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DIESEL PLANT RETROFITTING OPTIONS TO ENHANCE DECENTRALIZED ELECTRICITY SUPPLY IN INDONESIA

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Abstract

Over the last 20 years, the government of Indonesia has undertaken an extensive program to provide electricity to the population of that country. The electrification of rural areas has been partially achieved through the use of isolated diesel systems, which account for about 20% of the country's generated electricity. Due to many factors related to inefficient power production with diesels, the National Renewable Energy Laboratory, in conjunction with PLN, the Indonesian national utility, Community Power Corporation, and Idaho Power Company, analyzed options for retrofitting existing diesel power systems. This study considered the use of different combinations of advanced diesel control, the addition of wind generators, photovoltaics and batteries to reduce the systems overall cost and fuel consumption. This analysis resulted in a general methodology for retrofitting diesel power systems. This paper discusses five different retrofitting options to improve the performance of diesel power systems. The systems considered in the Indonesian analysis are cited as examples for the options discussed.

Introduction

One of the most prevalent means of providing power to remote communities is the use of diesel generators. The appeal of this approach is the relatively low capital cost of the generating equipment. However, increasing problems associated with burning fossil fuels are motivating many institutions to consider alternative means of meeting growing demands for rural electricity. Such means include improving the efficiency of the diesel plants and adding renewable energy sources to the systems. Because the renewables (primarily wind and solar) fluctuate, combinations of renewables with diesel gensets are often considered to be the most practical solution. If renewables are not cost effective, other options for improving the efficiency of diesel plants may be considered.

Over the last 20 years, the government of Indonesia has undertaken an extensive program to provide electricity to the population of that country. Electrification in rural areas has been partially achieved through the use of isolated diesel systems. About 20% of the country's generated electricity is produced by small, isolated diesel power plants employing over 1800 individual diesel units. Many factors associated with the use of diesel generators, from fuel cost and transportation to system maintenance expenses, have caused the Indonesian government and PLN to consider alternative methods for providing power to remote communities.

In collaboration with PLN and Community Power Corporation (CPC), the National Renewable Energy Laboratory (NREL) has analyzed options for existing isolated diesel power systems. This study considered the use of different combinations of advanced diesel control, wind generators, photovoltaics, and batteries to reduce the consumption of diesel fuel and the overall cost of power generation. Analyses were conducted looking at typical diesel systems of many sizes and considered parametric analyses on system size, configuration, and renewable resource to allow general conclusions to be formed. The analysis also considered the potential of increasing the operation hours of some diesel plants.

In this report, five possible retrofit options are identified which can be used to reduce the use of diesel fuel. Each of these retrofit opportunities is described. Finally, several case studies are cited as examples of recommended designs. These case studies are based on analyses conducted as part of the NREL, CPC, and PLN study.

This report does not provide discussion on methods to reduce energy consumption or increase energy capture. An energy audit of a community should be conducted prior too, or as part of, any retrofitting plan to identify energy saving opportunities. In many cases, the load on a plant can be greatly reduced by incorporating energy savings measures like florescent lighting and power switches. One should also look for methods to productively use waste energy and manage non-critical loads so as to obtain peak output from the power system.

Advantages and Disadvantages of System Retrofits

There are a number of advantages for retrofitting diesel plants, in addition to the obvious reduction in fuel consumption. One can expect to reduce the number of operational hours on an existing diesel generator with well designed system retrofits. Because diesels are usually the piece of equipment with the highest maintenance cost and the maintenance costs are a direct function of operating hours, this will reduce the required maintenance expense of the system. There will also be a reduction in the pollution due to the reduction in use of the generators. If an advance system control is also installed, a reduction in the number of system operators can be achieved, even with an expansion of service. In addition, most system controllers also incorporate a measure of system performance monitoring and data collection that can be useful in long term system monitoring. The benefits of diesel retrofits are dependent on the system design and retrofit option chosen; these results will vary from system to system

There are a number of disadvantages to completing a retrofit on an existing diesel system. The primary disadvantage is the capital expense of the additional equipment; however in a well-designed system this is usually returned in a matter of years. The installation of new and additional equipment can cause technical difficulties due to the increased technical complexity of the system and the need to service and maintain multiple system technologies. There can be problems associated with the increased start/stop cycles experienced by the diesels with most high performance hybrid systems. Although the result of repeated start/stop cycling on diesel systems is documented (Bleijs et al. 1993), the decrease in diesel operation can greatly reduce the overall diesel maintenance.

Retrofit Options for Diesel Power Systems

Five different diesel system retrofit opportunities are described in this section. These five options are considered the most likely to have positive economic impact on the operation and maintenance expenses of the diesel system. As with any potential retrofit, the final retrofit option is highly dependent on the existing system architecture, generator sizes, and load profile for the community of interest. Depending on the system operational costs, it may be that no savings can be achieved through the retrofitting the diesel system. Any type or size of diesel system may be a candidate for retrofit, from the small, one diesel system providing power for only a few hours a day to large multi-diesel systems providing 24-hour utility grade power.

The five retrofit options to existing diesel systems are:

- Type A: Adjust the size of installed diesels or install an additional engine to provide diversity in unit capacity.
- Type B: Add automatic controls to existing diesel plant.
- Type C: Install batteries and a power converter to cover low load periods.
- Type D: Install wind turbine generators and/or PV array to reduce diesel generation.
- Type E: Installation of an advanced renewable/battery/diesel hybrid power system.

Type A: Adjust diesel size or install an additional diesel engine

One of the ways of reducing the costs of operating an existing diesel plant is to insure that the generators are properly sized to the community load. Appropriate sizing of generators is important in systems of all sizes, from small, single generator systems to large multi-generator power plants. Typically the diesel engines in a remote power station are sized to adequately cover the yearly peak load and are thus oversized for normal day to day operations. Depending on the size of any existing generators and the community's load profile, the replacement of, or even the installation of a new, smaller diesel unit may result in a very quick return on investments. This is described graphically in Figure 1, where the fuel curves for two representative diesels are shown. A village with a maximum yearly load of 300 kW may have a 330-kW diesel installed to meet this load. The average daily load is only about 100 kW, so installing a smaller generator to cover the standard load could save about 15 liters of fuel for each hour of operation. The larger diesel would then be used during times of high load or as a backup when the first diesel is undergoing maintenance.

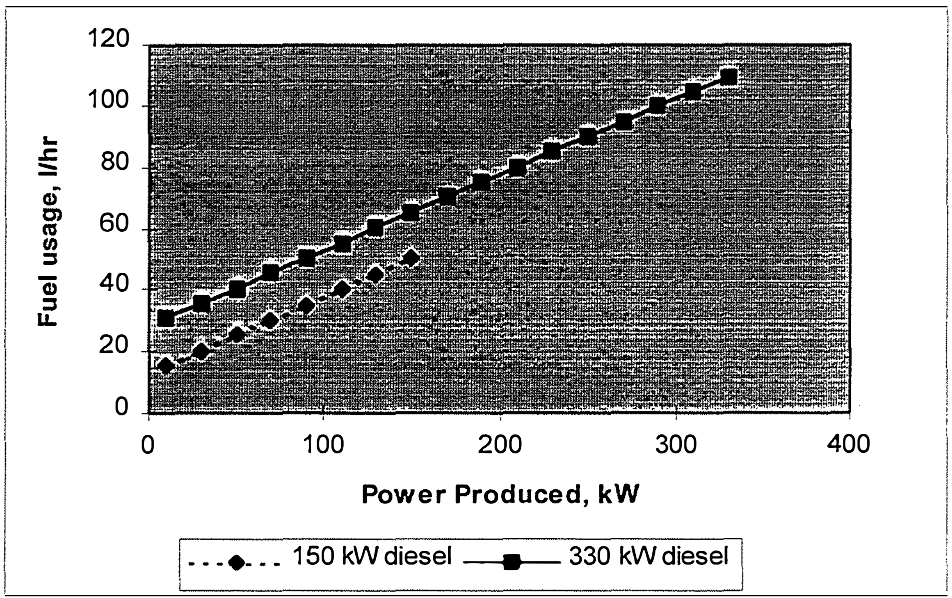

FIGURE 1. COMPARISON OF DIESEL SIZES TO MEET A SPECIFIED LOAD.

Type B: Add automatic controls to an existing diesel plant

Larger diesel plants often contain multiple diesel engines of various sizes. In these systems, it is more likely that the diesels will be the appropriate size; however, the diesels operating at any given point may not be the most efficient combination to cover that load. In these systems, controls can be placed on the diesel generators to enable automated dispatch and more efficient operation. Each genset is provided with controls for auto starting, synchronization, and load matching while a master control is used to coordinate diesel dispatching and load sharing. Automated systems have the additional advantage of detailed operational data collection and monitoring. Fuel savings depend on the current system design and dispatch strategy, but tend to be cost effective in larger systems where the current dispatch strategy is either inefficient or labor intensive. The use of advanced controls may add a level of technical sophistication that will only be appropriate in larger communities.

Type C: Install batteries and a power converter to cover low load periods

This approach is applicable in a single-diesel system if the community has periods of the day with very light loading compared to the peak load. In these cases, the existing diesel is generally oversized for the low load period, thus it operates with poor efficiency. A retrofit battery bank and power converter, where stored energy from the battery is used to power the converter and cover the load, allows the generator to be turned off during periods of light loading. The batteries are then recharged when the generator is operating at higher efficiency. This approach may also be used to expand the hours of service of a particular plant without greatly increasing the system operation costs. In multiple-diesel systems, the addition of batteries can preclude the need to start an additional generator that must run at low loading to cover fluctuations in power over the rating of the primary generator. In either case, the generator recharges the batteries during other periods of the day. The decision of whether to install a converter/battery bank or a smaller diesel to cover these low load periods is dependent on the ratio of low load to diesel size and should be considered carefully. The potential cost savings depend on the load profile and the sizes of the diesel generators. The size of the battery bank depends on the energy requirements of the low load period. The size of the inverter depends on the magnitude of the load during the low load period. Both the initial cost and the periodic replacement cost of the batteries must be weighed against the reduction in operation and maintenance expenses. This concept is shown graphically in Figure 2. In this system the batteries cover the load in the early morning and then are recharged by the diesel later. 27 liters of fuel is saved each day versus the original all-diesel system.

Type D: Install wind turbine generators and/or PV array to reduce diesel operation

Wind retrofits to diesel power plants are primarily useful in large systems with good wind potential and high fuel costs. In plants with many large diesels, where there is always a demand for power, the wind power is used to offset power production by the generators. The addition of the wind power may also reduce the number of generators operating at any given time, thus reducing the diesel maintenance requirements. Because system dynamics and power stability are of primary concern, at least one diesel generator is operated continuously and the wind penetration is usually only a fraction, from 20% to 50%, of the average load. Advanced controls are usually included with these systems to allow for the shutdown of individual wind turbines and/or diesels depending on the resource, load, and system control requirements. This approach can be very cost effective but is capital intensive due to the cost of the wind turbines and controls. The potential cost savings depend on the wind resource, diesel maintenance costs, and the fuel price. Based on current prices, PV is usually not cost effective in large systems when compared strictly to the marginal cost of diesel fuel. Figure 3 shows the

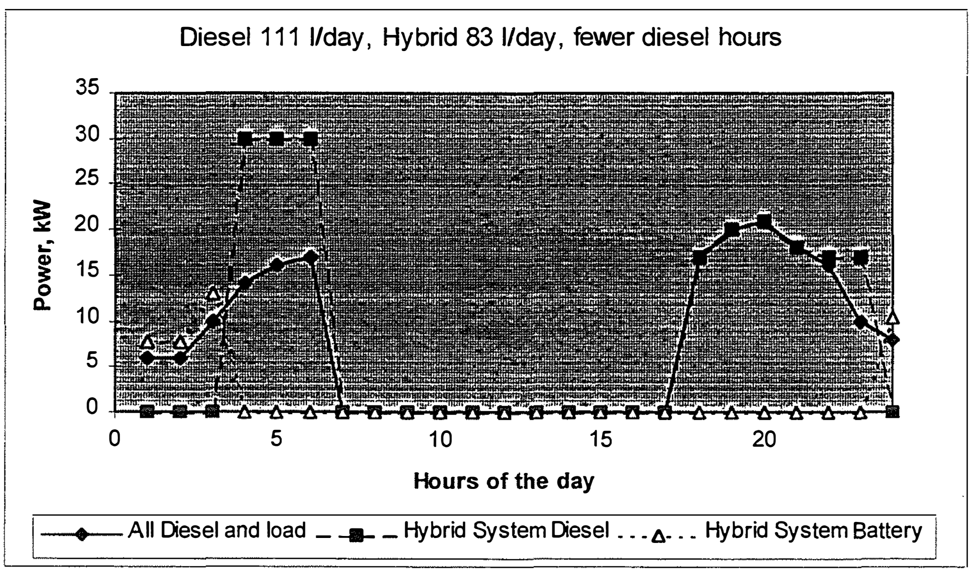

FIGURE 2. DIFFERENT MODES OF OPERATION FOR A BATTERY/DIESEL ONLY POWER SYSTEM.

hypothetical results of installing wind turbines and controls onto a diesel system. The wind power is used to directly reduce the load on the diesel engines. With the use of wind power, a smaller diesel may also be used to cover the remaining load, which will also result in larger operation and maintenance savings.

Type E: Installation of an advanced renewable/battery/diesel hybrid power system

In this case, a diesel system is retrofitted with both renewables and a battery bank. During times of high renewable production, wind and/or solar power is used to meet the community load and to charge the battery bank. When the renewable power is less than the load, either the batteries or the generator cover the shortfall. If the batteries become depleted, the generator(s) are started to cover the load and perhaps charge the batteries. The combination of renewables and batteries has the potential of reducing the diesel fuel usage to a very small portion of the amount required in a diesel-only system. The fuel savings, along with savings in diesel maintenance costs, must be weighed against the high system capital cost and the periodic replacement of the batteries. Diesel systems of any size can be retrofitted with renewables and batteries, although the system design and control will likely change dramatically. The size and purpose of the battery bank will also vary greatly depending on the available resources and system costs. A general size description for batteries is given in the following section. Hybrid system cost-effectiveness is highly sensitive to the abundance of the renewable resource, diesel maintenance costs, and the diesel fuel price. A 24-hour graphical description of system operation is shown in Figure 4. This system shows the diesel operating in the morning to cover the load and charge the batteries. After this the batteries and renewables cover the load until evening when the batteries are again charged, but this time by the wind.

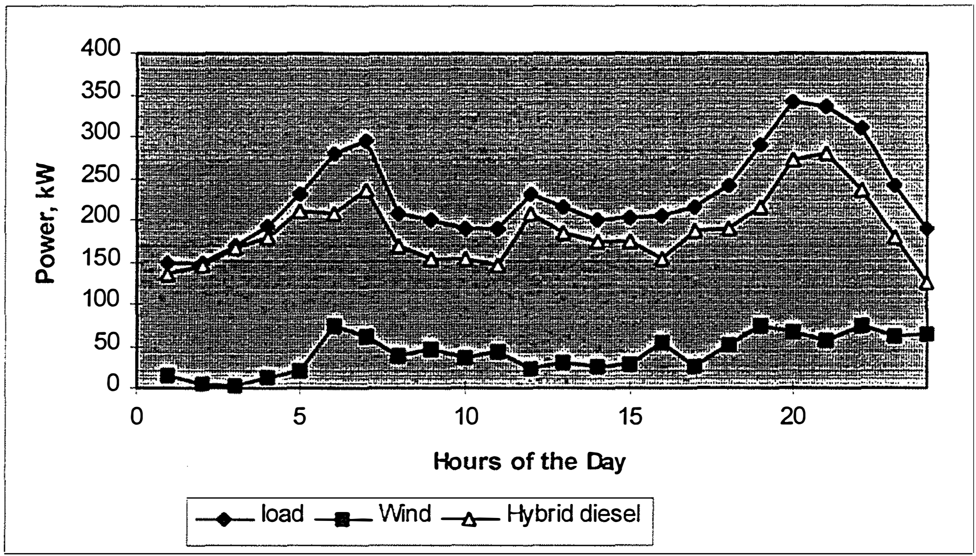

FIGURE 3. DIESEL POWER REDUCED BY THE INCLUSION OF RENEWABLES.

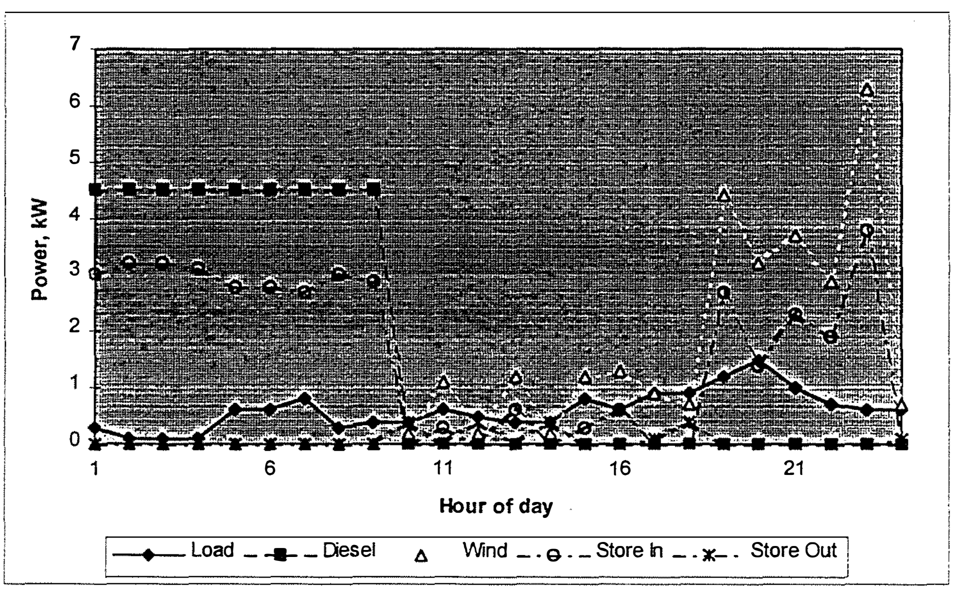

FIGURE 4. OPERATION OF ADVANCED HYBRID SYSTEM

Storage Requirements for Hybrid Power Systems

The amount of storage capacity, based on the approximate time of load-coverage capacity, may fall into one of the following categories. The appropriate level of storage depends on the cost trade-off involved at each stage in this progression and the general size of the power system.

1 to 7 minutes: Used to cover short turbulent peaks in the wind and to start generators, if required. Batteries are designed for high rates of discharge over short time periods to maintain grid stability.

7 to 30 minutes: Meet fluctuations in the net load (load minus renewables), thus allowing any diesels to remain off until it is clear that the lull in the winds is not a short-term fluctuation.

Hours: Allow diesels to run at rated capacity, rather than at part load, to maximize diesel fuel efficiency, storing the excess in the batteries to be used when beneficial for the system.

Hours to days: Time-shift an abundance of wind or solar energy to match the load. This is mainly applicable in places with small loads or where the operation and maintenance costs of a generator are larger than the cost of storing renewable power in the batteries.

Assessment Procedure

The process of retrofitting diesel systems is rather complex and requires the collection of resource and existing performance data to evaluate the available retrofitting options. A performance and economic analysis should then be completed to determine the economic benefit of the different options. Before this task is undertaken, it is necessary to determine if a particular system should even be considered for system retrofit. The following are some general indications that a diesel power plant would be a good candidate for retrofitting.

1. A large difference between diesel system-rated power and the average load for the community being served.
2. Large variations in the community load from the minimum to peak load.
3. If the plant diesels are spending long periods running at low power levels or at idle.
4. There are many system faults due to operator or systems errors.
5. High fuel costs including both purchase and transportation charges.
6. A local source of renewable energy such as sun, wind, or hydro.
7. High system costs due to maintenance or other problems.

Case Studies: Small and Large Systems in Indonesia

Indonesia, the fourth most populous country in the world, consists of 13,667 islands, of which at least 3,000 are inhabited. PLN operates in excess of 1,800 diesel power plants, which produce about 20% of the country's generated electricity. Of these diesel plants, 1,100 are below one MWe in total nameplate capacity and are widely distributed geographically, making fuel delivery, reliable operation, and maintenance expensive, time consuming, and difficult. Regulated tariffs on the generated electricity are causing PLN to lose money on the diesel plants, even with the price of diesel fuel fixed at $.17/liter. To limit costs, electrical service is limited to a few hours per day in some areas. In response to this need, the Indonesian government and PLN are considering alternative methods for providing power to remote communities. Three case studies that were part of the original study conducted by CPC, PLN, and NREL are described below. These case studies provide examples for some of the retrofitting options discussed above.

Case 1: Small system with good wind and solar resources

The diesel plant at Pariti is typical of many in Indonesia in that electrical service is provided only 12 hours per day, with the load profile shown in Figure 5 (solid curve). In this analysis, we consider the addition of a small daytime load shown with a dashed line and various retrofit options. Providing 24-hour power opens the door to the development of productive uses of electricity, such as micro-enterprises or small industry. The existing power system at Pariti consists of two 20-kW diesel gensets. Because the wind resource at this site is unknown, a scenario typical of many locations throughout Indonesia, wind speed data set from the nearby site of Sakteo, averaging 5.56 m/s at 30 m, was used in the analysis. Similarly, the annual average solar radiation, based on data from the nearby Kupang airport, is 4.4 sun-hours/day (kWh/m^2 day). These analysis were conducted using the Hybrid2 software (Baring-Gould et al. 1996).

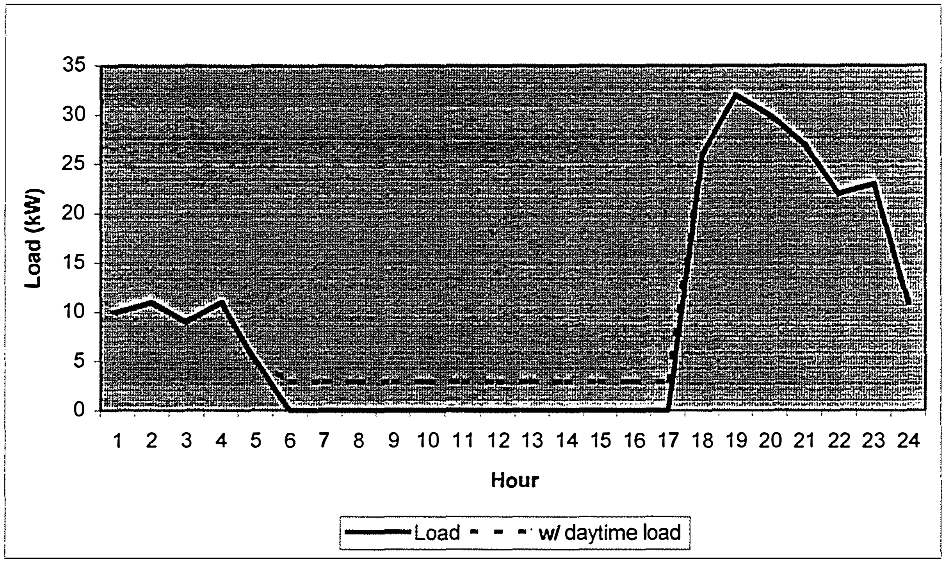

FIGURE 5. LOAD PROFILE AT PARITI WITH A 3-KW DAYTIME LOAD ADDED.

Retrofitting the existing diesel plant with renewables and batteries to form an advanced hybrid system while providing 24-hour operation will result in only a minor increase in cost over the existing all-diesel system that provides power for only 12 hours a day. The results of the different options are given below.

TABLE 1. A COMPARISON OF VARIOUS RETROFIT OPTIONS

System Type	**Service Period**	**New Equip. Cost, $**	**Fuel Use, l/y**	**Life-Cycle Cost $ (fuel @ $.17/l)**	**Cost, $/kWh ($.17/l)**	**($.34/l)**
Existing	12-hour	0	30,397	430,144	0.28	0.35
Existing	24-hour	0	46,383	697,377	0.38	0.48
Type B	24-hour	10,000	46,383	551,037	0.30	0.40
Type C (w/ controls)	24-hour	27,240	34,093	501,581	0.28	0.35
Type E (Wind)	24-hour	60,440	26,979	482,718	0.27	0.32
Type E (PV)	24-hour	55,240	31,850	507,192	0.28	0.35

Some of the recommendations resulting from the analysis are as follows;

1. For 24-hour service, controls and batteries are cost effective.
2. Measured wind and solar resources are needed for candidate sites. Wind turbines are cost effective at Pariti for this load scenario and a fuel price of $.17/liter, at wind speeds of about 5.6 m/s or greater. Photovoltaics are cost effective at a fuel price of about $.34/liter or greater.

3. Pilot projects for small diesel grid systems are recommended to demonstrate the feasibility of the approach.

Case 2: Large system with good wind resource

The analysis conducted looks at the potential inclusion of wind power into the large diesel plant in So'e, Indonesia. The inclusion of the advanced system controls and wind power could significantly reduce the consumption of diesel fuel and reduce the total number of diesel run hours. The analysis was expanded using parametric analysis to consider systems of similar size, where the fuel and wind potential may be different. The analysis considered various average wind speeds, wind penetrations, diesel fuel price, and different financing mechanisms. The retrofit systems considered did not include solar power due to the system size and available solar resource. The average load for the site was 505 kW and was supported by four large diesel gensets. The power plant provided power 24 hours a day and was controlled manually.

The basic result from the analysis is that given a delivered fuel cost of $0.17/l and an average annual wind speed of 5.56 m/s, the system is marginally feasible from a financial viewpoint. Similar systems in areas with higher fuel prices or wind speed should show dramatic economic viability, saving anywhere between $0.10 to $0.50 /kWh produced, as shown in Figure 6. In this type of system the potential for fuel savings increases as the installed capacity of the wind turbines is increased. This is shown in Figure 7, where the number of 50-kW wind turbines was increased from zero to 10 using a wind speed with an annual average of 5.56 m/s. Above about 300 kW of installed capacity, there is a diminishing return on the installation of additional turbines because, during high wind periods, more power is being generated than can be used. It should be again noted that above about 20% penetration of wind power, serious consideration must be given to power system dynamics to insure high quality, consistent power.

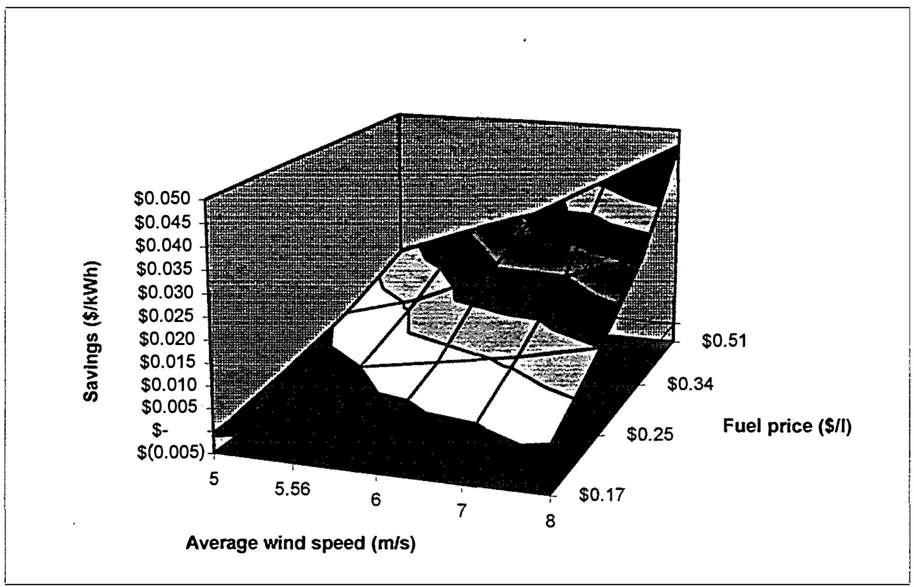

FIGURE 6. PARAMETRIC SAVINGS FOR WIND INSTALLATION

In addition to the analysis of using wind power to augment the diesel production for the So'e power plant, a simple control retrofit was also studied. In this analysis, the operational characteristics of the present diesel plant were compared to a version of that plant operated by an advanced control system. In addition, an analysis was conducted in which one of the larger diesels was replaced with a smaller one that could more efficiently provide power for periods of low load. The analysis showed that the cost of implementing the controls could be paid back in as little as 2 years. It was also found that the number of diesel starts was increased using advanced control, but that the total diesel run time could be reduced by almost half. This results in a large decrease in diesel O&M and overhaul costs. System savings of between $0.03 and $0.05 /kWh were produced with a very small outlay of approximately $50,000.00 for system and individual diesel controllers. Installing a smaller diesel to provide a better diversity in unit capacity was also shown to be cost effective.

Case 3: Moderately-sized diesel system without available renewable resources

The town of Lonthoir, Indonesia, is a large community that is provided power using two diesel engines. The town has power for 13 hours a day, from 5 p.m. to 6 a.m., and a base load of approximately 60 kW for services like street lighting and refrigeration. The load increases during the morning and evening up to about 135 kW. Because power is not available during the day, mainly due to the current tariff structure, no business or other productive uses of power are being realized.

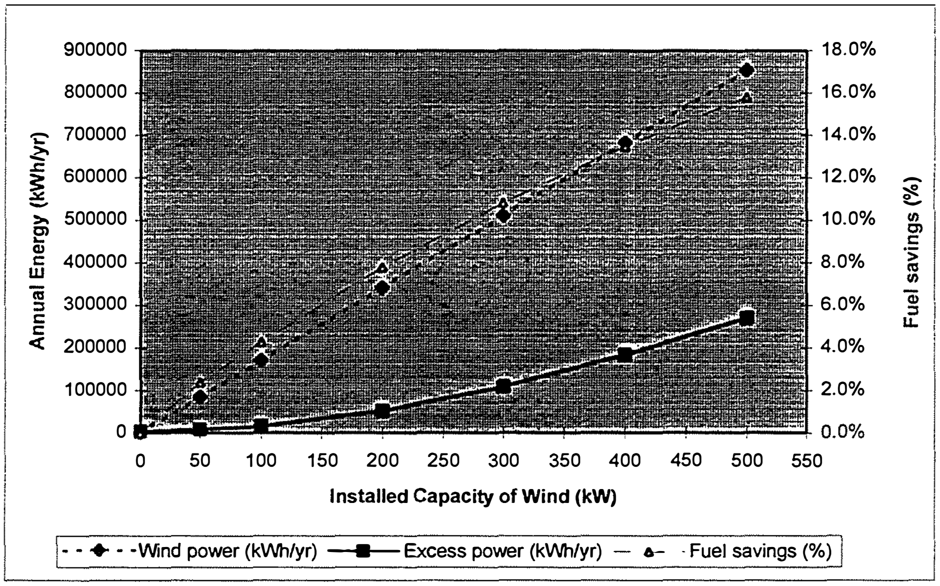

FIGURE 7. PERFORMANCE VARIATION WITH INSTALLED WIND CAPACITY

A power system was designed incorporating a battery storage bank and converter to allow the generators to cover the average load while using the battery bank to cover any fluctuations above the rated level of that generator. Due to the lack of data demonstrating a wind or solar resource, renewables were not considered. An analysis considering two fuel costs and converter/battery sizes was also completed. Incorporation of a small daytime load and upgrading the system to provide 24-hour power was also considered. These analysis were conducted using the Hybrid2 software.

Using a battery and converter saves money for either 13-hour or 24-hour power systems. The projected savings ranged from 1 to 5 cents for each kilowatt-hour produced. During the evening, the average load never goes above the rating of the 140-kW diesel, but fluctuations in the load do. A 20-kW converter and battery bank combination covers these fluctuations and makes the second 100 kW diesel unnecessary, (Figure 8, next page). In a 24-hour system, the battery bank is used during the daytime. This allows both of the diesels to be shut off when the load is low. The battery bank is then recharged during the evening and early morning when a diesel is forced to operate.

Conclusions

In any existing diesel power plant, it is quite likely that some improvement in economy of operation can be achieved through one of the approaches discussed in this paper. In many systems the diesels are oversized and significant improvements are possible merely through improved genset sizing. When even properly sized diesels operate at low loading much of the time, the addition of batteries is likely to be cost effective. The cost-effectiveness of adding wind and/or solar generators to the system depends primarily on the abundance of the renewable resource and on the fuel price. Of all the retrofit options, the greatest diesel fuel savings may be obtained by combining renewables with batteries. A time-series model, such as Hybrid2, is needed to properly analyze and compare the design options. Often, the most challenging aspect of the assessment of diesel retrofit opportunities is obtaining accurate resource data.

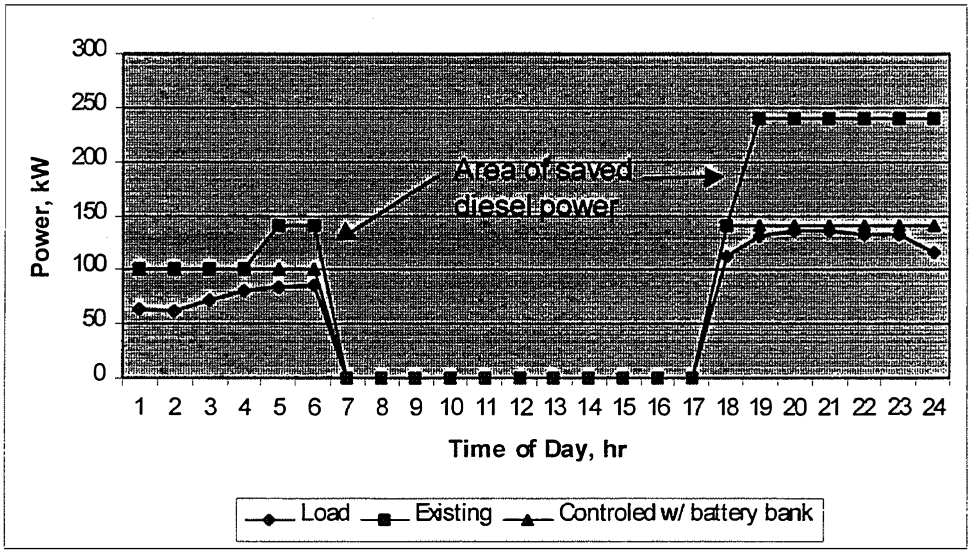

FIGURE 8. RUNNING DIESEL CAPACITY FOR ORIGINAL AND RETROFIT SYSTEMS

This analysis demonstrates two main points. Initially there are many options that governments, utilities and local groups can use to improve the operation of existing diesel power systems. Using the techniques discussed in this paper enables these organizations to free up funds now being spent on simple operation and maintenance. This capital can then be used to expand service to other rural areas. The second point that this paper makes clear is that there is a great deal of opportunity for the use of renewables and diesels, not only in new systems but in many older power systems worldwide. It should however be noted that this is a paper study and that systems implemented using these retrofitting options may result in different savings than are expressed. In addition, rural areas usually provide very different engineering experiences than urban centers and technology that has been proven in the latter may not provide the same performance in the former. However, with the expansion of power needs worldwide, the emphasis now being placed on environmentally friendly energy systems and the reluctance of many governments to be tied to volatile fuel prices, the potential for effective diesel retrofitting and the installation of new hybrid power systems has never looked better.

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