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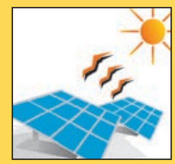

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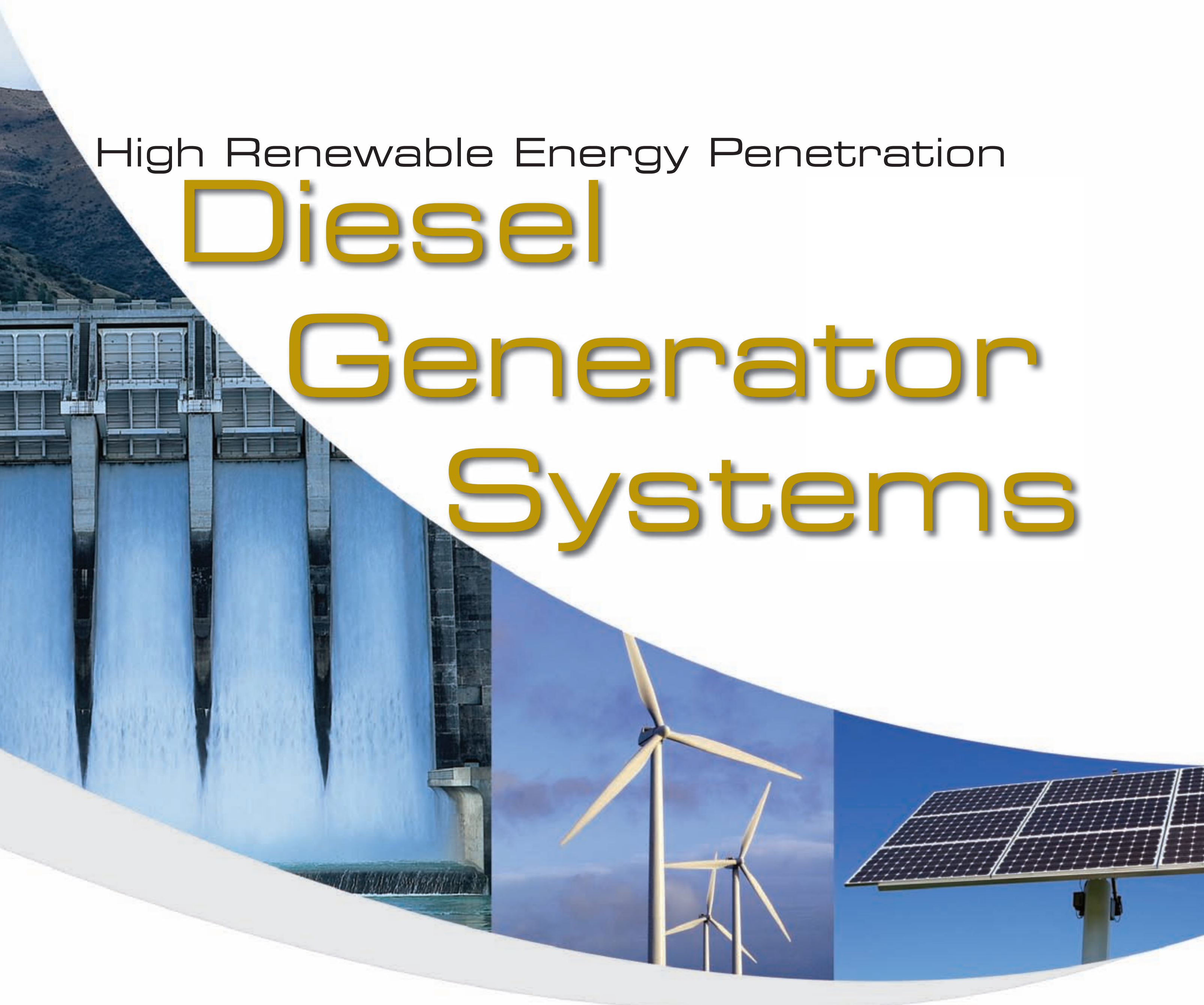
Diesel Generator Systems



Many remote communities around the world are dependent on diesel generators for their energy requirements. Diesel generators are also a major source of backup power in India and other countries experiencing frequent power cuts and power reliability concerns. 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. Solar and wind power technologies are clean, affordable, readily available, sustainable and can replace or supplement generators in both residential and commercial applications. Hybrid energy systems integrate these renewable energy technologies with diesel generators with or without battery storage to provide grid quality power in remote areas not connected to a utility.

- Prof Chemmangot V Nayar

In this paper, an innovative hybrid power system incorporating variable speed constant frequency diesel generator, photovoltaic arrays and wind turbine generators is described. The system has tremendous potential in remote area power systems where solar photovoltaic and small scale wind generators can reduce the diesel fuel consumption. The system also has great potential in the back-up power market, where diesel generators run infrequently, where solar photovoltaic systems offer emission free and secure power for smaller customers in case of blackouts or brownouts.

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. Having said this however, 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 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 residential and commercial applications. Hybrid energy systems integrate 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 a stand-alone Micro-Grid and is widely recognised as the remote area electrification technology for the 21st century.

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 wind turbines, photovoltaic modules and details how an innovative variable speed diesel/bio-diesel generator (HybridGenTM) can be integrated into such systems.

Remote area Power Supply Options

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 Fig. 1.

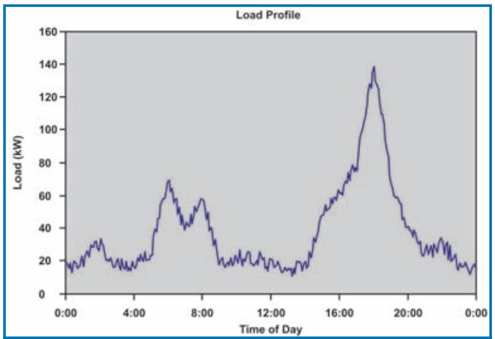


Fig. 1: Typical load profile of a remote community

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

Hybrid energy systems integrate renewable energy technologies with diesel generators, inverters and batteries to provide grid quality power in remote areas not connected to a utility grid.

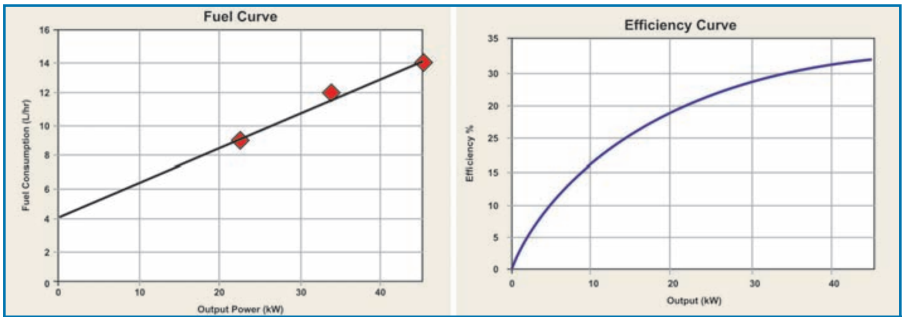


Fig. 2: Typical fuel consumption characteristics of diesel generator

light loads.

The typical fuel consumption characteristic of a 50 kVA diesel generator is shown in Fig. 2.

In some remote locations, a dual diesel generator system is employed. When the load is light, the smaller generator is used; as the load increased, the manual switch is transferred to the larger generator. This approach results in some fuel savings, however managing this dual system is time consuming and impractical.

Another solution proposed and implemented in many parts of the world involves a battery/diesel/inverter hybrid system as shown in Fig. 3. This hybrid system configuration allows all energy sources to supply the load separately at low or medium load demand, as well as supplying peak loads from combined sources by synchronising the inverter with the constant speed driven alternator output waveform. The bi-directional inverter can charge the battery bank (rectifier operation) when excess energy is available from the diesel generator, as well as acting as a DC-AC converter (inverter operation) when the diesel generator is switched off. The inverter may provide 'peak shaving' as part of a control strategy when the load demand exceeds the supply capacity of the diesel generator.

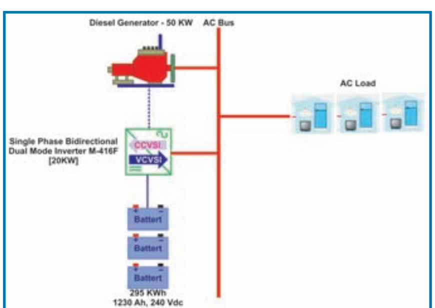


Fig. 3: Battery/Inverter/Diesel Generator hybrid system

The author was involved in the design and implementation of hybrid energy systems in many parts of the world. Two such case study examples are summarised in the following sections.

Case studies of Micro-Grid Systems

Wind/PV/Diesel Micro Grid System implemented in remote islands in the Republic of Maldives

The electricity in the Maldives is exclusively produced by diesel generators run on every inhabited island. Based on the energy consumption and the availability of renewable energy sources, it was decided to implement a micro-grid hybrid distributed generation system combining several small scale wind generators, solar photovoltaic panels, battery storage, advanced power electronics equipment and existing diesel generators. The system architecture employed in the hybrid micro-grid system is "AC Coupled" whereby the renewable energy sources and the conventional diesel generators all feed into the AC side of the network as shown in Fig. 4.

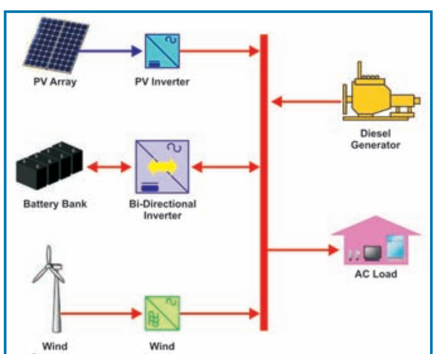


Fig. 4: Hybrid system schematic diagram showing renewable energy sources coupled to the AC side

Three remote islands in the northern, central and southern part of the country were selected. Fig. 5 shows

Fig. 5: Aerial view of the Uligam island

an aerial view of the northern island known as Uligam. The wind resource information was sourced from a report prepared by the National Renewable Energy Laboratories (NREL) in the USA which gives various maps of the Maldives showing the wind resource potential. Fig. 6 shows the wind resource map of the three locations selected for the pilot installation in the country. The wind map shows the highest resource in the north-central part of the Maldives just north of the capital of Male, from 4.5° North latitude to 6.5° North latitude. The level of resource in these areas is considered good for small-scale village applications. The wind resource gradually decreases from Male southwards with the lowest resource found on the atolls south of 1° North latitude. Fig. 7a gives an overview

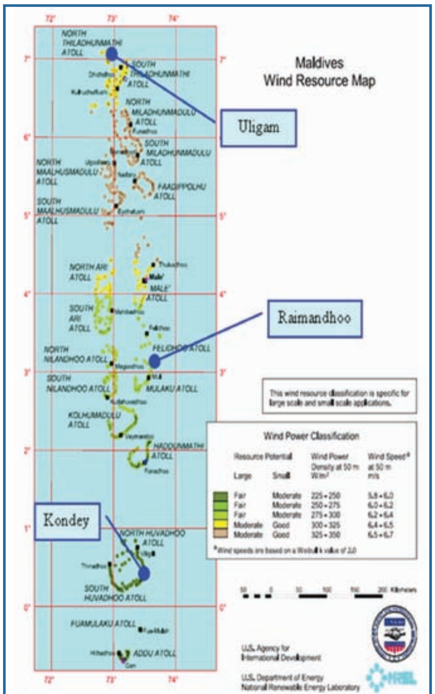


Fig. 6: Wind power resource and the selected islands

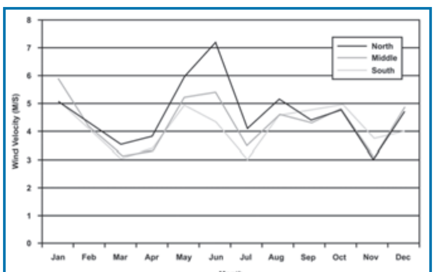


Fig. 7a: Wind resource map for selected locations for pilot installations in Maldives

Fig. 7b: Solar radiation levels for locations of pilot installations in Maldives

of the wind resource at the three locations. The solar resource for this study is obtained from NREL and NASA data and is shown in Fig. 7b.

Most of the islands in the Maldives have basic infrastructure such as a school, health clinic, island administration office and mobile phone communication tower. The three selected islands have 24 hour power supply using diesel generators. The load demand profiles of most of the outer islands (excluding the capital, Male) have a similar profile with peak load occurring in the night, as in Fig. 8.

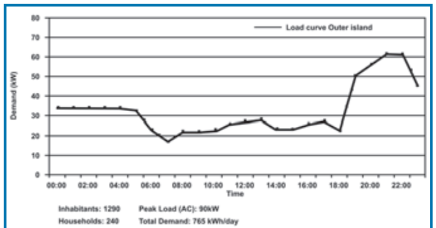


Fig. 8: Typical daily load profile

Hybrid systems consisting of a cluster of small wind turbines, photovoltaic modules, a bi-directional grid forming mini grid inverter (which can also work as a battery charger), battery storage and the existing diesel generators were installed and commissioned in the three islands in July-August 2007. Fig. 9 is a photograph of the micro-wind farm and solar panels installed on the Uligam Island.

Fig. 9: Micro-wind farm and photovoltaic panels as installed in the Uligam island

Performance data of this system in each island can be accessed through a remote monitoring system. Fig. 10 shows real-time captured information of the system on 29th October 2007. It can be seen that the combined of the output of the wind farm on the morning of the day is around 34.2 kW, out of which 15.3 kW goes into the island load and 19.3 kW goes into the battery. The grid is provided by the bi-directional

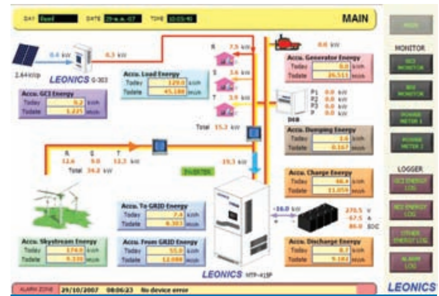


Fig. 10: Real time monitoring of Uligam Island power system

inverter when the diesel generator is not running.

Fig. 11 shows measurements of the power contribution from solar, wind and diesel generator over a four day period.

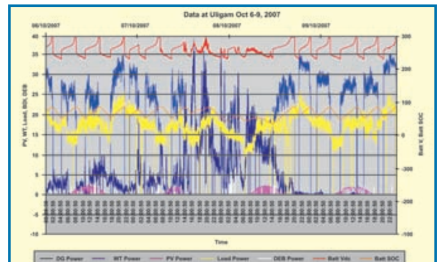


Fig. 11: Recording of the power contribution from solar, wind and diesel generator

PV/Diesel Micro Grid System implemented in a remote tourist resort in Western Australia

The Eco Beach Wilderness Retreat is located amongst a pristine, untouched environment about 2000 km north of

Fig. 12: Aerial view of the Eco Beach Resort

Perth, the capital of Western Australia. An aerial view of the resort is shown in Fig. 12. Western Australia (WA) is blessed with ample solar radiation and wind resources as shown in Fig. 13.

The author was approached in June 2008 to undertake a feasibility study to

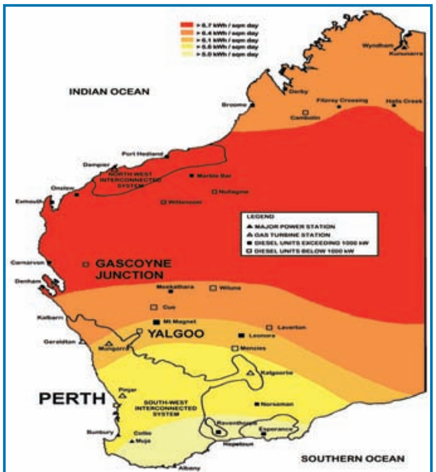


Fig. 13: Annual Solar Radiation in Western Australia

implement a renewable energy based hybrid power system for the Eco Beach Wilderness resort in Broome, WA. As the resort was under construction during the project inception stage, the power and energy requirements were unknown. Hence, a detailed energy audit was carried out, and the system loads were predicted. From this analysis, a peak load of 120 kW and a daily energy consumption of 600 kWh were predicted. The resort occupancy was factored to create seasonal and monthly load profiles.

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 2 kW PV arrays, a 120 kW 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 2 kW PV array installed on its north-facing side of the roof, as shown in Fig. 14.

Two main considerations were adhered to while designing the system. One was to minimize the use of diesel fuel, as it was an eco resort and the


Fig. 14: Eco resort villas with photovoltaic panel installation

second was the need to switch off the generators at night, so that the 'sounds of nature' could be heard. 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.


Fig. 15: Diesel Room at Eco Beach Resort

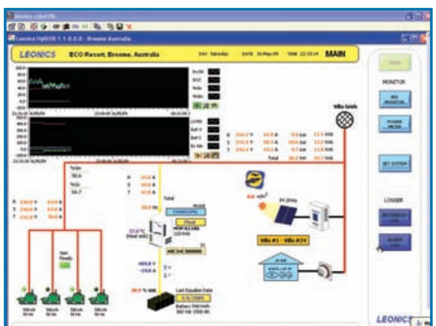


Fig. 16: Remote monitoring display

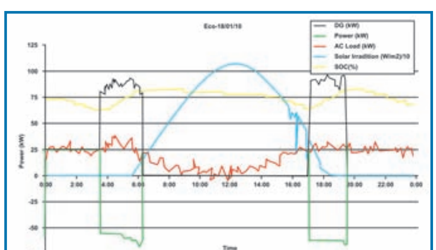


Fig. 17: System operation on a clear sunny day

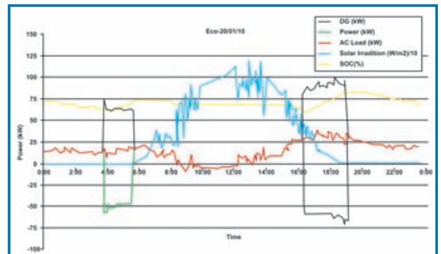


Fig. 18: System operation on a cloudy day

Fig. 19: Monitoring of energy generation and consumption in villas

Variable Speed Operation of a Diesel Generator

A conventional diesel generator consists of an engine connected directly to a synchronous alternator to produce electricity. Since the electricity produced must be at a fixed frequency, normally 50Hz or 60Hz, the engine must rotate at a constant speed (typically 1500 rpm for 50Hz or 1800 rpm for 60Hz), regardless of the power demand. 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.

There are a number of applications for which the power demand varies greatly that can benefit from this technology which include-

- Staff accommodation on oil, gas and mineral exploration sites
- Construction sites where electrical demand fluctuates day and night
- Remote villages, islands, houses, cabins
- Telecom towers with air conditioning units that start and stop

The use of a variable speed generator has many advantages compared to a standard diesel generator, as outlined below.

Fuel savings

A variable speed generator can save fuel in two ways. First, running the engine at its most efficient speed for a given power demand allows for considerable fuel savings. A comparison of the fuel efficiency of a constant speed diesel generator and a variable speed generator is shown in Fig. 20. Estimation of the real saving in fuel consumption would depend on the load curve in a particular application.

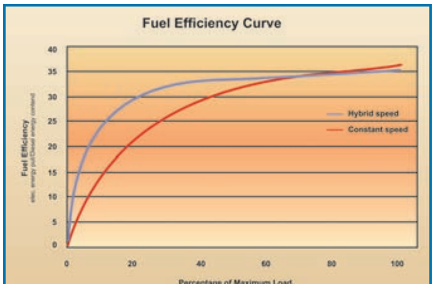


Fig. 20: Typical Fuel Efficiency curve of a diesel engine in Variable Speed (HybridGen) and constant speed genset

Fuel savings can also be achieved, as a variable speed genset requires smaller engine compared to a fixed speed generator of the same power rating. A standard engine power curve (shown in Fig. 21) illustrates why the engine on a variable speed generator can be smaller. On a standard fixed speed generator, the engine can only operate at 1500 rpm. This means all the power above the nominal rated speed (Fig. 22 - red area) is unavailable. A variable speed generator can use the engine over its full speed range, allowing a smaller engine to be used

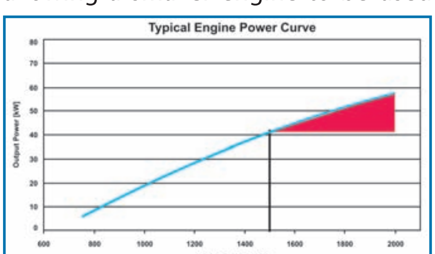


Fig. 21: Typical Diesel Engine Power Curve (Red Area: Engine power available above 1500 RPM)

as compared to a fixed speed generator of the same power rating. Depending on the engine, its application, normally 50Hz, and its power curve, a variable speed generator can extract up to 30% more power from the engine. It is worth noting that since generators rarely run at their rated capacity full time, the average operating speed of the engine will be below 1500 RPM.

Reduced Noise

Almost all the noise produced by a generator is due to the engine and the speed of revolution. When the engine speed is reduced, noise is also greatly reduced, which means that in power saving mode, when the engine is at a low speed, a variable speed generator is much quieter.

Prolonged Engine Life

Variable speed generator in remote area applications will mostly run at lower speeds. This can prolong engine life. The moving parts in an engine are subjected to a "load cycle" every time the engine rotates. A reduction in speed results in a reduction of the number of load cycles resulting in extended engine life.

The second advantage is the elimination of a common problem in engines called cylinder glazing or wet stacking. Cylinder glazing usually occurs when an engine runs too cold and combustion is inefficient. This happens in fixed speed diesel engines when operating at low load. At low loads, the engine runs colder, which results in deposits on the cylinder walls of the combustion chamber. When the engine is continuously at its most efficient point, it remains hot and bore glazing is greatly reduced and/or eliminated, resulting in prolonged engine life.

Reduced Emissions

Results from testing variable speed generators indicate that emissions are reduced proportionally to the fuel economy generated by the variable speed generating system.

HybridGenTM - An Innovative Variable Speed Generator

HybridGen is 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. The basic system topology for a DFIG is shown in Fig. 22.

In this scheme, the Rotor Side

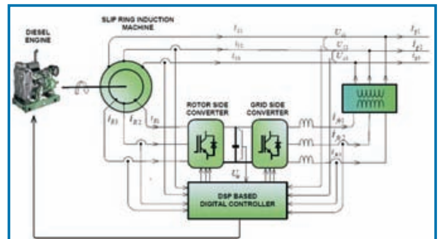


Fig. 22: Diesel powered Variable speed Doubly Fed Induction Generator

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.

Salient features 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 .

Fig. 25 shows a schematic diagram showing multiple variable speed diesel generators with AC-coupled wind generators and photovoltaic generators. Future hybrid energy systems will be using variable speed generators instead of conventional constant speed diesel generators.

Fig. 23 a: HybridGen (40kVA) consisting of diesel engine, generator and electronic fuel regulator

Fig. 23 b: Power conditioning unit

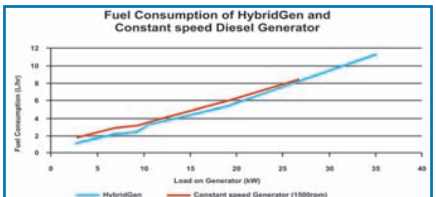


Fig. 24: Fuel consumption of a constant speed generator and HybridGen

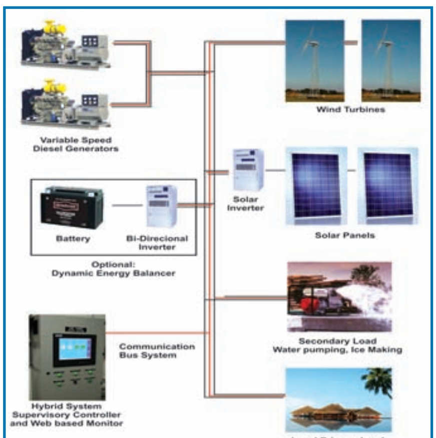


Fig. 25: Multiple variable speed generators with AC-coupled wind turbines and solar panels

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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