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HATCH MICROGRID CONTROLLER FOR INTEGRATION OF VERY SMALL MODULAR REACTORS WITH OFF-GRID POWER SYSTEMS

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Abstract

Several nuclear companies are developing very small nuclear reactors to provide heat and power to remote off-grid mines in Canada. Off-grid mine power systems experience large and sudden load fluctuations and it is unlikely that small nuclear power plants alone will be able to meet the load following and frequency control requirements in such systems. The integration of small modular reactors (SMRs) within a mine power system needs to be treated as a whole grid system development with provisions to respond to load fluctuations and for spinning reserves.

While SMR integration with a mine power system is expected to be challenging, many lessons learned from renewable power system integration with stand-alone power system including rapidly varying load-generation balance can be adapted. Hatch has successfully integrated wind power with a remote mine power system in northern Canada. The Hatch microgrid system components and functions described in this article are readily adaptable for a SMR integration application with a stand-alone mining power system. In addition to the technical descriptions, the operational experiences from integrating renewable technologies with mine power system are discussed.

1. Introduction

Several nuclear technology vendors have been developing very small modular reactors (VSMRs or micro-SMRs) in recent years to provide power and heat to remote mines. In the SMR design considerations paper published in 2014 [1], Hatch discussed the operating conditions and design requirements of micro SMRs in a stand-alone mining power system. Hatch then emphasized that micro-SMR vendors must approach the technology development as a part of the power system design project, with adequate considerations given to the mining micro-grid characteristics and behaviors. The paper identified the technical challenges in controlling the grid stability in a mining power system due to abrupt load swings associated with large and reactive loads. It concluded that the load following capacity provided by a typical small nuclear power plant alone is not adequate to maintain the stability of a stand-alone mining power system, and the supplies and loads in the system must be actively managed.

Furthermore, the paper also drew a parallel between wind and nuclear applications in a stand-alone power system and described the power quality control options used in wind power integration with isolated grids. The paper showed that complex control systems are required to integrate wind power with a mining power system because of the generation intermittency. If the wind power is integrated with a residential or commercial grid with slowly changing loads, the technical difficulty mostly originates from the supply side (i.e., wind power generation is uncontrolled). In case of wind power integration with a remote mining power system, the technical difficulties come from both supply and load sides. In addition to the generation intermittency, the load may fluctuate abruptly and destabilize the network if sufficient spinning reserve is not maintained. In case of SMR integration with a mining power system, the supply side is expected to be stable while the load may change rapidly. Thus, the technical issues associated with an SMR integration with a mining power system is similar to the issues associated with wind power integration in a mining power system.

As remote mines have adapted renewable power technology to offset diesel power generation in recent years, Hatch has been developing renewable power integration strategies including developing a proprietary smart grid controller technology (HμGrid). This article presents an overview of challenges of variability of generation and load power balance and the role of the microgrid control system in energy management and power system control. It also includes a brief description of the application of HμGrid in integrating wind power and multiple energy storage systems at the Glencore Raglan mine electrical power system in northern Quebec near the Canadian arctic. The methodology and technologies are expected to be readily adaptable for integration of small nuclear power plants with mining power systems.

2. Load-Generation power balance in off-grid mining system

Diesel gensets are typically utilized in off-grid mines to provide readily dispatchable assets that can follow load variations. Figure 1 shows a plot of the load fluctuation at a remote mine.

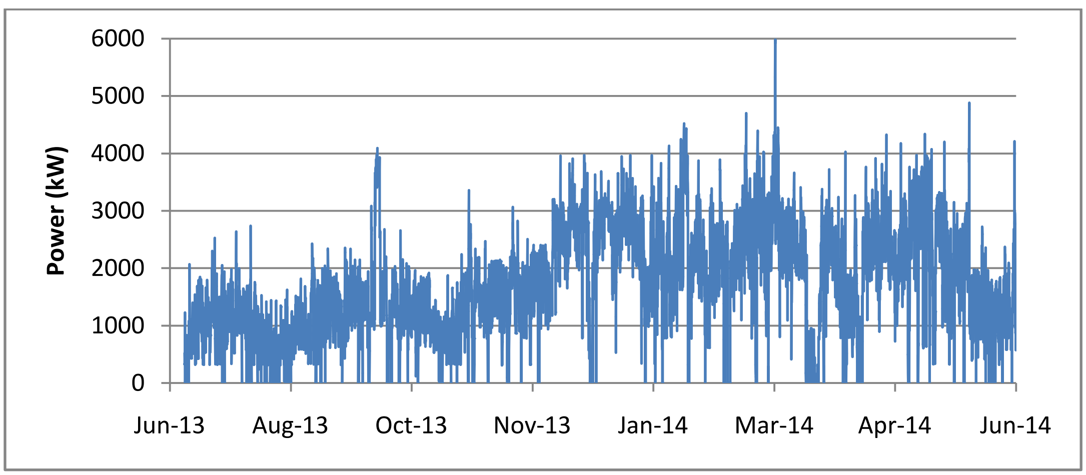

Figure 1 Remote mine load fluctuation

Adding a renewable power source such as wind or solar PV, introduces a new technical challenge. Unlike conventional diesel power generation, wind or solar PV power is not dispatchable. The amount of power that can be delivered by wind turbine/ or PV panel fluctuates in relationship to wind speed or irradiance variations.

Figure 2 shows measured time-series data of a 3-MW wind turbine power. The blue curve shows the actual turbine output, while the red curve shows the "potential" wind power as calculated based on wind speed and turbine characteristic. In some cases the wind turbine output is curtailed below the potential output based on site operational requirements.

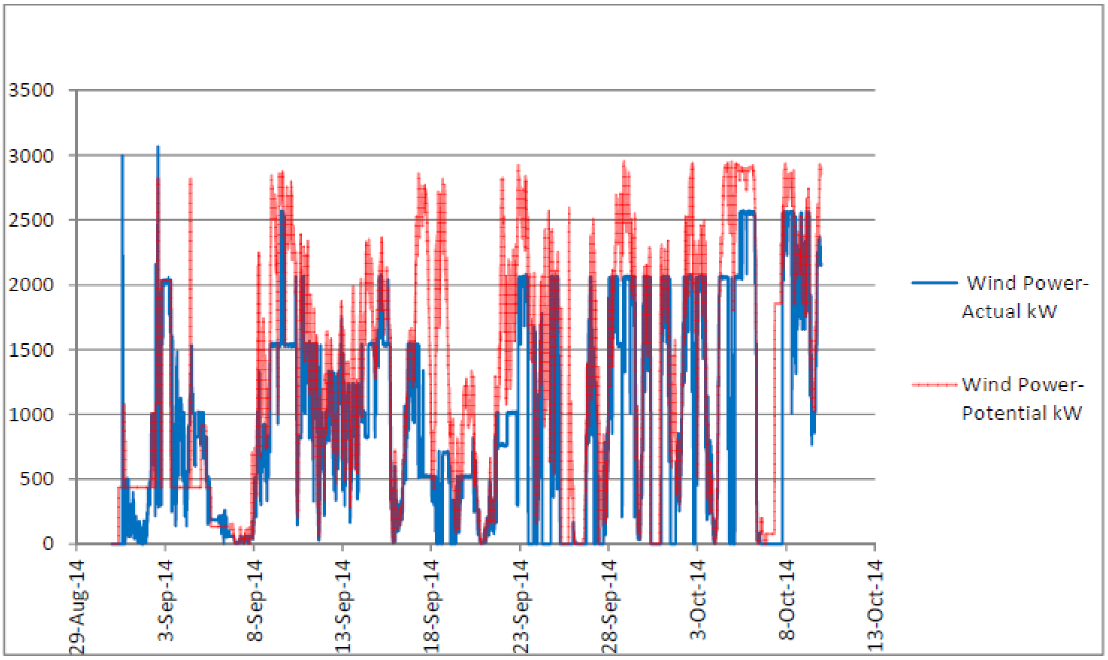

Figure 2 Wind turbine power (kW) fluctuations – actual versus potential

Fast variations of renewable source or load power can cause variations of the power system frequency. Extreme frequency fluctuations are not desired and may require partial load shedding to prevent black-outs. This relationship between power system frequency and generation-load power balance is explained below.

For a diesel power plant, generated power is adjusted continually via fuel valve throttling. However, the mechanical action of fuel valves is relatively slow. Therefore, fast changes in renewable source or load power cause a momentary difference between the mine power demand and the diesel power before the fuel valves can fully adapt to the new demand. Momentary power differences are handled by variations in the kinetic energy stored in the diesel genset rotating mass before they can be met by more fuel flow. The change in the kinetic energy corresponds to a variation in rotational speed that is equivalent to changes in the electrical frequency. The relationship between this power difference and the electrical frequency is expressed by Equation 1.

$$\Delta P = \frac{2H}{f_n}\frac{df}{dt} \tag{1}$$

where f is the electrical frequency, H is a constant related to the mechanical inertia of the genset rotating mass, fn is the nominal system frequency and ΔP is the power difference as per unit of the size of the operating power plant.

The effect of renewable power fluctuations on frequency variations is more pronounced as fewer diesel gensets are on line as there will be less mechanical inertia. This will be the case as more renewable power is added.

Beside the issue with dispatchability, the operation of a renewable-diesel hybrid system has to consider several operational constraints. Renewable power acts as a negative load on the grid, thus reducing the diesel genset loading. However, each genset must operate within a prescribed range of minimum and maximum genset loading. In addition, enough spinning reserve should be maintained to compensate for major grid events (for example sudden loss of renewable source).

3. Hatch Microgrid Controller for hybrid power

The Hatch Micro-Grid Controller (HµGrid[1]) system handles the energy management and power flow control of the integrated renewable-diesel power system using a distributed control system architecture. The overview of the HµGrid architecture comprising a high speed network, a SCADA network, and distributed controllers to preserve power system stability in contingencies is shown in Figure 3.

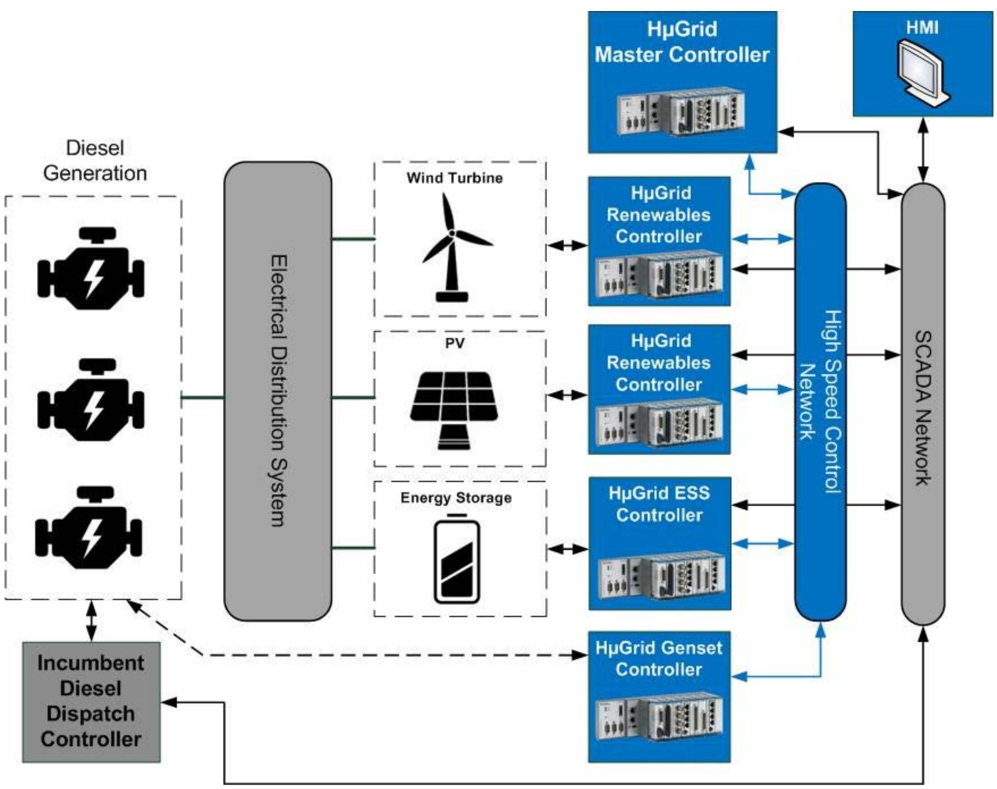

Figure 3 HµGrid architecture

[1] Hatch microgrid control system development was in part funded by NRCAN under the following project: http://www.nrcan.gc.ca/energy/funding/current-funding-programs/eii/16095

The salient features of HμGrid are as follows:

- High-speed and coordinated control of energy storage systems to provide voltage and frequency support and assist in preserving the power system reliability and stability. In particular HμGrid is designed for:
    - direct interface to various energy storage/generation equipment controllers including direct connection to grid-tie inverter controls
    - dedicated low latency communication network
- Utilize the energy storage to make use of excess wind capacity and to increase the wind power contribution
- Control the operating mode and the state of charge of the energy storage systems based on the overall operational strategy
- Provide wind curtailment command when required
- Present an HMI for the system operator for fleet operation and monitoring
- Utilization of p renewable power generation and load forecasts for operator use in decision making
- Robust hardware rated for operating temperatures as low as -40 deg C.

By high speed control of energy resources and the energy storage system, the HμGrid is able to effectively shape the loading of the diesel gensets. As a result, the effects of the renewable source or load variation on power system voltage and frequency are reduced, and power system disturbances are controlled within the ramp rate capability of generation equipment. Such stabilizing effect results in an increase in renewable source contribution by smoothing sudden and fast changes in renewable power output as depicted in Figure 4.

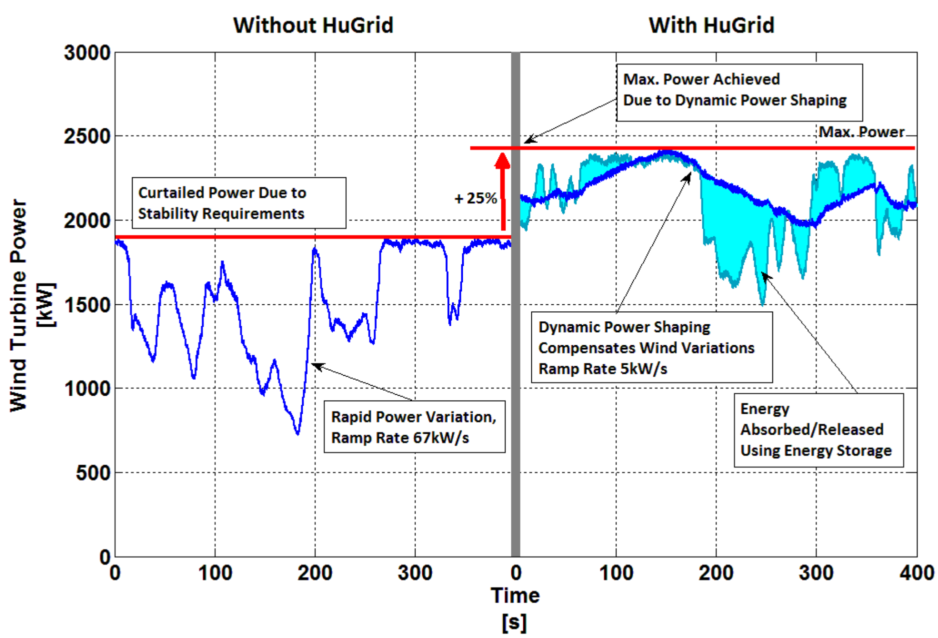

Figure 4 Effect of fluctuation smoothing on wind power penetration level increase

The HµGrid can also operate in the grid connected mode in which the controller controls the ramp rate of the tie-line power to values set by the applicable grid codes. In addition, the controller can control the tie-line power to allow scheduled system islanding, economic handling of time-of-use tariffs, and/or tie-line power limit requirements.

HµGrid is designed with an optimization engine to provide real-time dispatch commands to microgrid elements based on forecasts on renewable power and load, operating costs of assets and constraints of equipment to attain the optimum operating point (Figure 5).

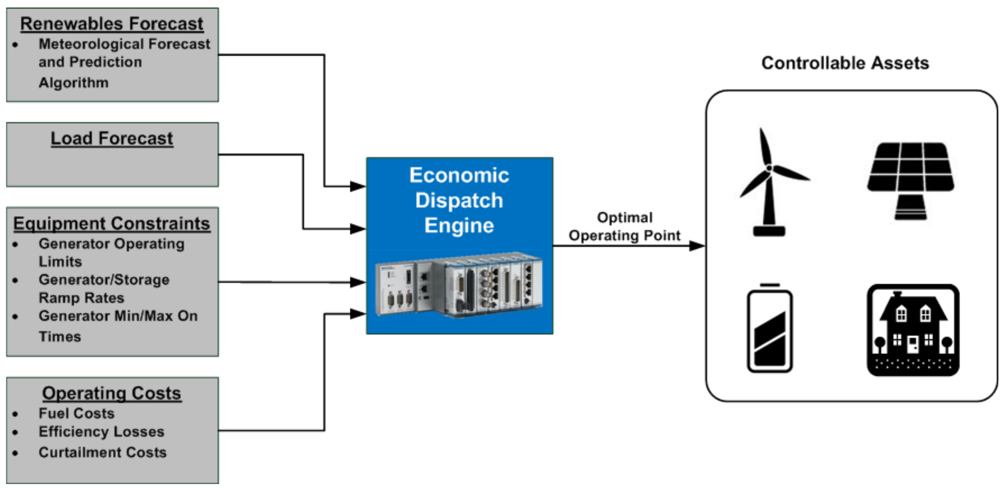

Figure 5 HuGrid real-time power dispatch engine

4. Hybrid power at Glencore Raglan mine

Glencore Raglan mine is a remote copper and nickel mine located in northern Quebec, which spans over 80 kilometers. The site is only accessible by air or seaway, and the electricity and

heat are generated at site primarily through the use of diesel gensets. Glencore has decided on a phased approach in renewable power introduction and has initiated a pilot project to incorporate a single 3-MW Enercon wind turbine at Raglan. Hatch has engineered the system for the mine in collaboration with Tugliq Energy which owns and operates the Turbine.

The renewable integration project at Raglan also includes three different energy storage technologies: a high speed flywheel, a lithium-ion battery and a hydrogen storage loop complete with an electrolyzer and a fuel cell. The power flow from the wind turbine and energy storage units are managed by the Hatch microgrid control system, HµGrid. Figure 6 shows a high level overview of the pilot project and various project stakeholders.

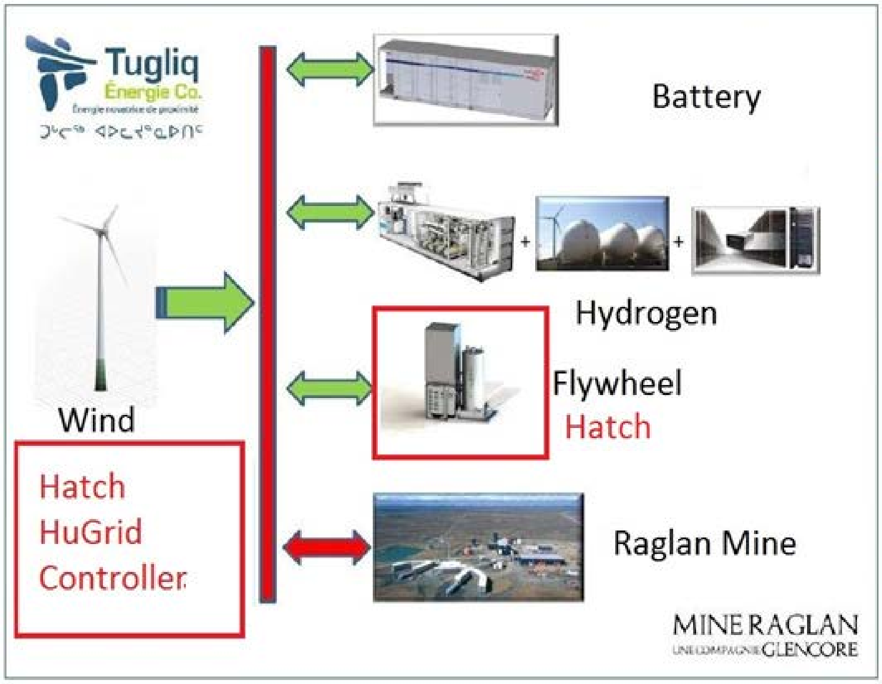

Figure 6 Overview of Raglan Hybrid Power Pilot Project **[2]**

4.1 Energy sources

4.1.1 Diesel generators

The mine is currently powered by a number of gensets in the main mine and with the satellite mines supplied locally with additional gensets or via medium voltage transmission line from the main site.

4.1.2 Wind turbine

An Enercon E82 wind turbine [3] with rate output power of 3,000 kW is installed. The turbine has a fully electronic power interface and is equipped with features such as blade de-icing and extreme low temperature operation down to -40 degrees C.

4.1.3 Hydrogen Energy Storage System

The Hydrogen Energy Storage System (HESS) consists of:

- a containerized electrolyzer system including a rectifier that converts the available ac power into dc and uses dc current to extract hydrogen from water,
- a set of hydrogen storage tanks,
- a containerized fuel cell system that can use the stored Hydrogen to produce dc electricity and converts it into ac power using a grid-tie inverter.

The amount of energy stored is scalable as it is dependent on the size and the number of storage tanks. The HESS is controlled to use the excess wind energy to produce hydrogen. The stored hydrogen is then utilized to provide electricity when the wind contribution drops. In addition to producing electricity, hydrogen may have a secondary use as the fuel for vehicles.

4.1.4 Flywheel Energy Storage System

The Flywheel Energy Storage System (FESS) is factory integrated by Hatch and consists of a skid-mounted high-speed dc flywheel system and a grid-tie inverter. Figure 3 shows a picture of the flywheel system as housed in a prefabricated e-house. The flywheel system has a rotor made of composite material turning at a high speed (36,000 rpm maximum). When required, the electrical energy can be used to speed up the rotor. The kinetic energy stored in flywheel rotor then can be supplied back to the electricity system as needed.

One of the advantages of high-speed composite flywheel system employed in this case is that it does not require significant site preparation such as concrete bunkers for safety containment.

Figure 7: Flywheel Energy Storage System

4.1.5 Battery Energy Storage System

The Battery Energy Storage System (BESS) is composed of a containerized lithium-ion battery system along with an integrated grid-tie inverter. The electrical energy can be used to charge the battery. The chemical energy stored in battery then can be supplied back to the electricity system as needed.

The three different types of energy storage systems employed have complementary characteristics. HESS and BESS are both suitable for storing excess wind power, although the HESS has a markedly larger energy capacity. On the other hand, the FESS and BESS have a very fast speed of response that make them suitable for handling the wind power variations due to changes in wind speed. In addition, the FESS is suitable for operation at a very large number of full charge-discharge cycles without loss of life.

4.2 Operational results

Figure 8 shows the initial results of the measured performance of the system with both the flywheel and battery systems. The blue curve shows the wind turbine power. The red curve shows the power output from the combined flywheel and battery energy storage systems and power turbine. The combined power ramp rate is effectively controlled to a setpoint of 11 kW/sec (or 0.35% of installed capacity).

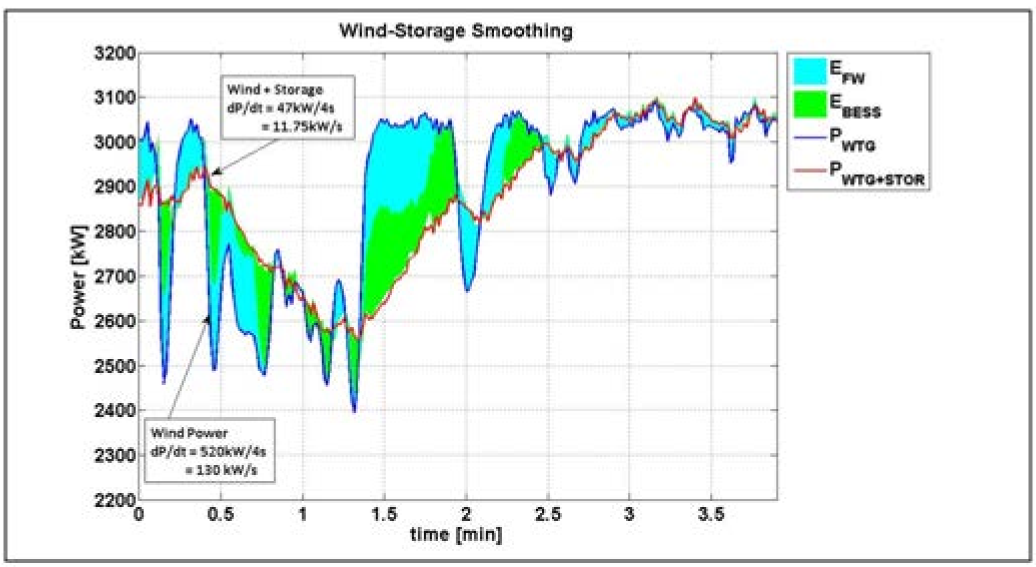

Figure 8 Wind power smoothing

5. Application to nuclear microgrids

This paper examined a hybrid wind-diesel power system configuration that can effectively match supplies and loads in an isolated mine power system. Even when an intermittent power source and rapidly fluctuating loads exist in the system, the hybrid power system using the Hatch microgrid controller, combined with fast acting energy storage systems is able to balance the supply and loads in the system and achieve stable grid operation.

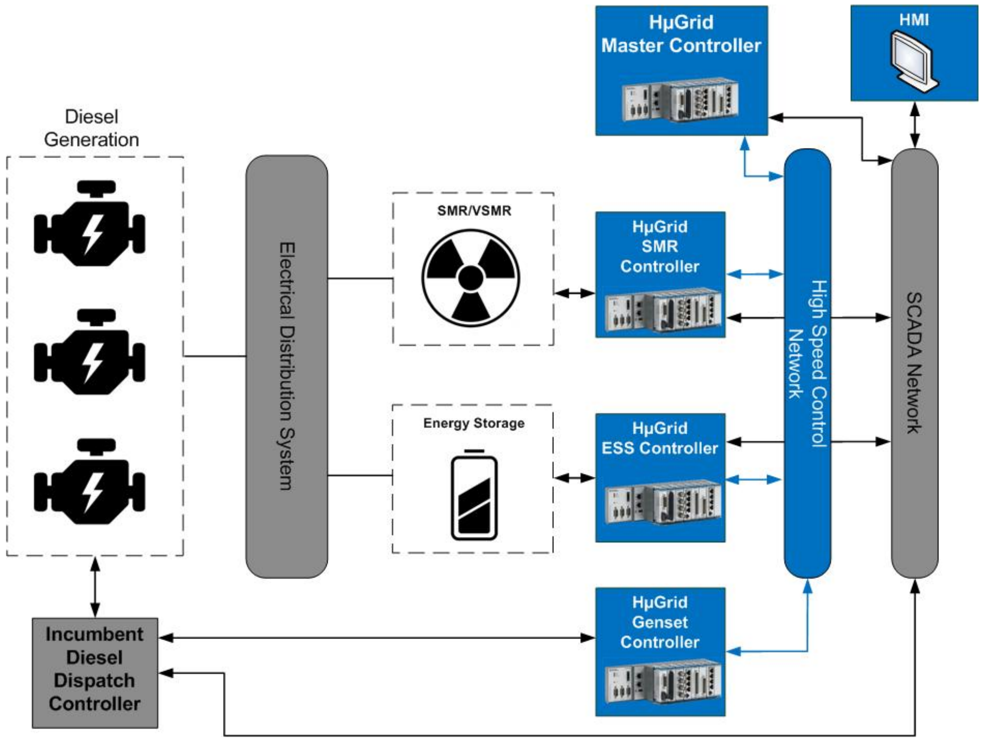

Figure 9: HμGrid for nuclear microgrids

It is anticipated that the same system can be readily adapted for integrating small nuclear power plants with mining power system, as depicted in generic form in Figure 9. The benefit of HμGrid use in integrating an SMR with a stand-alone power system is that it allows the SMR to operate in base load configuration, without any reactor technology based provision for load following capability. Load variations are handled by readily dispatchable sources, and potentially through supplementary energy storage systems. This will result in simplification of an SMR design requirements and potential reduction in reactor capital cost.

6. References

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[3] Enercon. (2016, February) Enercon Products. [Online]. http://www.enercon.de/en/products/ep-2/e-82/

[4] Mohammad Sedighy, HuGrid Control System for Hybrid Wind-Diesel and PV-Diesel Power Systems, 2016.