

Innovative Remote Micro-Grid Systems

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Abstract

Most small islands and remote communities around the world today are dependent on imported fossil fuels for most of their energy requirements. High fuel costs in recent time have translated into tremendous increases in the cost of energy generation in remote areas. Solar and wind power technologies are clean, affordable, readily available, and sustainable and can replace or supplement generators. Hybrid energy systems integrate these renewable energy technologies with diesel generators, inverters and batteries to provide grid quality power in remote areas not connected to a utility grid. Such an isolated grid is known as Remote Micro-Grid and is widely recognized as the remote area electrification technology for the 21st century. It is predicted that there will be a 21% increase in capacity for the remote micro-grid market by 2017, from 349 MW to 1.1 GW with a projected total revenue of more than \$10 billion. One solution to save fuel in a diesel generator is to enable the engine to operate at variable speeds in direct relation to the electrical load demand. The author has developed an innovative variable speed generator technology (patent pending) with high penetration of renewable energy. There are a number of applications where the power demand varies greatly that can benefit from the new technology which maintains constant voltage and frequency while adjusting the engine speed to power demand. This paper will present case studies on previous hybrid power system projects and the limitations of the existing technology. Case studies on applications in remote mining, holiday resort and remote mobile telecom base stations are described.

Keywords: *Solar Photovoltaic- Diesel Generator- Hybrid Systems- Micro-Grid- Remote Area Power Systems*

1. Introduction

Most small Island and remote communities around the world today are dependent on imported fossil fuels for most of their energy requirements. These communities are exposed to diesel fuel price volatility, frequent fuel spills and high operation and maintenance costs including fuel transportation and bulk storage. In addition to remote area power systems, commercial and residential customers in urban areas are also seeking new sources of back-up power located on their premises. Diesel generators are a major source of backup power due to ease of

transportation, installation and removal, as well as the mature and stable nature of the diesel industry with reliable suppliers. In the past decade, diesel prices have more than doubled. High fuel costs have translated into tremendous increases in the cost of energy generation. Diesel generators are also a major source of pollution.

Renewable energy sources such solar photovoltaic (PV) and wind power are clean, affordable, readily available, and sustainable and can supplement generators in both grid connected and off-grid

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residential and commercial applications. Hybrid energy systems integrate these renewable energy technologies with diesel generators, inverters and batteries to provide grid quality power in remote areas not connected to a utility grid. Such an isolated grid is known as Remote Micro-Grid and is widely recognized as the remote area electrification technology for the 21st century. It is predicted that there will be a 21% increase in capacity for the remote micro-grid market by 2017, from 349 MW to 1.1 GW with a total revenue of more than \$10 billion [Pike Research, 2012].

The author has been involved in the development of off-grid remote area power systems over the past two decades. This paper presents case studies of micro-grid distributed generation systems using photovoltaic modules and details how an

innovative variable speed diesel/bio-diesel generator (HybridGenTM) can be integrated into such systems.

2. Off-Grid Remote Area Power Systems

2.1. Diesel Generators

There are two general methods of supplying electricity to remote areas: grid extension and the use of diesel generators. Grid extension can be very expensive in many locations. Diesel generators are therefore the only viable option for remote area electrification. However, remote areas with relatively small communities generally show significant variation between the daytime peak loads and the minimum night-time loads. A typical example of a load profile of a remote community in Western Australia is shown below in Figure 1.

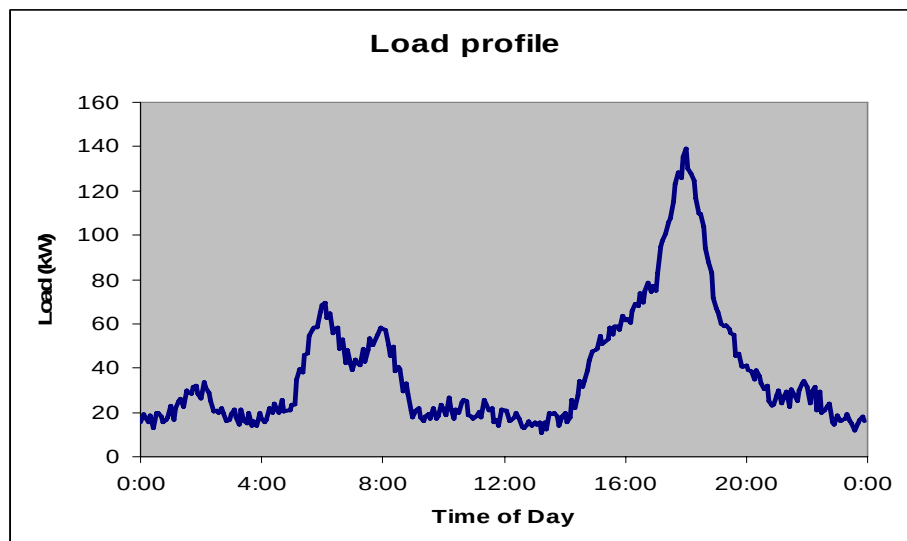


Figure 1: Typical load profile of a remote community

Diesel-powered electric generators are typically sized to meet the peak demand during the evening but must run at very low loads during “off-peak” hours during the day and night. This low-load operation results in poor fuel efficiency and increased maintenance. The main problems of remote area power generation using diesel generators are:

- High cost of electricity due to increasing fuel and transportation cost.
- Air and noise pollution.
- Loss in diesel fuel efficiency and increased operation and maintenance cost due to incomplete combustion of fuel during light loads

Conventional diesel generators operate at a constant speed, typically 1500 RPM for a 50Hz system and 1800 RPM for a 60Hz system, regardless of the power demand of the load. As these generators usually operate at low load operation mode, high fuel consumption is the

result. Prolonged low load operation can also eventuate in mechanical problems in the engine, and this may reduce the shelf-life of the diesel generator. The typical fuel consumption characteristic of a 50kVA diesel generator is shown in Figure 2.

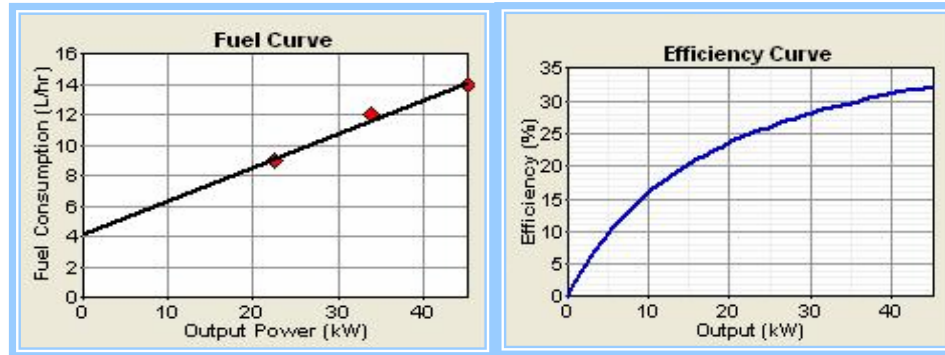


Figure 2: Typical fuel consumption characteristics of diesel generator

2. 2. Variable Speed Diesel Generators

To overcome the problems of conventional diesel generators, two types of variable speed diesel generator systems (marketed as **HYBRID GEN**) were developed :

(1) based on a Doubly Fed Induction Generator (DFIG) system which uses a wound rotor induction machine with the rotor's voltage controlled by two converters in a back to back configuration [9] and

(2) based on a Brushless Alternator.

2.2.1. Variable Speed Diesel Generator using DFIG technology

The basic system topology for a diesel engine coupled to a Doubly Fed Induction Generator is shown in Figure 3 [Nayar, 2008].

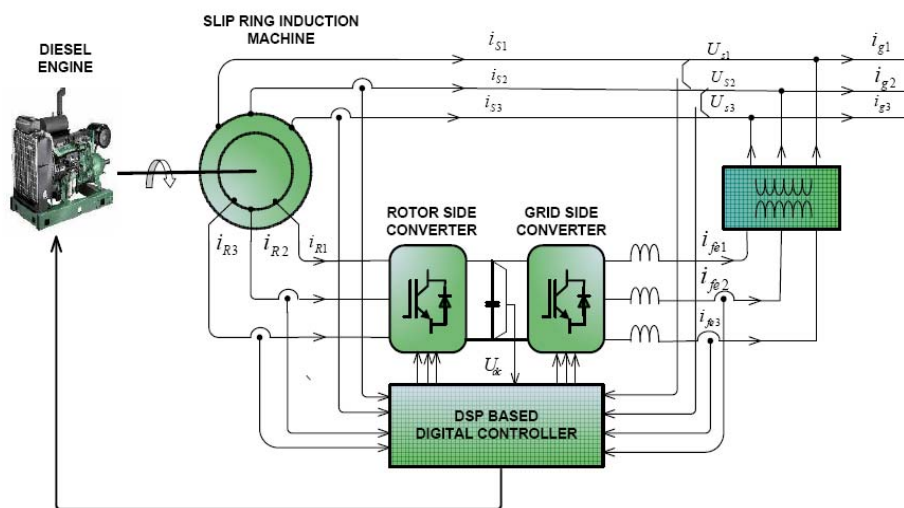


Figure 3: Diesel powered Variable speed Doubly Fed Induction Generator

In this scheme, the Rotor Side Converter produces variable voltage at rotor frequency. Grid Side Converter controls the DC-link voltage and provides independent control of active and reactive power. In order to control the machine, the voltage impressed on the rotor must be capable of varying its voltage magnitude, phase shift, frequency and phase sequence. A voltage source for the rotor that is capable of meeting these requirements is created by connecting two PWM converters back to back. One of the inverters in the configuration is connected to the stator which is ultimately connected to the grid. This inverter is known as the stator side converter. The other inverter in the configuration is connected to the rotor's slip rings; this inverter is known as the rotor side converter. A DC bus is formed where the stator side converter connects to the rotor side converter. The stator and rotor side converters work together to create a frequency changing circuit. On the grid-side the frequency is fixed normally at 50Hz, and on the rotor side the frequency will vary depending on the rotor speed.

HybridGen is designed for maintaining rated output voltage and output frequency of the wound rotor generator irrespective of the engine shaft speed. Diesel engines will be operated at the optimum speed depends on the load to reduce the fuel consumption. By utilising state of the art technology a high efficient, easy to use, variable speed generator has been designed with good dynamic performance. The Salient features of the generator are:

- Constant voltage/constant frequency output irrespective of the prime-mover speed
- Programmable voltage and frequency
- Engine to operate at optimum efficiency at different to load conditions
- Capable of producing higher power output (more than the rated power) at higher speeds to meet the higher load demand without overloading the system
- Less maintenance cost /down time of prime mover
- Ease of synchronizing with grid without additional synchronising relay
- Wide operating range (750 RPM to 2000 RPM)
- Programmable PI controllers for optimum transient response and steady state regulation
- Sophisticated PLC based supervisory control
- Advanced DSP based digital control and IGBT based inverter
- Flexible operating modes either as a stand-alone or grid connected generator
- Programmable output power at grid connected mode
- Programmable operating power factor
- Multi-data display: displays voltage, current power, and power factor
- Advanced protection systems to limit over voltage, short circuit and, over current



Figure 4a: HybridGen (40kVA) consisting of diesel engine, generator and electronic fuel regulator



Figure 4b: Power conditioning unit

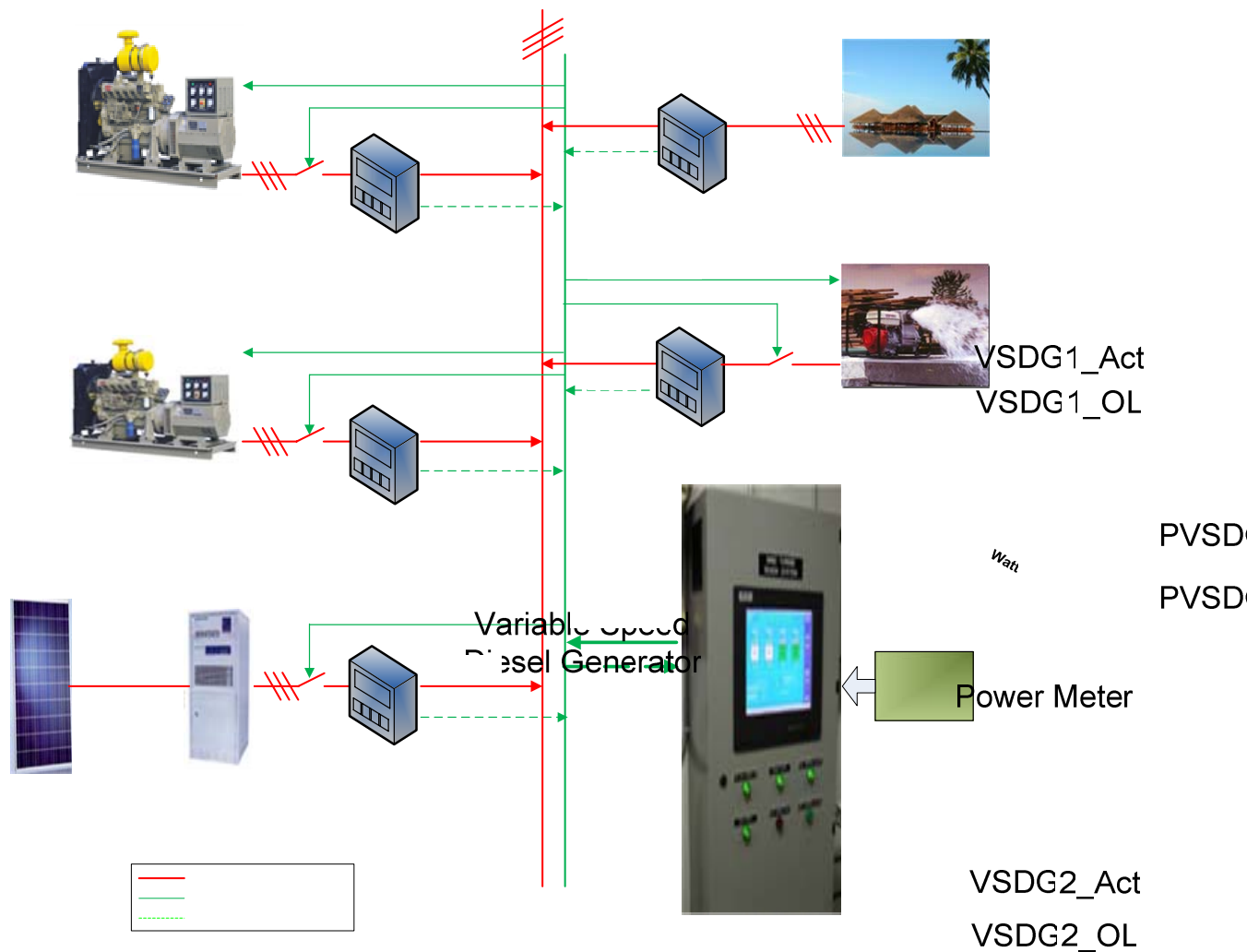


Figure 5: Multiple variable speed generators with AC-coupled solar panels

Figure 5 shows a schematic diagram showing multiple variable speed diesel generators with photovoltaic generators coupled to the ac side through inverters [Lim,2012].

2.2.2. Variable Speed Diesel Generator using Brushless Alternator

This scheme is preferred when battery storage can be included in a hybrid system. A variable speed engine is connected to an alternator that is specifically built for direct connection to a DC bus. The unit has three components: (1) An Engine Management Controller (2) a Battery Management Controller and (3) an efficient Battery Charge

Controller to charge the battery by running the engine at the optimum speed at which the fuel consumption is the minimum. The engine speed is automatically controlled depending upon the state of charge of the battery, the load and power from the solar panels. The main objective of the hybrid system is to provide uninterrupted power at minimum diesel runtime and fuel consumption. The engine is started when the battery reaches a preset discharge level and is then run to charge the battery to a float level and supply the load. The DC power output can be converted to AC power through an inverter for supplying AC loads. Fuel injection to the engine is controlled and the engine

speed is adjusted according to the power demands. A typical off-grid system consists of solar panels, battery and the Variable Speed Diesel Generator is shown in Fig.6. The generator can operate as a standalone constant speed Diesel Generator producing three phase supply or in variable speed

fuel efficient mode to charge the battery bank. The output of the battery bank is connected to a single phase sine wave inverter. The energy from the PV modules supply the load and charge the battery on a priority basis. If the engine is running, its function is to meet the short fall in energy required.

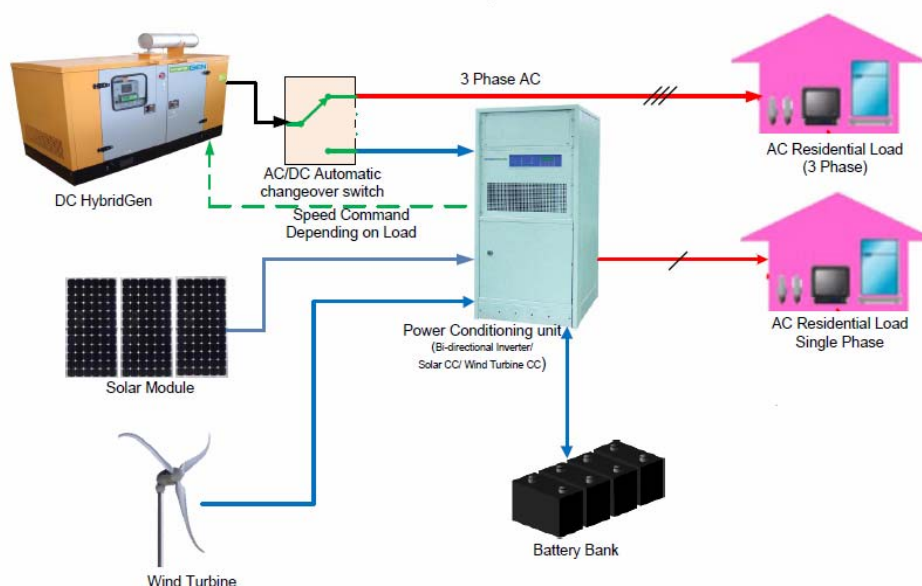


Figure 6: Variable speed ac/dc generator based hybrid system

In the constant speed mode, the engine runs at synchronous speed: the alternator then delivers three phase ac power directly to the load. This can be used for three phase loads such as motors and tools. Single phase power can still be obtained from the inverter depending on the state of charge of the battery. Main features of the system are:

- Uninterrupted single phase / three phase ac power
- Priority for solar power when available
- Diesel engine runs in variable speed mode to charge the battery and supply the load
- Battery management control included
- Engine management control included
- Provision for running the engine at constant speed mode to deliver three phase 415V, 50 Hz supply.
- The engine, the generator, battery monitoring system, engine management controller, 250

litre fuel tank – all in an acoustic enclosure (less than 70dB at 1m)

- Maximum Power Point Tracking Solar Charge Controller
- High efficiency bidirectional inverter/charger
- Complete system wired and housed in a 20ft shipping container

2.3. Renewable Energy Penetration

Generally, renewable energy based hybrid power systems are classified into two broad categories [Wichert, 2000, Seeling-Hochmuth, 1998] based on the penetration level of renewable energy. These are summarised as follows:

- Systems with diesel generators as main power supply: In these systems, diesel generators are designed to operate daily, along with renewable energy generators, to supply power directly to the load. The functions of renewable energy generators are to reduce fuel

usage and generator mechanical servicing. Small batteries can be used in these systems to meet high load demand that lasts for a short duration only and the system batteries may be recharged by diesel generators.

- Systems with renewable energy generators as main power supply: In these systems renewable energy generators are designed to supply a high fraction of total energy demand. The functions of the diesel generator are to recharge the battery bank and to complement the renewable energy generator power supply when there is insufficient renewable resource. Due to the high penetration level of renewable energy, large battery banks are usually required in these systems.

The penetration level of renewable energy in a hybrid power system mainly depends upon local weather conditions and the customer's preference. With a given renewable energy penetration level, system components can be sized using various approaches.

A number of software packages that facilitate the design of a hybrid power system have been developed. These software packages are summarised as follows:

- HOMER [HOMER Energy, 2011] renewable energy optimisation software was developed by the National Renewable Energy Laboratory (NREL) to facilitate the design, analysis and financial evaluation of hybrid power systems. It is well-known for its user-friendly program interface. The number of its users is increasing rapidly. Based on the user-defined components' types and ratings, HOMER can perform long-term electrical, environmental and economical

performance analyses. Sensitivity analyses can be included to provide a list of optimisation results to the users.

- RETScreen [National Resources Canada, 2011] was established by the Natural Resources Canada with contributions from the Canadian government, industry and academicians. Components are modelled in Microsoft (MS) Excel format, and therefore it requires the MS Excel simulation platform. The software can be used to evaluate performance of various power systems ranging from residential to industrial applications.
- HYBRID2 [Manwell, 2006] was developed by University of Massachusetts and NREL. The simulation models are programmed using MS Visual Basic. This software can simulate overall system performance and economics for various system configurations to assist the system designer in decision making.

3. Case Studies of Micro-Grid Systems

3.1. Case Study 1: PV/Diesel Micro Grid System implemented in a remote tourist resort in Western Australia [Darbyshire, 2010]

The Eco Beach Wilderness Retreat is located amongst a pristine, untouched environment about 2000 km north of Perth, the capital of Western Australia. An aerial view of the resort is shown in Figure 7. Western Australia (WA) is blessed with ample solar radiation and wind resources as shown in Figure 8



Figure 7: Aerial view of the Eco Beach Resort

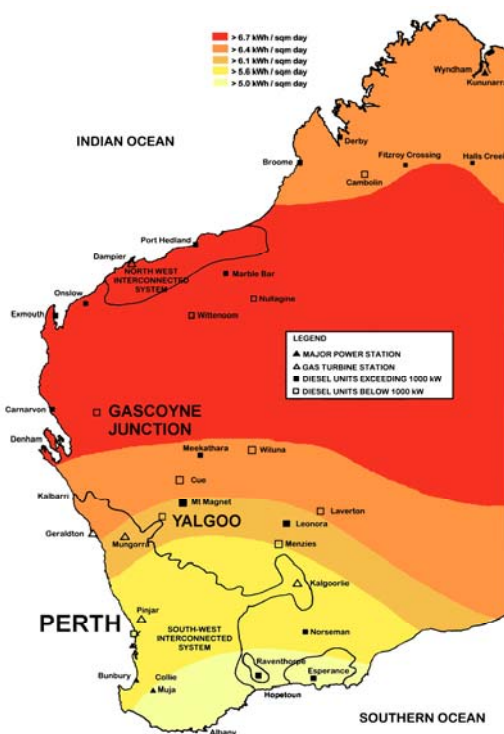


Figure 8: Annual Solar Radiation in Western Australia

The entire project including installation, testing and commissioning was carried out within a period six months and the resort was operational by May 2009. The system installed consists of 24 x 2kW roof top PV installation, a 120kW central bi-directional inverter with a 360V, 1500Ahr battery bank and 4 x 50kW diesel generators. Each villa had a power monitoring device installed which tracks the renewable energy generated and the actual energy used in the villa. This allows energy

conscious guests to audit their usage during occupancy. Each villa has a 2kW PV array installed on its north-facing side of the roof, as shown in Figure 9a



Figure 9a: Eco resort villas with photovoltaic panel installation.

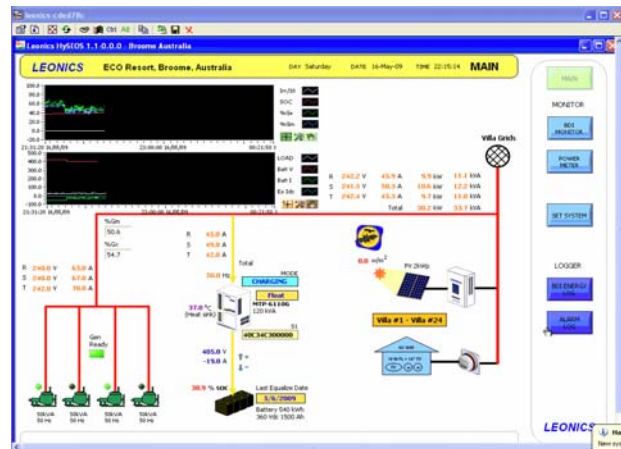


Figure 9b: Remote monitoring

In addition to the capability to monitor the entire resort, the performance of each villa with solar PV on the roof, can also be individually monitored.

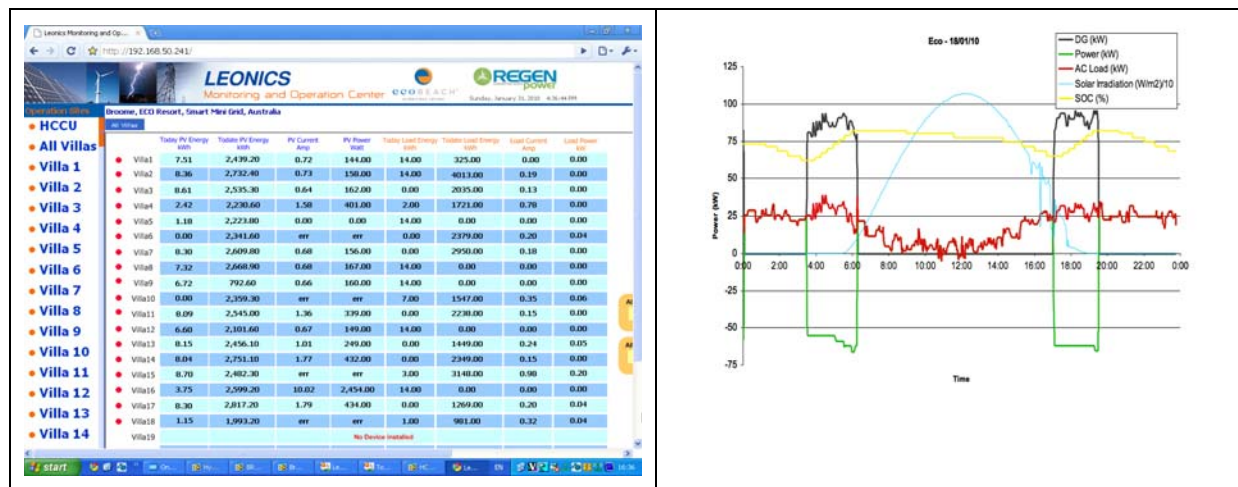


Figure 10: Remote monitoring display

3.2. Case Study 2: Variable Speed Diesel Generator system for powering an off-grid Telecom Tower (BTS), Sri Lanka [Lim, 2012]

An off-grid power supply for a Base Transceiver Station (BTS) at Niripola village in Sri Lanka. (Coordinates: 6°54'0"N; 80°6'0"E). Due to the remoteness of the site, where the public electricity grid is inaccessible; the station is powered by a conventional constant speed diesel generator and a battery bank. The BTS load runs on a 48V DC bus and the average power requirement is 1kW continuous where the daily energy demand is approximately 24kWh. For the present

configuration, the diesel generator operates 20 hours a day. Fuel consumption of this system using the existing control strategy and conventional DG is high. Therefore, retrofit solutions employing a variable speed DG and PV were proposed.

The system consisted of a 6kW HybridGEN DC VSDG and 2 strings of 300Ah battery. Its diesel engine would be operated at the optimum speed, based on the load and battery power demand. During field testing, the daily generator operation hours were in the range of 9 to 11 hours per day, with the batteries supplying the load for up to 11 hours per day. This represents a 55% reduction in diesel generator operating hours compared to the

present system configuration. This could be of benefit in reducing refueling trips. It also allows for a significant reduction in generator servicing costs; increasing engine life and reducing

maintenance requirements, which in turn would reduce the system's annual operating and maintenance costs.



Figure 11: Field testing of BTS power system using HybridGEN DC VSDG

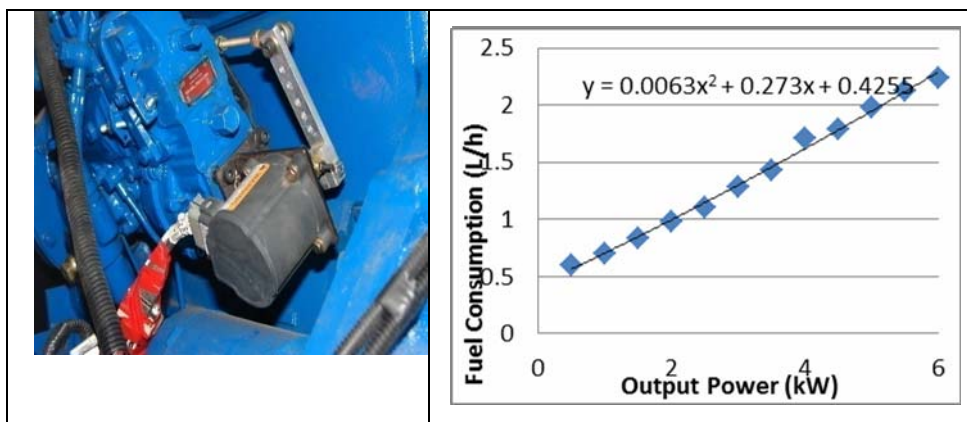


Figure 12: Fuel control and fuel characteristic of a 6kW HybridGEN DC VSDG.

Figure 12 shows the fuel control equipment for the VSDG, and its fuel characteristics obtained during field testing.

3.3. Case Study 3: PV/Diesel Micro Grid System at Pulau Ubin Island, Singapore

Singapore govt agency, Energy Market Authority (EMA) has embarked on a micro-grid test-bed to assess the reliability of electricity supply from a

micro-grid infrastructure using intermittent renewable energy resources at the jetty area of Pulau Ubin, an island north-east of Singapore [EMA Singapore, 2012]. The system will consist of 6 nos of DFIG based variable speed diesel generators, 100kW of PV and a grid forming inverter configured to form a micro grid. The system shown in Fig 13 will be fully operational by Sept 2012.

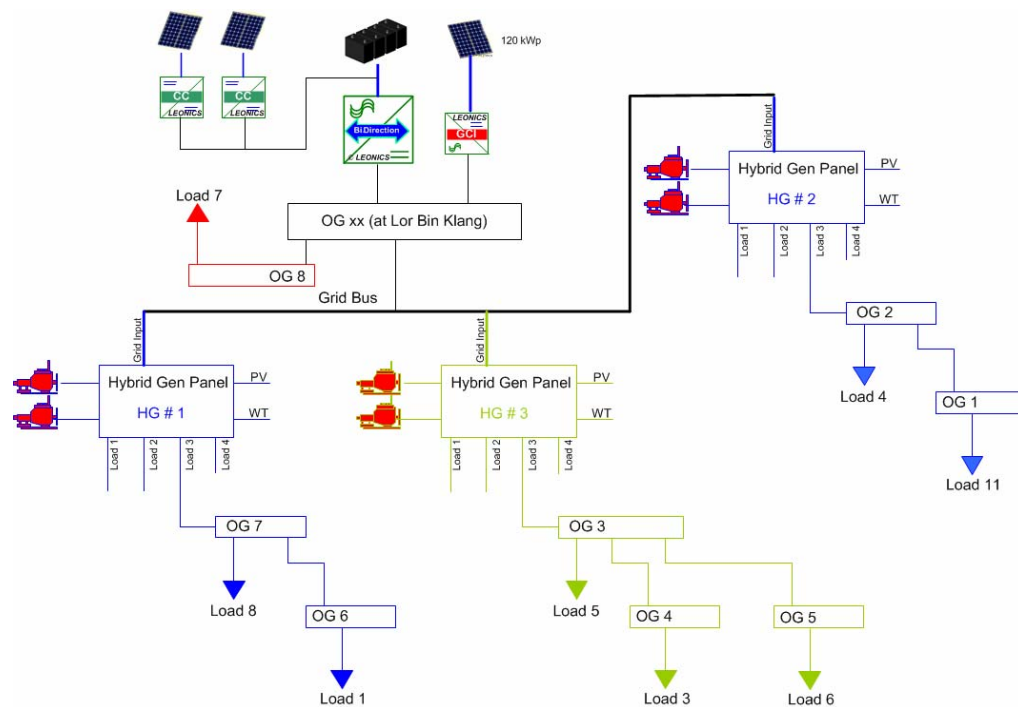


Figure 13: Micro-Grid system in Pulau Ubin, Singapore

4. Conclusion

Islands and remote communities represent a big niche market for the application of renewable energy technologies and are very important when it comes to the promotion of renewable energy worldwide. From the experience learned from the implementation of several remote area power systems, it is clearly evident that hybrid, renewable micro grids are a reality and the right step towards making resorts and remote islands self sufficient. It also opens up the potential for tourism, apart from making the earth a cleaner place to live. The newly developed variable speed diesel generator system is expected to provide very good opportunities to showcase high penetration of renewable energies

using state-of-the-art wind turbines and photovoltaic modules. The new hybrid system configuration offers several advantages such as maximised diesel efficiency, minimised maintenance of diesel generators and a reduction in the required capacities of diesel fuel and battery storage.

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