Review paper: smart energy grids

Hossam A. Gabbar

Email: Hossam.gabbar@uoit.ca

Smart energy grids enable efficient bidirectional energy supply while reducing cost and GHG emissions. The target smart energy grid will feature distributed energy generation and smart components, which will allow scalable architecture as integrated with interconnected micro grids. In order to facilitate the design and implementation of such dynamic superstructures with local and global performance optimisation, it is important to provide intelligent modelling and simulation environment with distributed decision making capabilities to manage data gathering and analysis functions and map to static and dynamic models of smart energy grid components. This will support the design, control, and operation of smart energy grid in distributed manner, along with the integrated applications. As smart energy grid is a multi-player domain, this requires collaborative decision making and control with distributed knowledgebase to support different views (e.g., utilities, OEM-HEV, and consumers). This will support the automatic and dynamic identification and evaluation of control and protection boundaries and operational scenarios of micro grids with renewable distributed energy generation nodes. In addition, it supports the design and operation of smart energy grid technological architectures as integrated within practical business models related to practical implementation of different components within the smart energy grid architecture. The proposed intelligent and distributed modelling and simulation environment will provide functionalities to support these views. The proposed solution will enable the University of World Institute of Technology to be the leader in smart energy grid with proven low carbon and improved efficiency and reliability of the target smart energy grid infrastructure.

Recently, the world is witnessing demand increase in electricity and energy. It was clear that energy use has direct negative impact on climate changes, which provoked governments and industries to invest more in renewable energy technologies as alternative energy sources and power supply systems. There are increasing tendencies to utilise renewable green energy sources (solar, PV, wave, tidal, fuel cell, biogas, and hydrogen), which are supported by economic and environmental factors. The increasing reliance on fossil fuels with increasing rate of resource depletion is causing a basic shift to green renewable energy alternatives, clean fuel replacement and energy displacement of conventional fossil energy sources to new green renewable, environmentally safe and friendly counterparts. Photovoltaic and distributed energy resources (DERs) generation schemes are considered the most viable and economic choices for micro grid electrical energy generation. The focus is on small isolated standalone integrated AC-DC grid power system that utilises a combination of photo voltaic, fuel cell and a diesel generator with a local grid backup with capacity usually ranging in sizes from 15 KW to 1,500 KW. Typical applications include electricity supply to remote isolated islands/villages with limited utility grid, heating, water pumping, and ventilation and air conditioning systems. Diesel generators are the backup source of electricity in most remote cases.

Copyright © 2014 Inderscience Enterprises Ltd.

As part of the future implementation of smart energy grid, it is important to demonstrate regional smart energy grids and micro energy grids with renewable energy as distributed generation. This decision involves capital cost for changing infrastructure to support the target dynamic and scalable smart energy grid. 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 smart energy grid. 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 smart energy grid. 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 smart energy grid physical structure models with dynamic simulation capabilities. This will lead to limitations on performing accurate optimisation of grid performance.

A design and planning of resilient smart energy grids is required via automated and intelligent monitoring, planning, and distributed modelling and simulation to support the design and operation of smart energy grid. The solution will support real-time modelling and simulation of the superstructure of smart energy grid 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 smart energy grid 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.

Technological features will be proposed for 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 smart energy grid 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 smart energy grid. Deterministic and predictive smart energy grid models will be developed and associated with static and dynamic parameters of physical smart energy grid 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.

In order to achieve smart energy grids, it is important to define possible generation/supply scenarios based on available technologies and resources, and in view of demand profiles in a given geographical area. ESN is proposed to model all potential energy supply scenarios and to map them to all available energy demand of thermal, gas, and electricity. ESN structures can be modelled, evaluated, and tuned with computational intelligence techniques based on engineering design, simulation, real-time data, and human experience.

Within ESN, oil and natural gas are used to produce the type of oil that is used in power plants and generators in individual production plants to produce electricity. Coal is also used by power plants or directly by end-user such as home, building, facility, etc. On the other hand, biomass is used after suitable conversion, to produce ethanol, methanol, or biodiesel, which are used in generators or power plants. Hydrogen can be synthesised from biomass or directly from air, and can be used to produce energy using fuel cells. Fuel cells are another clean source of electricity that can be used by vehicles, homes, and facilities in small scale. Thermal energy is another type of clean energy where special materials are used to store energy in thermal form that can be converted into energy at a later stage. Most of the current energy supplies are based on direct energy supply from different sources or by combining the soft-energy sources into the grid for mass supply. In this research, another alternative is proposed where intelligent energy supply unit, called HENSU or hybrid energy supply unit, is used to select, manage, and optimise energy supply via combined energy technologies.

Using the proposed ESN, the different energy production and supply chain scenarios of the selected case studies can be evaluated.