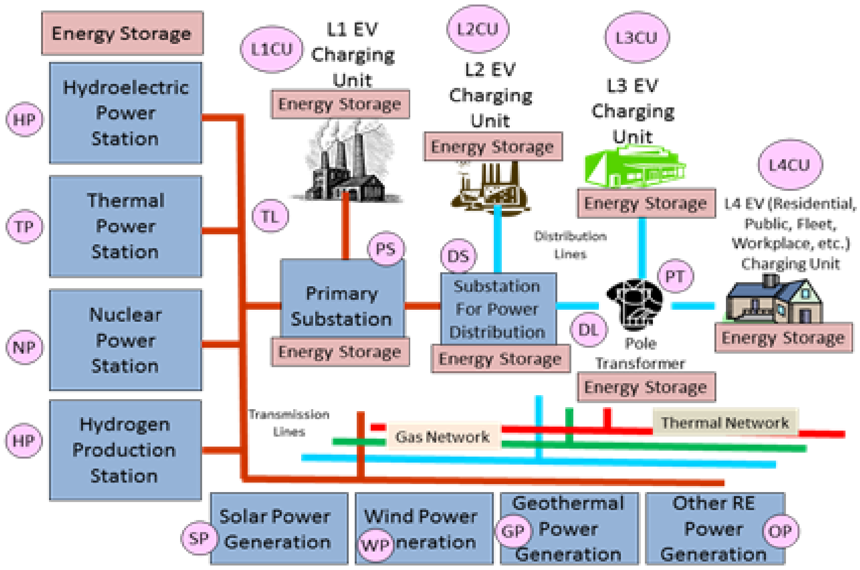
Figure 1 Energy semantic network (ESN) with interconnected MEGs (see online version for colours)



Technological features will be proposed to automatic and dynamic identification of practical distribution and partitioning strategies of micro-grids with the ability to define operational and alternative scenarios based on performance indicators and protection strategies. The target application will be web-based interface with simulation engine and distributed collaborative supply chain simulation models to allow local and global optimisation for different SEG performance indicator parameters for design and operation scenarios. User interface will be accessible via cell phones to enable mobile access from remote locations to identify optimum ways to support energy supply and use within SEG. Deterministic and predictive SEG models will be developed and associated with static and dynamic parameters of physical SEG superstructure and represented as energy semantic networks (ESNs), which will be used to synthesise practical and optimum scenarios for micro grid generation, protection, and application integration. The proposed modelling and simulation will be mapped to GIS for geographical and environmental data analysis, and to monitor and analyse real-time risk index calculation with different energy supply chain scenarios.

ESN is proposed dynamic and adaptive superstructure to model and simulate energy supply and production chains. ESN provides means to integrate generation (G), storage (S), and loads (L). ESN is used also to integrate electricity (E), gas (G), and thermal (T) grids. ESN is also used to interconnect MEGs, with transfer lines (T). Figure 1 shows the proposed ESN to model transmission lines (TL)/distribution lines (DL) of electricity networks (EN), gas networks (GN), thermal networks (TN), water networks (WN), and transportation networks (RN). ESN includes the integration of TL/DL with MEGs via electricity feeder lines (EF), gas feeder lines (GF), thermal feeder lines (TF), water feeder lines (WF), and transportation feeder lines (RF). ESN includes nodes of energy generation: electricity generation (EG), gas generation (GG), and thermal generation (TG); energy storage: electricity storage (ES), gas storage (GS), and thermal storage (TS); and energy loads: electricity loads (EL), gas loads (GL), and thermal loads (TL). The interconnection between MEGs includes: electricity transfer lines (ET), thermal transfer lines (TT), gas transfer lines (GT), water transfer lines (WT), and transportation transfer lines (RT). ESN static structures are synthesised and dynamically tuned with computational intelligence techniques using real-time data and simulation.

Figure 2 Energy supply chain infrastructures (see online version for colours)



Energy infrastructures includes energy generation, and multi-generation, transmission and distribution infrastructures, and integration with utilisation networks from transportation, buildings, industries, commercial buildings, and infrastructures, which is shown in Figure 2.

The performance of the target SEG is evaluated in different levels: overall micro grid, energy generation, energy storage, power lines, power compensators, regulators, FACTS devices, controllers, sensors, and loads. Initial study has been performed to investigate key performance indicators to evaluate micro grids. The ultimate goal of analysing SEG performance indicators is to identify best set of micro grid parameters to meet the multi-objective optimisation criteria of performance, cost, quality, safety, and environment performance indicators.