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ScienceDirect

Energy Procedia 159 (2019) 466–471

Energy Procedia

www.elsevier.com/locate/procedia

Applied Energy Symposium and Forum, Renewable Energy Integration with Mini/Microgrids, REM 2018, 29–30 September 2018, Rhodes, Greece

# Smart Grid in Isolated Power Systems – Practical Operational Experiences

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**Abstract**

Moving away from a centralized diesel generation plant, future isolated power systems will increasingly depend on renewable generation which can be distributed across larger areas, due to lower energy density of renewable resources. In future distributed generation systems, a key enabling technology for operating high renewable energy penetration system will be a high-speed communications infrastructure. This new infrastructure can then be used for real-time power system monitoring and control of customers loads, as well as for control of the distributed generation. Our paper presents the concept of a high-speed wireless network capable of real-time monitoring and control of both loads and distributed generation across an isolated power system. The paper also presented real-world measurements taken during a multi-year operation of an isolated power system, and specifically, presented how utilizing communications networks can prove beneficial to increasing renewable penetration in the system whilst preserving power system stability.



*Keywords:* Demand Response, Isolated Power Systems, Microgrids, Smart Grids

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Selection and peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, Renewable Energy Integration with Mini/Microgrids, REM 2018.
10.1016/j.egypro.2018.12.039

## 1. Introduction

Electricity consumers living in remote areas or on islands often cannot be supplied from conventional interconnected power systems. These consumers are usually serviced by a local electricity generation and distribution system which we will refer to as an 'isolated power system' (IPS). Electricity in IPSs is traditionally generated using diesel fuel. Due to remoteness and consequent high cost of diesel fuel supply, the cost of electric energy in IPSs is high compared to conventional interconnected systems. In remote locations the cost of generating electrical energy can be up to US $0.5/kWh which is an obvious incentive for introducing renewable energy (RE) generation. Unfortunately, RE from the two most abundant energy sources – wind and solar – incurs significant stability and reliability issues due to the intermittency of those sources. This issue has been widely discussed in the research and industry literature [1]. Many existing conventional and isolated power systems have already integrated RE. Because a small investment can have a relatively large impact, the RE contribution in some IPSs has reached high levels (i.e. greater than 30%). Consequently, IPSs are at the forefront of high RE power systems research. One of key lessons this research has provided is that RE sources need complementary or enabling technologies to deal with the intermittency of RE generation. Examples of enabling technologies include: resistive dump loads, new types of conventional generators (e.g. bio diesel, low load diesel generators (DGs)), energy storage (e.g. battery, hydrogen, flywheels), and communications networks enabling control of loads and generation (e.g. smart grid services).

There are many technologies in IPSs which are capable of supporting high RE penetration. Resistive dump loads help ISPs to integrate higher amount of RE by consuming the RE surplus [1], which could potentially threaten power system stability. Low-load diesel engines could operate at as low as 10%, and therefore, sustain higher amount of RE in a system at any time. Most researchers see energy storage as the appropriate enabling technology for high renewable penetration in power systems [2-4]. But complex battery technologies are costly and exercise high variability of performance under different circumstances which increases operational and maintenance costs; therefore, most IPS planners will investigate other technologies before considering energy storage.

In this paper, we will argue that IPS with existing communications infrastructure can utilize this technology not only for monitoring and generation control, but fast load control as well. We use the term Smart Grid (SG) when communications infrastructure is used in unison with controllable field devices on one end and computer systems running demand and generation control algorithms on the other. By demand control we imply automated, real-time control of residential, commercial and industrial loads.

SG technologies, and more specifically demand control, has been introduced in the literature, and many authors proposed using this enabling technology in traditional and isolated power systems [5-7]. Some authors even proposed using smart grid technologies for supporting frequency control [8, 9], and a concept of virtual power plant is widely used [10]. Authors have explored how demand can be dispatched in power systems, proposed algorithms for controlling it and even gave some pilot study examples.

The contribution of our paper is in a concept and practical application of a real-time (sub-second) control of distributed loads; in concept of considering aggregated demand as a dispatchable generator in an IPS; in example of using this technology for increasing RE penetration and in presenting real-world measurements from a successful multi-year operation of such system.

## 2. Smart Grid in Isolated Power Systems

In IPS, SG usually consists of communications network backbone, field devices and a centralized computer controller, and differs significantly from other RE enabling technologies. While all other technologies support high RE penetration by generating electric energy at key moments, SG can control the load itself. Also, other enabling technologies usually come with inefficiencies such as inverter-battery losses, friction losses in flywheels, or inefficient fuel usage. The efficiency of SG is close to 1 because the losses are contained in small control devices. There are three major differences between loads and generators for the purposes of meeting short term demand increases: demand loads are not owned by an electricity supplier; individual loads provide statistical, not deterministic resource; and, they are better suited to fast, short, infrequent events [11].

### 2.1. Communications Infrastructure in IPS

IPSs are usually automatically controlled power stations with one central power station controller (PSC). The PSC is typically implemented with a programmable logic controller or a station computer. The role of the PSC is to schedule available generation in accordance with the current power system constraints and to maintain system stability. In addition, a PSC may be programmed to maximize the amount of RE generation and, consequently, minimize running costs. The PSC effectively controls the entire IPS by collecting data on the current system status and by issuing commands to various generation sources.

When the PSC has a goal of maximizing RE, it will dispatch as much renewable generation as the power system can handle while simultaneously maintaining an appropriate level of spinning reserve to ensure system stability. If the amount of RE drops, and the system suddenly does not have enough spinning reserve, the PSC will start a diesel generator. The role of SG controlling demand loads is now clear – it has to support high RE penetration by providing additional spinning reserve during sudden drops of RE. If sufficient spinning reserve is provided by the SG, diesel generator startup is prevented.

One way of aggregating demand response and dispatching it as a generation is presented in [12]. Simplified architecture of such system is presented in Fig. 1. Slave controllers at customers' premises report their status to the SG Master Controller (SGMC) using a communications infrastructure. SGMC aggregates all loads according to their dispatch constraints and constantly reports availability of demand to PSC. At any time, PSC can issue a command for dispatch of a required amount of demand. SGMC decides which loads to dispatch and sends the command over the communications network to slave controllers.

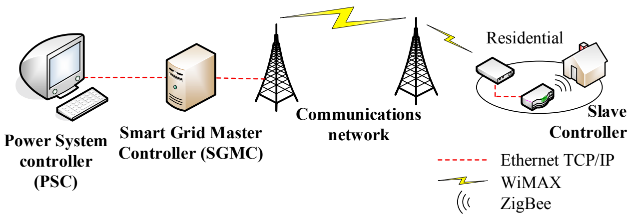


Fig. 1. Fast Demand Response Architecture [12]

The idea of aggregating and controlling small loads to create a large block of variable demand has been discussed in the power engineering literature where it is often referred to as a 'virtual power plant' [10]. While recent research describes demand control as in-advance schedulable load [13], or suggests price driven signals [14], Fast SG demand control is based only on the current availability of demand - an important concept noted by some authors[15, 16]. As such, it can participate in adding to second-by-second power system reserve.

### 2.2. Fast SG demand response as a Load-Following Spinning Reserve

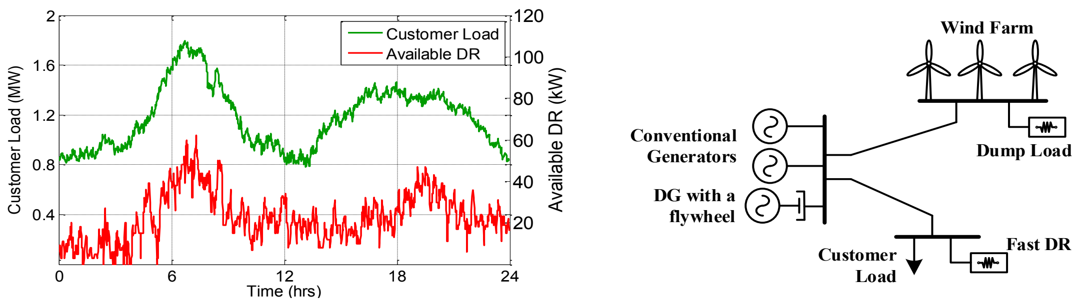


Fig. 2. (Left) The amount of available demand response follows power system load curve. Data presented in this graph is from the case study system, described in Section 3. Total demand is presented on the left, primary vertical axis. Available DR is presented on the right, secondary vertical axis. (Right) Simplified schematic of King Island power system. Aggregated Fast DR is presented here as Fast DR - dump load located at customers' premises.

SG demand control consists of a number of loads capable of a quick adjustment of their power demand. Demand response capacity is a portion of power system load and, as such, follows a similar shape (Fig. 2 left).

Spinning reserve is usually created in power systems by additional generation to ensure system stability by covering for the sudden loss of a generator or drop in RE output. The smaller the load is in a given system, the less conventional generation is needed to provide spinning reserve. On one hand, Fast DR could be perceived to decrease the total system load, and as effect, decrease the amount of conventional generation needed to provide spinning reserve. Or, it could be regarded as a 'virtual power plant' which is capable of covering a certain amount of load when conventional generators are reaching their limits. Either way, Fast DR contributes to increasing power system reserve.

## 3. Case study system

King Island (KI) is an island with a population of 1700 situated between the Australian mainland and Tasmania. The economy is dominated by farming and fishing with some associated food processing. The climate is quite consistently cool, windy and rainy. KI has a sophisticated electricity grid (Fig. 2. Right) with a peak load of 2.5 MW (average 1.5 MW), about 6 MW of installed diesel capacity, 2 MW/3MWh battery, frequency controlling resistive load bank and two 1MW Diesel-UPS machines.

King Island Smart Grid is an aggregator of a number of households' hot water boilers across this 30 by 80 km island and is facilitated by purpose-built island wide WiMax wireless network. Total installed capacity of Smart Grid aggregated loads is about 200 kW. KI Smart Grid theory and principles of operation was presented in detail in [12]. KI Smart Grid has the goal of supporting higher levels of wind energy integration on KI by providing:

- Spinning reserve by implementing the Fast SG demand control, and
- Immediate fine-grained under frequency load shedding (based on the local unit model).

Major equipment components are presented in Fig Various major components of the KI DRG architecture outlined in Fig. 3.

Fig. 3. (Left) King Island DRG Master Controller is installed on a server computer located in the power station control room and directly connected to power station controller. (Centre) Standard WiMAX network antennas were used for the communications backbone. Photo shows equipment installed on a standard 15m distribution pole. (Right) WiMAX modem is installed at the customer premises (box on the right-hand side), together with a slave controller which sends signals to smart switches inside switch box on the left.

## 4. Measurements

In this section we present measurements showing normal IPS operation. Demand measurements were recorded by Saturn South field devices, while total load and generation measurements were taken by Allen Bradley PowerMonitors 1000, at the power station 11kV switchgear circuit breaker cubicles. Most measurements were sampled at 1 second resolution.

KI Smart Grid is automatically scheduled and dispatched, often many times during a day. Fig. 4. below demonstrates high frequency of its operation, demonstrating multiple load dispatches during a single day. Testing results presented in Fig. 5. (left) demonstrate that the implemented Smart Grid was able to accurately respond to given setpoints. The figure also shows that Fast SG demand capacity is being dispatched reliably in 1 second. In fact, not only is the load being switched, but confirmation of the switching is being reported back to the PSC with sub-second response.

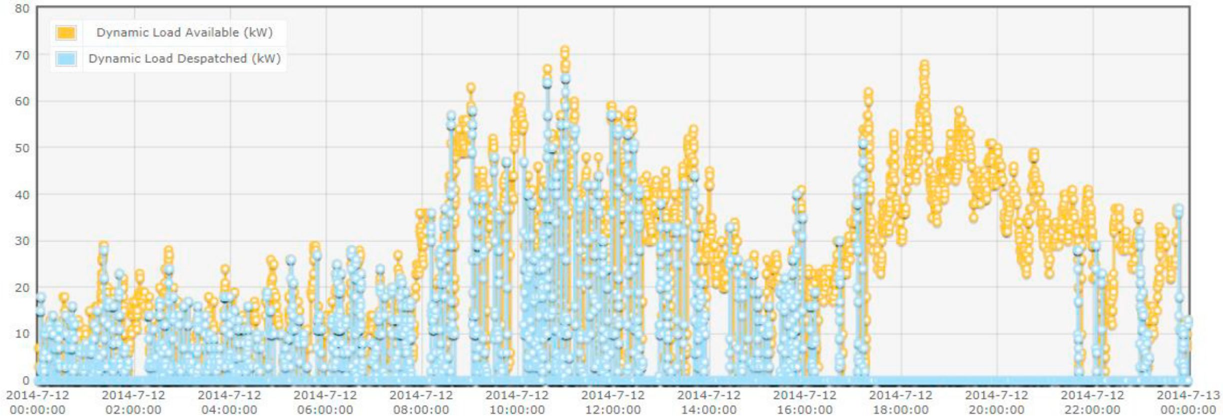


Fig. 4. Operation of the Smart Grid aggregate load during a 24-hour period. Dynamic load dispatched (blue line) shows a number of commands sent and executed by the island smart grid.

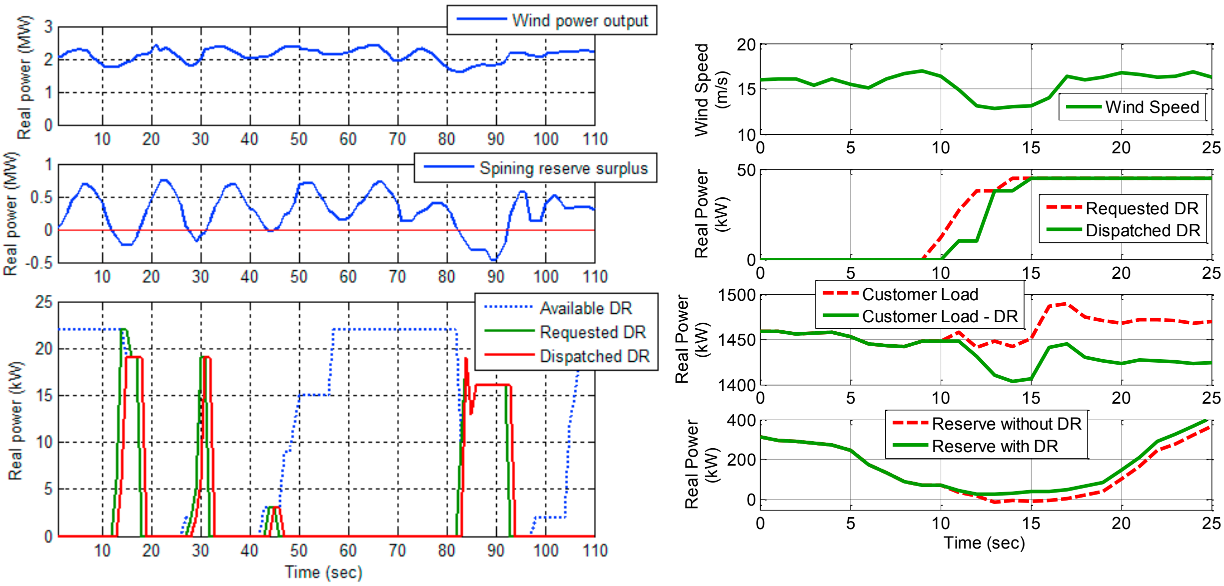


Fig. 5. (Left) Early King Island DRG operation results. (Right) Start-up prevention of conventional generation due to operation of Fast DR in KI power system.

The KI power system is also capable of sustained zero-diesel operation (ZDO) using DGs with a flywheel for instantaneous backup and voltage control, and frequency controlling resistor (Dump Load). During ZDO, the system controller monitors the amount of spinning reserve, or over-generation of wind turbines and estimates if a conventional diesel generator should be started or not. KI Smart Grid, which can respond within 1 second, is added to the total amount of spinning reserve in the KI power system and is dispatched if a sudden drop of wind generation is detected during ZDO. Such operation of Fast SG demand control was recorded during September 2014 (Fig. 5. (Right)) when by dispatching almost 50 kW of demand the amount of spinning reserve for the entire system was kept above the threshold. The System Controller decided no additional conventional generation was necessary. Effectively, start-up of a diesel generator was postponed, and zero-diesel operation extended.

## 5. Discussion

Modern IPSs started integrating renewable generation into their systems. Compared to fossil fuels, renewables are low-density, and are naturally distributed across larger areas. At the same time, renewables are variable and are requesting fast control and fast provision of spinning reserve, which could come from both online generations, or from aggregation of non-essential loads.

Communications infrastructure, and its Smart Grid platform is an enabling technology which will be needed in high RE penetration IPSs in the future for integration of generation and loads. Once the infrastructure is installed, it may be used as a medium for monitoring and control of the entire power system, far beyond the power station yard.

Smart Grids have obvious disadvantages in terms of complexity, utilization of new technologies and consequently, higher operation and maintenance costs. This is especially true for demand control with a high number of distributed users. However, we would pose several arguments in favor of smart grid technologies in IPSs:

- Future high RE penetration systems would depend on communications infrastructure for the control of distributed generation, hence such a network will exist in the future,
- Smart Grid technologies could be used on the back of the IPS-wide communications infrastructure,
- Control of both distributed generation and loads on a sub-second basis is possible using Smart Grid technologies,
- Fast SG demand control, can provide spinning reserve and consequently, increase RE penetration in IPSs.

## 6. Conclusion

Recent research in the field of high renewable penetration IPSs suggests using enabling technologies as means to integrate high levels of RE in power systems. Concepts and real measurement examples shown in this paper support the case of the Smart Grid and its ability to achieve sub-second demand control and by doing so, contribute to IPS spinning reserve, and increase RE penetration in IPS.

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