Off-grid 2.0

Fuel save controller: standalone power systems offer remarkable new opportunities for photovoltaic technology. Among other things, the combination with diesel generators lowers the costs of fuel consumption. In the meantime, there are new control devices in order to ensure both supply and mains stability with a high share of solar electricity.

Photo: Donauer Solartechnik

Solar roof of the St. Damien hospital in the Haitian town of Tabarre. Here the D:Hybrid, which was developed by Donauer, is responsible for controlling the 85 kWp solar installation that is switched parallel to a diesel generator with 200 kVA. The annual electricity consumption amounts to approximately 788,400 kWh. Photovoltaics accounts for 18% of the electricity generated at the hospital, so that a total of 106 liters of diesel are saved on average each day.

Diesel generators are common. They often form the core of standalone power systems. In the case of consumers connected to the mains they are used for emergency power generation, which is not only common but, in some countries, goes on for up to 16 hours per day. Typically, diesel generators are located in countries in which there is strong population growth and where the consumption of electricity is increasing. This is expensive, with an upward tendency. Thus, there is a strong incentive to seek out alternatives.

The costs of photovoltaic systems have been halved in the past three years and are now competitive. The cost per kilowatt hour of generated electricity with diesel engines essentially depends on the operating costs (diesel fuel and maintenance) and in smaller measure on the costs of investment. When it comes to combinations with photovoltaic systems, the number of operating hours of these units can be substantially lowered. The fuel costs between 25 and 35 cents per kilowatt hour of electricity. Since the operating costs of photovoltaic systems are relatively low, the total costs of the system can thus be reduced. The focus when designing PV-diesel hybrid systems thus lies in minimization of the period of operation of the diesel generators. At the same time, the stability of the electricity supply and the loads must be guaranteed. Therefore, it must be ensured that the generators operate in their work area.

Enormous market potential

This market could potentially become quite large. Although there has been a lot of fluctuation in the global sales of diesel generators in the past three years, it was nonetheless at a high level, rising from 38 GW in 2010 to nearly 48 GW in 2011, only to decline to 40 GW in 2012 (according to Diesel & Gas Turbine Publications, 36th Power Generation Order Survey). More than 50% of this quantity was accounted for by off-grid industrial plants or grids with frequent supply failures.

The most important factor for the profitability of photovoltaic-diesel hybrid systems is the fuel price that the plant operator pays, which is dependent on the respective taxes applied, subsidies and the distribution channel (retail or wholesale), as well as other factors. Short payback periods are usually required to obtain corporate finance for these type of investments. With amortization periods between three and six years, the economic viability is quite attractive.

Such a hybrid standalone system requires a unit that provides for the AC mains power supply. Additional generators can be connected to it by synchronizing their frequency, voltage and phase position to the AC mains power supply made available by the diesel generator. The unit responsible for the electricity mains must ensure that the voltage and frequency remain within the prescribed limits and just as much electricity is generated as consumed. In hybrid systems a bidirectional inverter with a battery can also take responsibility for grid management. At the moment, however, this is still too expensive; their life spans are relatively short and, in addition, it makes the systems much more complex. In the case of most of the systems that are currently available, the integration of batteries is supposed to be postponed until costs have declined and various technical questions are clarified. Thus it is still

Photo: SMA Solar Technology AG

Photovoltaic systems can substantially reduce the operating costs of industrial plants – like the standalone power system, which SMA equipped with the required fuel save controller, in this mine in South Africa. Diesel generator output: 2x800 kVA; photovoltaic output: 1 MWp; savings according to SMA: up to 450,000 liters of diesel per year.

unclear how long the devices last, how a wide range of temperatures affects operation, how maintenance and service can be organized in remote areas, and how recycling functions. That is why most manufacturers designed their first generation of fuel save controllers for systems in which a diesel generator builds the grid and determines its parameters. Thus a diesel generating unit must be in constant operation. If there are additional generators, then they are operated in accordance with consumption and the photovoltaic output.

KEY POINTS

- Given the expense of diesel generators, PV-diesel hybrids are an affordable compromise, provided they strike the correct power balance.
- Despite a contraction in 2012, the market for diesel hybrid systems boasts a great deal of future potential.
- To achieve sustained growth, the next generation of hybrid systems must pinpoint the most efficient degree of penetration.
- Fuel save controller devices ensure that in instances where higher solar penetration occurs, the hybrid system balances the load accordingly.
- This controlling device must equally measure and monitor the power range, ensuring sufficient reserve power is available.
- Technological advances that have benefited off-grid systems could also have a part to play in the future of battery backed grid-connected systems.

Degree of penetration is crucial

How interaction between the diesel generators and the photovoltaic system is to be controlled is dependent on the momentary or average degree of penetration of solar energy in a particular period. The momentary degree of penetration represents the instantaneous output of the photovoltaic generator in relation to the peak load. The average degree of penetration is energy generated divided by energy consumed. The relationship between both degrees of penetration depends on the temporal distribution of consumption and weather conditions. In order to obtain average degrees of penetration of more than 20%, one generally requires momentary degrees of penetration of more than 50%.

Integration of the photovoltaic system is rather simple with relatively low momentary rates of penetration of less than 20%. The generation of solar electricity can be regarded as a "negative load." Then no additional control unit is necessary since the diesel generators automatically throttle their output if less power is required. However, there is an effect that becomes increasingly relevant with increasing photovoltaic output. If solar electricity flows into the standalone power system, then under certain circumstances several diesel generators may be switched off for a longer period of time. Thus, system inertia is reduced. This in turn increases the tendency toward frequency fluctuations. Therefore, solar inverters in such systems must satisfy higher requirements than those in grid-connected systems and operate in a stable manner over a greater voltage and frequency range.

Controller for high degree of penetration

With higher rates of solar penetration, the fluctuation of solar power generation becomes an increasing challenge, particularly if one intends to use as much of the produced solar electricity as possible so that diesel consumption is reduced. The diesel generators have to ensure that production is equal to consumption at all times. If there is a large flow of solar electricity, then the diesel generators operate with a very low load. In this case the minimum load may not be undershot. More-

Photo: SMA Solar Technology AG

This diesel hybrid system in India is another example of the cost-savings in these fuel save control systems. SMA was also responsible for this installation.

over, decline in the fuel consumption of the diesel generators does not stand in linear relation to reduced consumption. With lower loads they work less efficiently than with higher ones. Thus a diesel generator operating at 30% of its rated power consumes 20% more fuel per kilowatt hour produced compared with a diesel generator under full load. This leads to greater engine wear and an increased maintenance requirement due to deposits in the waste gas system and in the pistons, which are caused by incomplete combustion, banging in the pistons, fuel contamination and condensation from water in the lubricating oil.

In the case of more modern engines with common rail injection – which are being used on an increasing basis – the situation is somewhat better than in the case of engines with mechanical injection. For such diesel generators it suffices if they are always operated with a load of at least 30%.

If the diesel generators are combined with a photovoltaic system then an additional control unit must ensure compliance with this 30% minimum load. Such a device is sold, for example, by SMA under the name "Fuel Save Controller." Other manufacturers have so-called SPS-based models on offer that are connected with solar inverters and diesel generators via a communication interface (generally Modbus) and continuously monitor the mains parameters (electricity/voltage) at the connection point of the loads. As soon as the diesel generator load approaches the minimum load, the controller reduces the power output of the solar inverters in order to maintain the load of the generators above the minimum capacity. The diesel generators respond indirectly since they supply the residual load, defined as the electricity demand minus the photovoltaic output.

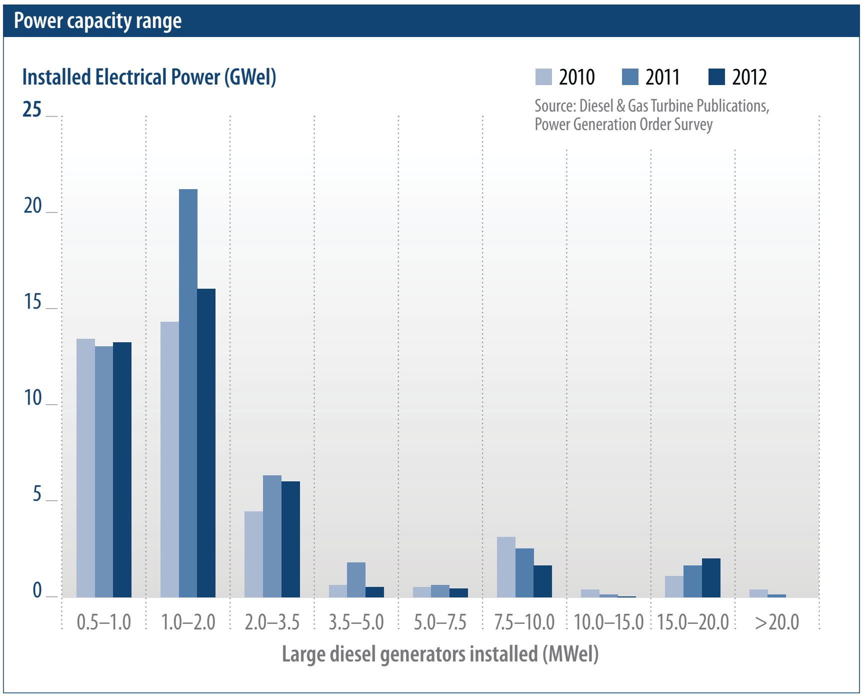
The controller must also quickly respond in the case of a sudden load drop, or for example in case switchgear trips off due to a fault, because if solar power generation exceeds the load in the system, then the diesel generators automatically switch off in the best of cases. If for any reason this should not occur, then the solar power feeds the diesel generator, which would then operate as the engine. This can cause irreparable damage to the combustion engine. And thus the controller must respond quickly enough. Should it be necessary to respond very quickly, then the controller automatically switches off the inverters. However, this happens only rarely – it usually suffices to reduce the inverter output.

The controller is equipped with logic for load optimization in the system. The aim is to not deactivate the photovoltaic system any more than necessary. How this is accomplished depends on the mode of operation of the diesel generators. They can operate with a load-dependent frequency or speed. That is, if there is a high load, then the frequency in the system is reduced. Or they can oper-

IN A NUTSHELL

The annual sales of diesel generators for industrial electricity applications lies between 40 and 50 GW. The average costs of diesel fuel for generating electricity in industrial plants amount to $0.25 to $0.35 per kilowatt hour. In technical terms it is possible to save up to 30% of diesel fuel by integrating PV systems without batteries into the diesel production systems without jeopardizing the supply or mains stability. By incorporating storage units, the hybrid system can be expanded even further in the future – as soon as the required capital outlays are reduced and the life span extended. The integration of batteries would eliminate the upper limit of the penetration rate of photovoltaic output in standalone installations when it comes to generating electricity.

Graphics: Solarpraxis AG/Harald Schütt



The largest share of the market (between 80 and 90%) for diesel generators for industrial applications lies in the capacity range of between 500 kVA and 3.5 MVA. Thus there is a significant untapped market for large-scale solar systems integrated into PV-diesel hybrid solutions for industrial applications.

ate with a fixed speed at a nominal frequency. This is most often the case since consumers usually do not want any fluctuations in frequency. In the first case the droop mechanism can be used in order to reduce the inverter load. Independently of whether a synchronous or a droop mechanism is used for load allocation in the system, the inverters should be able to control or limit their power output with an increase in the PV penetration rate, whether through communication interfaces or as a response to frequency fluctuations in the mains.

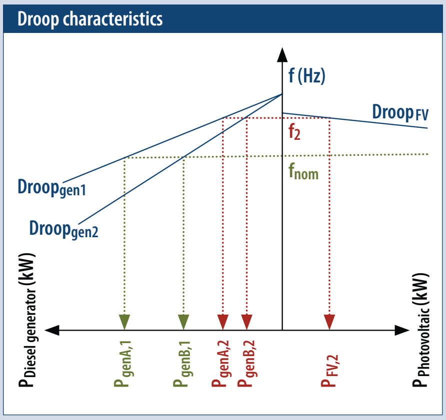
Considering the power range

The power limiting capacity of the solar inverters is also used in order to make enough operating reserve available in the system. This is indispensable if the standalone power system is to function in a reliable manner. In diesel generation systems the spinning reserve that is quickly available is the difference between the current output and the maximum power of the generators. A frequent requirement for specification of the required operating reserve is the so-called N-1 rule. It specifies that the supply is to be maintained in the case of failure of one of the diesel generators. This means that the overall capacity of the diesel generators must still cover the entire load in the case of a failed unit. For this purpose, one or more generators are usually used as a backup. In addition, a spinning reserve is provided for so that the overall capacity of the diesel generators, which at the same time may be in operation, is always greater than the maximum power requirement. Here the rule of thumb requires 110% of the estimated maximum load.

Integration of solar energy with its natural fluctuations increases the need for the operating reserve even further. This additional requirement depends on how quickly the solar output varies; for example, if a cloud passes by. That depends, among other things, on weather conditions and the size of the solar installation. Thus far there have only been a few studies on the topic. Nevertheless, those that were conducted in different regions arrive at a similar result – within ten minutes the output reduction is with a high level of confidence less than 70% of the original PV output. If one assumes that ten minutes is sufficient in order to switch on and synchronize an additional diesel generator, then a share of between 20 and 30% of the average forecasted AC output of the PV installation can still be expected and, therefore, can be considered as safe power output. The required spinning reserve can be reduced if the solar generator is oversized in comparison to the rated output of the inverter. This smooths the load variation at the diesel generators.

The controller must ensure that a sufficient spinning reserve is always available. If it determines that the spare capac-

CONTROL MECHANISM

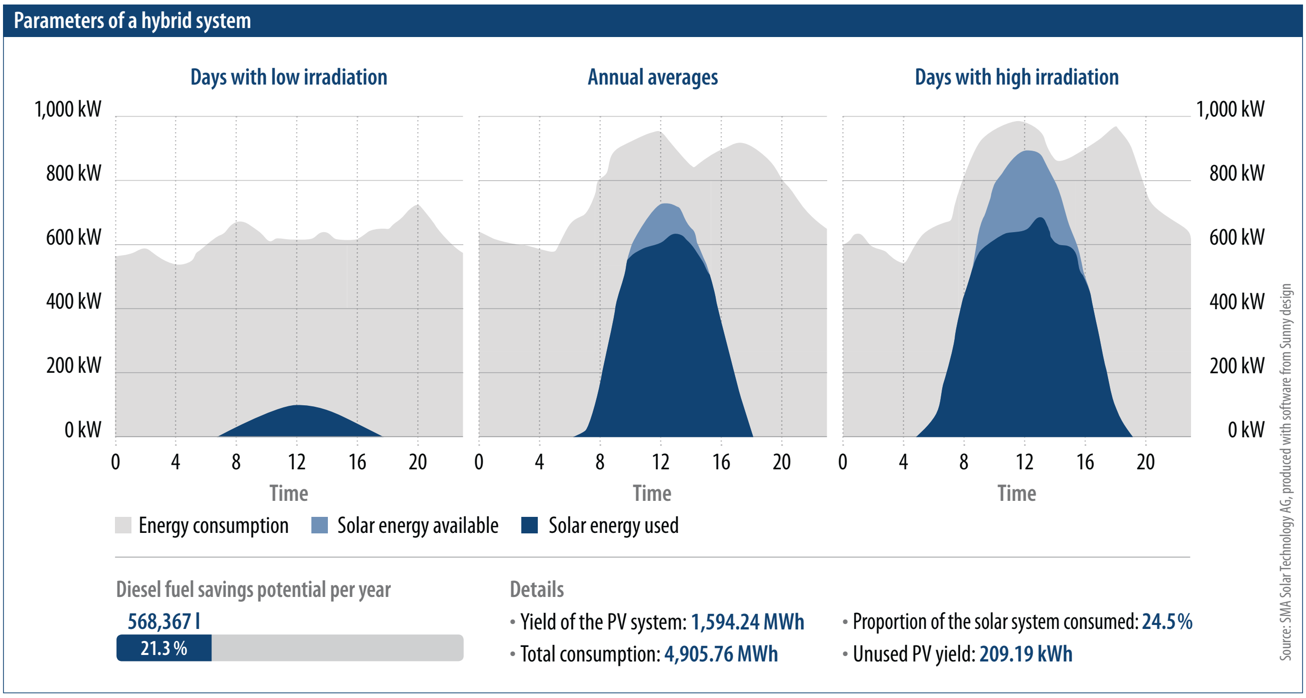


The mode of operation of the control unit in the fuel save controller for diesel generators that work with load-dependent frequency: The diagram shows the characteristic curves (droop) of two parallel switched diesel generators and a solar inverter. The slope of the characteristic curve or "droop" is proportional to the rated real power output of each generator, with a less steep (flatter) characteristic curve for the larger generator. With the nominal frequency of the system (green lines) the load is thus distributed to the generators in proportion to their rated output, whereby the larger generator provides the output $P_{genA,1}$ and the second generator $P_{genB,1}$. In this case the solar inverters can supply their entire output (the green line does not overlap with the characteristic curve of the solar generator).

If consumption decreases, then the frequency of the system increases from f_{nom} to f_2 since more energy is generated than consumed (red lines). In order to balance out consumption and production again, the first diesel generator reduces its power output to $P_{genA,2}$ and the second generator to $P_{genB,2}$.

At the same time, the controller limits the power output of the inverter to $P_{FV,2}$. Should the power output of the diesel generator fall below the prescribed minimum load, then the PV output drops to zero.

If the standalone power system does not work with load-dependent frequency, but rather with a fixed frequency, then the controller determines dynamically the characteristic curves by shifting for example the droop's idle frequency of the different generators.



A simulation of the operating parameters of a hybrid system, consisting of a bank of diesel generators with a rated active power of 1.45 megawatts and a solar system with one megawatt of rated output for a mine in Chile. One can observe how the controller reduces the power output of the inverters in order to keep the system stable and to ensure optimum operation of the diesel generators.

ity of the engine-generator (gen-set) units in operation are insufficient, then it must occasionally reduce the output of the solar inverters. Then the load supplied by the diesel generators exceeds the threshold value at which an additional generator is activated. If, on the contrary, the controller determines that the required spinning reserve can be covered by fewer diesel generators than currently in operation, then it can make use of an earlier deactivation of the photovoltaic output or any oversizing of the photovoltaic system in order to temporarily increase the photovoltaic output. Thus the load carried by the diesel generators drops below the shutoff value leading to the disconnection of a gen-set unit. If the controller works efficiently, then it limits the starting and shutdown of the diesel generators to a minimum.

With high solar power production and low consumption, the risk of overvoltage in the system also increases. In the case of hybrid systems, the voltage control through provision of reactive power is less efficient than in the case of conventional electricity mains because the lines have a low X/R relationship between reactance and effective resistance. Therefore, the controller monitors the current values of the consumed effective and reactive power and if necessary controls the solar inverter in such a way that it delivers reactive power. This regulates the system voltage, and the diesel aggregates no longer have to make so much reactive power available. The solar inverters should be able to produce both inductive and capacitive reactive power (at a capacity range of +0.8/-0.8) in order to ensure trouble-free synchronization of the generator with the grid.

Well suited for limited grid access

The integration of solar installations represents an extremely interesting option, in particular for industrial applications which – up to now – have been supplied by diesel generators; for example, mines, commercial facilities with a high consumption due to cooling systems, computing data centers, and water purification or desalination plants. Additionally, the controller can also be integrated into grid-connected photovoltaic installations that use emergency power generators due to frequent power failures. They are already being further developed: The manufacturers are working on systems with batteries that can be integrated into photovoltaic diesel hybrid systems.

The integration of batteries makes it possible for the diesel generators to not take over grid management, but rather for the battery inverters to. Then there is no longer any upper limit for the rate of photovoltaic penetration in standalone systems. Is Off-grid 3.0 just around the corner? ◆

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Photo: RENAC

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