Power Conditioning of Microgrids and Co-Generation Systems

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Content

1 Introduction

Instead of receiving all electrical power from the utility more and more industrial facilities and data centres are considering to produce their required electrical power right on-site. In the case that they want to keep the on-site power generation operational during mains outages, measures need to be taken to disconnect from the mains supply and to maintain a reliable power supply by stabilizing the operation of the island grid.

Rotary stabilisers utilizing robust synchronous generators are specially designed to operate independently from the mains supply while ensuring high quality power fed to the loads. Thanks to their integrated energy-storage devices, these systems are able, independently of the interconnected network, to form a high-quality local supply network and to supply the loads connected to them with uninterrupted power at constant voltage.

Equipped with bidirectional operating energy storage devices rotary stabilisers are therefore well suited for supplying and stabilizing power networks which are predominantly fed by other energy sources. Using stabilisers can eliminate the necessity of oversizing the power generation in a micro grid to ensure stable operating conditions in case of load or power supply fluctuations.

The conditions which they must meet to achieve this and their incorporation into such a network are explained below.

2 Basic requirements of a stable isolated network

When assessing the quality of a supply network, a critical criterion is the maintenance of voltage and frequency within predetermined limits. Both of these parameters depend on different influencing variables and can therefore be considered separately from each other to a large extent.

Frequency stability

The maintenance of a constant frequency directly depends on the active power balance within the network. If more active power is fed into the network than that consumed by the loads, the superfluous active power has to flow away somewhere in order to maintain the power balance. Without additional stabilizing measures, this excess active power automatically results in a frequency increase. This frequency increase is caused by the acceleration of the rotating masses, such as generators and motors, connected to the network, since in most cases only these have the capability to absorb the superfluous power and convert it into rotational energy.

Conversely, if less power is supplied than is consumed, the missing energy is taken from the rotating masses and consequently this leads to a reduction in frequency. Frequency fluctuations in the network can therefore be directly attributed to fluctuations in the active power, both at the loads and at the supply.

On the one hand, power fluctuations of the supply can be caused by failures of generators or frequency converters, for example, and on the other hand – in the case of regenerative energy sources – by a change in the incident of light in solar generators or by a change in the wind velocity or wind direction in the case of wind farms. In a large interconnected network, these effects usually lead only to a slight disruption of the power balance, so that no fast automatic control action is necessary in order to maintain the frequency constant within the specified limits. This differs in the case of small, isolated networks, so-called micro grids, which have no connections to a large and damping interconnected system. In this case, fluctuations in the power generation have a considerably greater effect on the active power balance of the network and therefore frequently lead to appreciable frequency fluctuations. The energy sources, including their control systems, are usually not able to adjust the output power to the new situation within a few seconds, so that fast-acting stabilization systems are needed to promptly restore the power balance and with it the frequency.

Ideally, the stabilization systems should be equipped with an energy-storage device, which allows equal amounts of energy to be absorbed as well as delivered, in order to react to both a power deficit and to excess power. (see Fig.1)

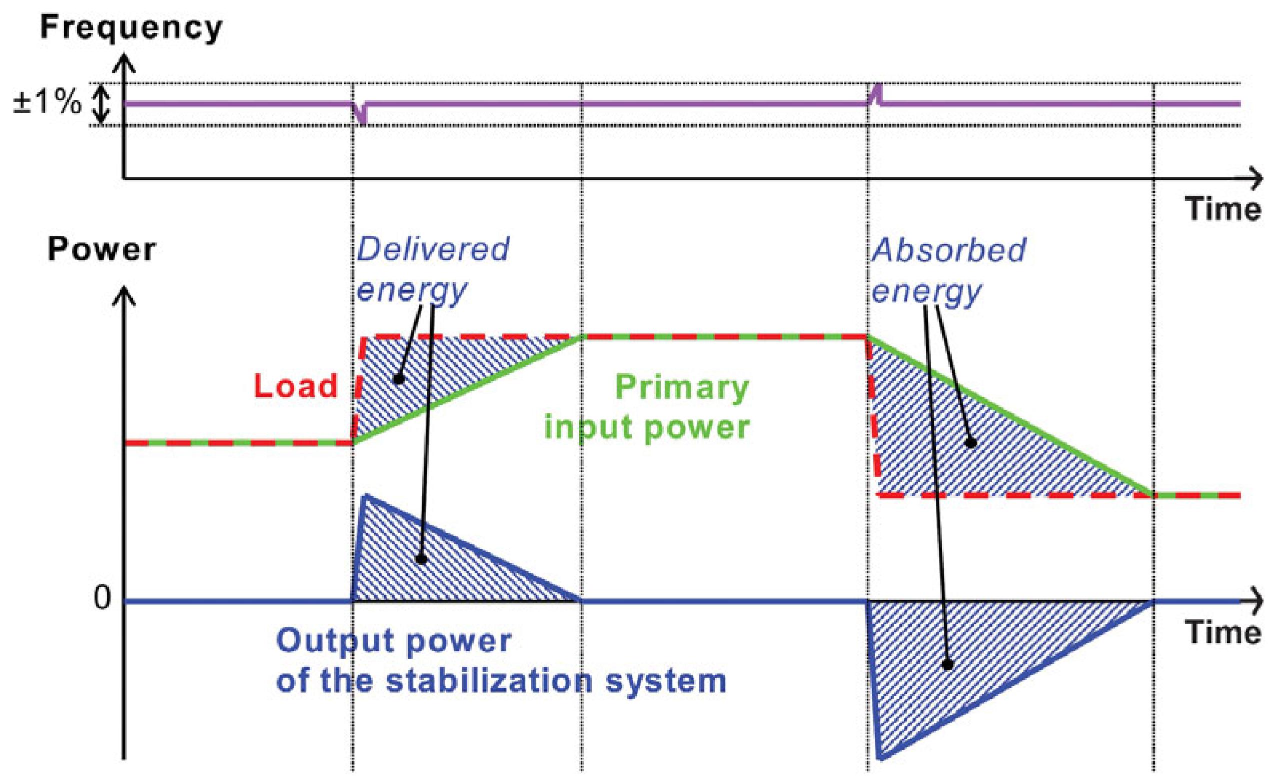

Fig.1 Mode of operation of a stabilization system with bidirectional energy-storage during load fluctuations in an isolated network.

This requirement makes conventional battery systems less suitable for this task since the power consumption is restricted by the combination of high internal resistance and upper cell voltage limit. On the other hand, batteries make sense if only the energizing of large loads or a power deficit caused by the failure of a supply system needs to be compensated. Flywheel storage devices are the first choice if excess power caused by load shedding is to be compensated.

In conjunction with bidirectional frequency converters, flywheel storage devices can provide stabilization in cases of power deficit as well as excess power. With reaction times lower than 20 milliseconds, the frequency in a micro grid can be kept constant in virtually all situations.

Voltage stability

There is a dependency between reactive power and voltage that is similar to that between active power and frequency. If the demand for reactive power increases in the mains, this additional power causes an increase in the voltage drops across the network impedances and the impedances of the in-feeds, resulting in a voltage drop at the loads. Conversely, a reduction in the reactive power leads to a rise in the supply voltage since in this case there are no voltage drops across the impedances.

Generally speaking, a disruption to the reactive power balance is easier to control than a disruption to the active power balance. The reason for this is that, if no counter-measures are taken, disruptions to the active power balance lead to a continuously increasing frequency deviation, whereas disruptions to the reactive power balance only result in a static voltage deviation.

3 Requirements for stabilization systems in isolated networks

The primary requirements for a stabilisation system are

… to rapidly react to active power fluctuations and to correct these so that the frequency is maintained at a constant value.

… to provide short-term reactive power on demand and thus maintain the voltage at a constant value for the load.

A stabiliser should therefore have the following major characteristics and functionalities:

- It should be designed for bidirectional power flow in order to provide stabilization for a power deficit as well as for excess power.
- The energy-storage device should be capable of being maintained at a mean charging state in order to absorb and to deliver energy at any time. This requires active regulation and knowledge of the charging state.
- The energy-storage unit must be rated so that sufficient energy is available to bridge the time interval required by the primary energy generator …

  … to restore the power balance of the network following a malfunction and …

  … to achieve a stable operating condition.
- It must be capable of being operated in parallel with other power sources, like for example wind farms, solar power generators, small-scale hydro generators, gas turbines, Diesel generators, etc.
- Their nominal power must be in the same range of the expected power deficit and excess power to allow sufficient compensation.
- They should be robust enough to withstand short-term overloads undamaged while continuously contributing to the adjustment of the power balance even accepting voltage and/or frequency deviations.

4 Realization

Rotary stabilisers of the types Piller UNIBLOCK™ UBT+ and UBTD+ (see Fig. 2) in combination with an energy storage and an output voltage generated by a synchronous generator are able to meet all of the requirements listed above.

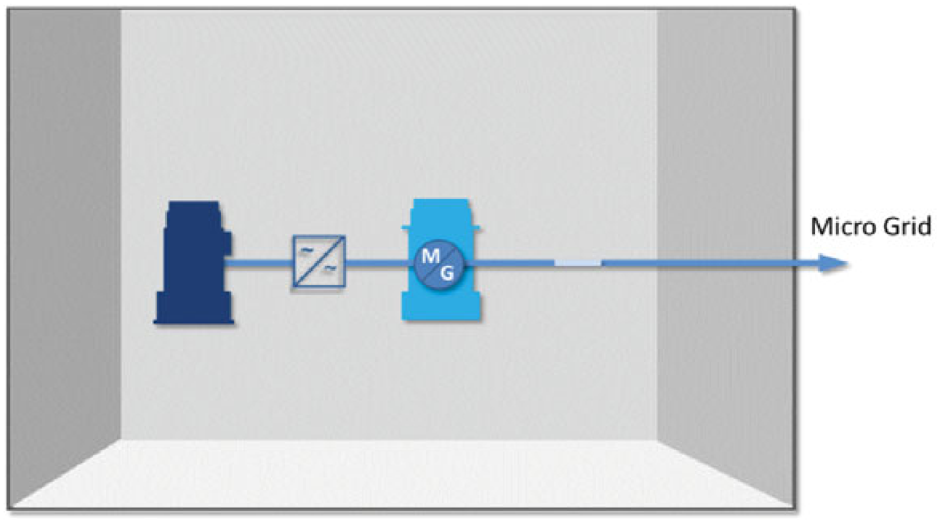

Fig. 2 Electrical single line diagram showing a basic stabiliser of the type PILLER UNIBLOCK™ UBT+ with the integrated flywheel energy storage POWERBRIDGE™. Here in the version to support an isolated grid without connection to utility.

As energy-storage units batteries can be used as well as the POWERBRIDGE™, a bidirectional operating flywheel energy storage device. The comparison of Fig. 3 and Fig. 4 as an example shows the influence of bidirectional frequency stabilization on a network supplied by a Diesel generator.

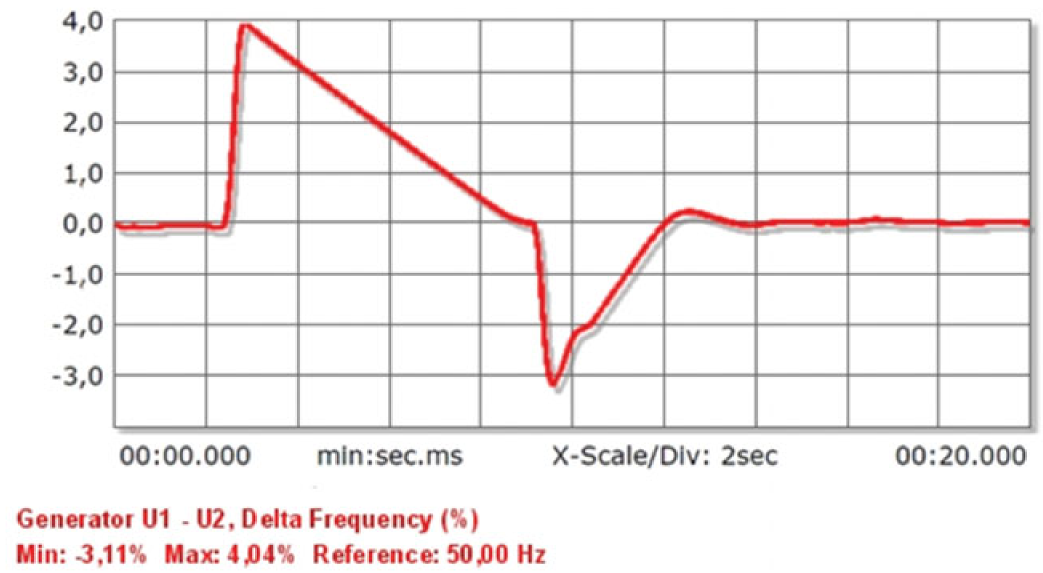

Fig. 3 Frequency response of a Diesel generator during 50% load disconnection and reconnection, here without additional frequency stabilization.

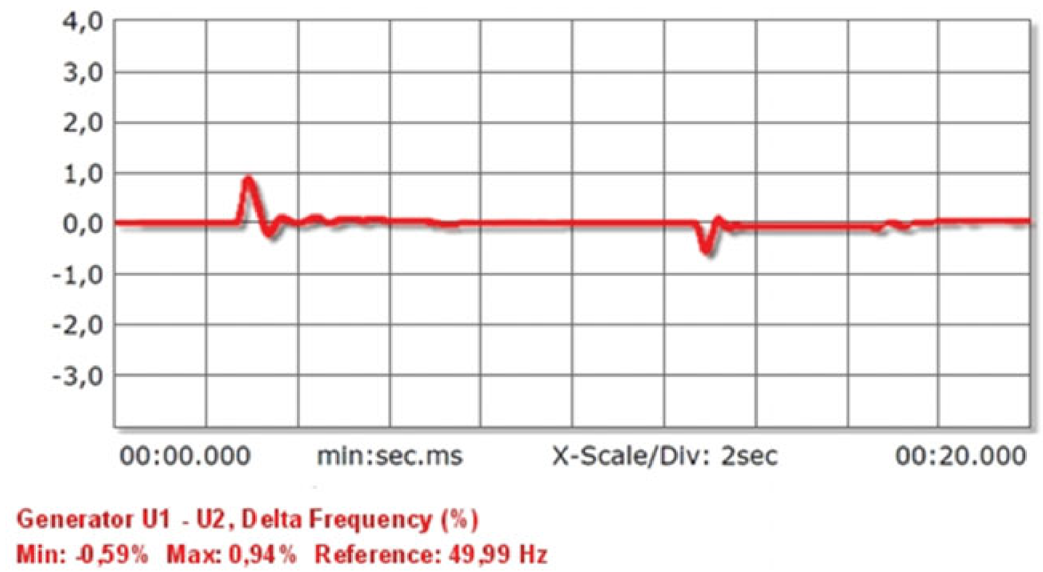

Fig. 4 Frequency response of a Diesel generator during 50% load disconnection and reconnection, with bidirectional frequency stabilization by a Piller UNIBLOCK™ UBT equipped with a POWERBRIDGE™ flywheel energy storage device.

Regarding these frequency stabilisation abilities rotary stabilisers can also ensure that the power generation in a micro grid does not need to be oversized to achieve stable operating conditions in case of load or power supply fluctuations.

In order to compensate for failures of the primary power generation and the lack of active power coming with it, the systems can also be designed with an integrated Diesel engine (for example see Fig.5). This combination also allows to cover load peaks in the local electrical network should the power of the primary energy generators not be adequate for this. In this case the Diesel would be started automatically when a complete discharge of the dynamic energy-storage unit approaches, so that the network can profit from the support of the stabilization system without interruption. If required, the Diesel can also be started manually at any time.

The synchronous alternators of the Piller system provide sufficient reactive power for voltage back up and make additional short-circuit power available to the network. In the case that inverter driven power generation like photovoltaic or micro turbines are to be used, the synchronous generator acts as a stable voltage source allowing the inverters to be operated in the same mode as if they would be connected to utility.

Piller UNIBLOCK™ UBT+ and UBTD+ are suitable for every standard voltage and frequency. In addition to the complete low voltage range from 380 V to 600 V they are also available in medium voltage up to a single module output power of 3000 kVA.

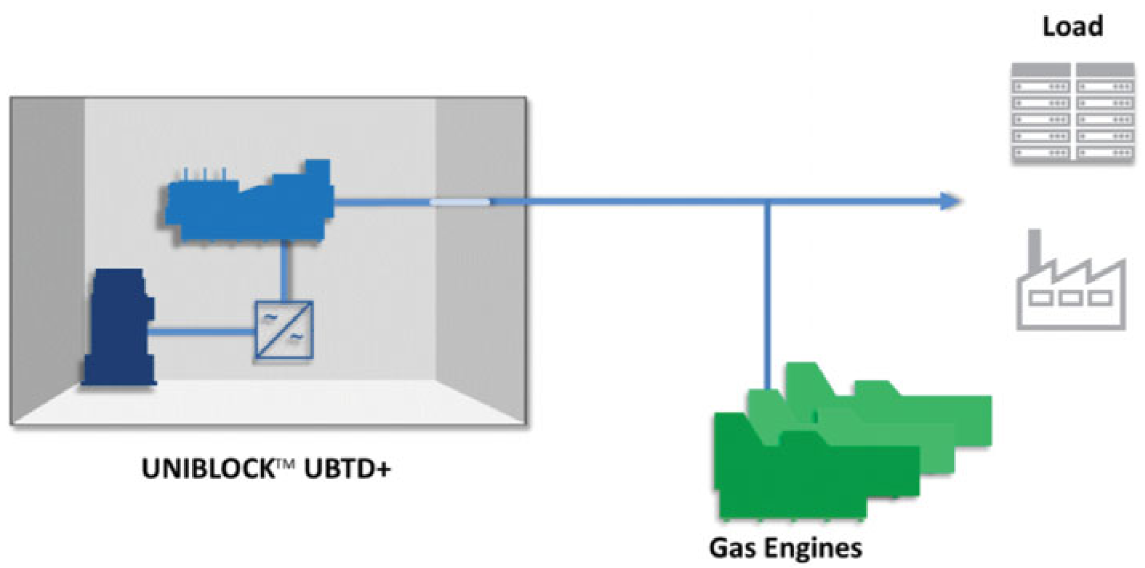

Fig.5 Stabilization and back-up of an isolated micro grid supplied by natural gas engines and a Piller UNIBLOCK™ UBTD+

If a network with autonomous energy supply is to have an additional link to the grid system, the rotary Piller systems can also be used as a mains coupling, as shown in Fig.6. The implementation of a choke allows utility independent high quality voltage regulation in the load network. Apart from protection against voltage fluctuations and mains failures the system enables the load network both to draw energy from the grid and to export superfluous energy to the grid. In the event of a mains failure, the stabilization system immediately isolates the load network from the grid and, depending on whether power was previously exported or imported, can then take up or deliver active power until the power generation in the now isolated network is adjusted accordingly.

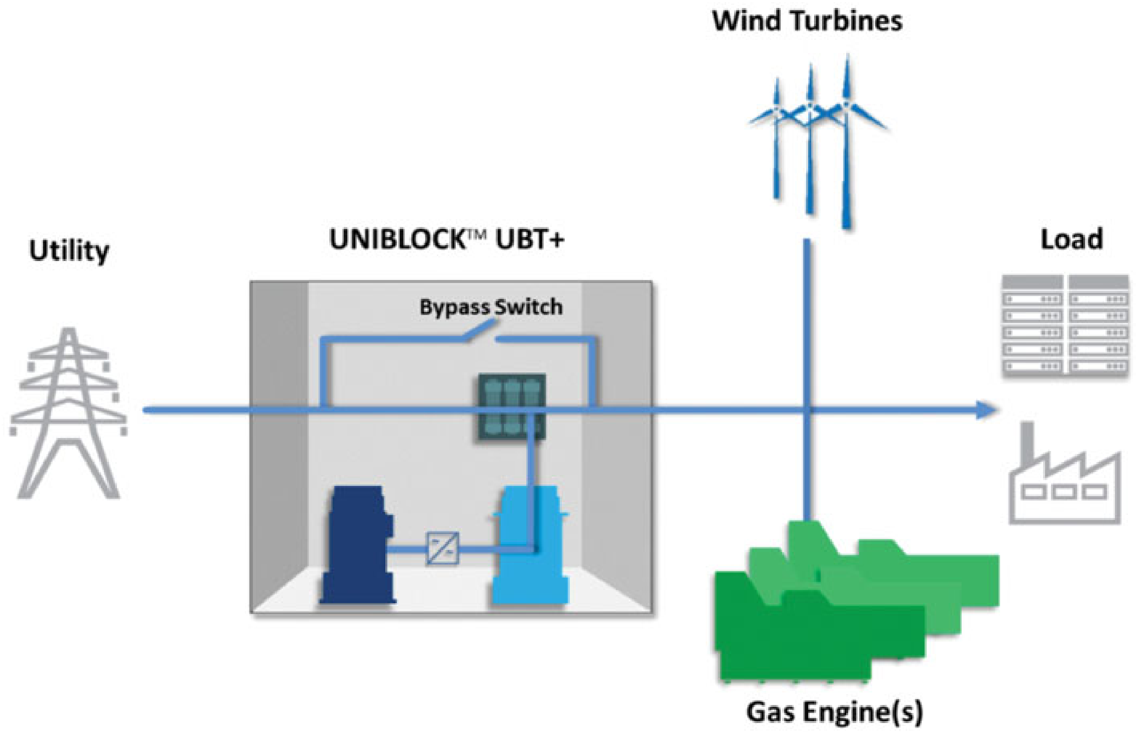

Fig.6 Use of a stabiliser as a mains coupling for a micro grid having its own power generation

There are two basic ways to integrate rotary Piller stabilization systems into an isolated network:

1. As a simple energy source which only takes up or delivers energy when values exceed or fall below given limiting values.
2. As the determining element of the frequency and voltage regulation which, in co operation with the other power generators, provides high quality power suitable to supply critical loads as data centres and semiconductor fabrications.

In each case the optimum individual solution for grid stabilization needs to be determined by the quality requirements and the complexity of the power supply network.

5 Case studies

5.1 Power Supply of a 35 MW Semiconductor Fab

This example shows the power supply system of a semiconductor fab, which includes a cogeneration plant of nine 3.9 MW generator sets with natural gas engines. Both electricity and heat power is transported over several hundred meters from the energy plant to the production facility.

The role of the stabiliser system is interfacing the high quality supply bus with the raw utility bus in order to provide back up from utility while blocking all grid born disturbances. Due to this interface it is possible to exchange electrical power with utility up to a level of 5 MW in each direction. This allows operating the gas engines on a high efficiency level according to the current heat demand of the fab.

The second task of the stabilisers is to disconnect the high quality supply bus from utility in case of a mains failure and to ensure power balancing in the resulting island grid.

The unique mode of operation of the flywheel storage allows contribution and absorption of full power. The ability of bi-directional power flow ensures excellent frequency control especially under transient conditions, keeping the whole systems frequency within tight limits. A single line diagram of the principal layout is shown in Fig. 7.

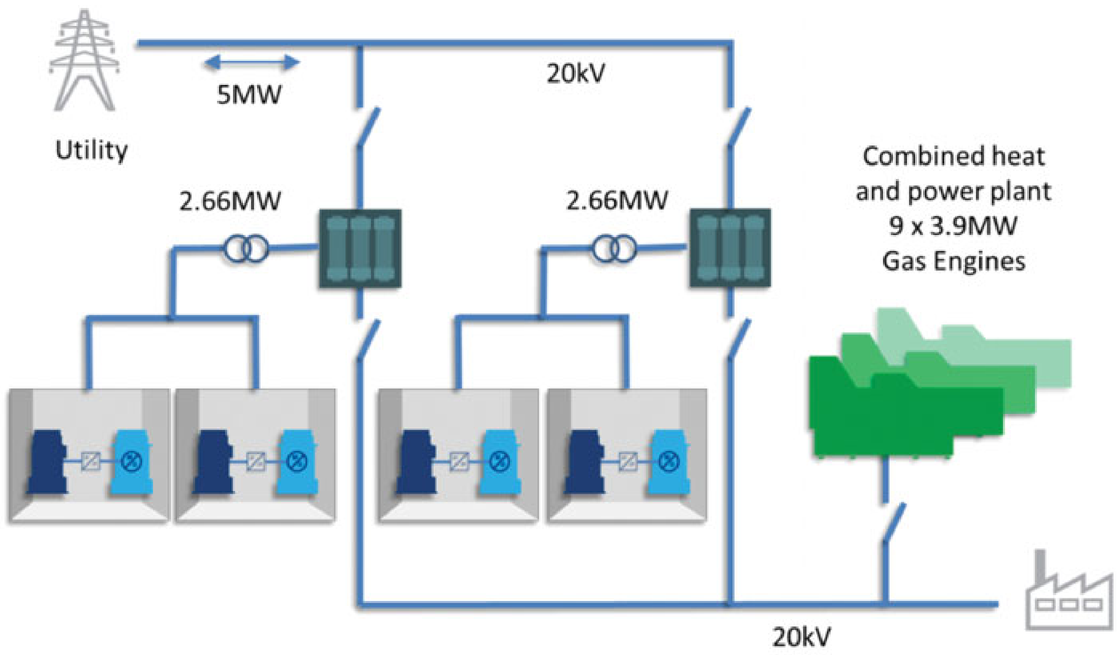

Fig. 7 Combining cogeneration and grid backup to a high quality power supply for a semiconductor fabrication

5.2 Utility independent power supply for a plasterboard producing facility in Dubai

Due to the lack of utility power on a site for a new plasterboard fabrication in Dubai, the required power of about 3.5 MW is produced locally, utilizing 3 Gensets with 1400 kW natural gas engines. The waste heat of the gas engines is used for the facility as well, so that the whole power plant is operating on a very high efficiency level. As a basic energy source a photovoltaic plant with 400 kW output power is planned for the future. (see Fig. 8)

To compensate the load changes caused by the production process and to inhibit that they result in inadmissible frequency deviations due to the relatively slow reacting gas engines, a rotary stabiliser with a bidirectional operating kinetic energy storage is installed. As there is no connection to utility available the stabiliser does not require a choke and an input breaker in this case.

To ensure a sufficient power supply even in the case a gas engine is dropping off-line, the stabiliser is equipped with an integrated Diesel engine which is able to drive the synchronous generator via an overrun clutch. The Diesel engine is automatically started once a complete discharge of the kinetic energy-storage approaches. The long term power regulation ensures that the required power is provided by the gas engines as the primary energy source. If the gas engines should not be able to produce all the power required by the facility, the Diesel engine of the stabiliser is used as second instance, and the flywheel as the third. Regarding the dynamic power contribution the order of the power sources is just reverse, according to the individual dynamic abilities of the systems.

So in case of a sudden failure of a gas engine the regulation ensures that initially the missing power is provided by the flywheel of the stabiliser, maintaining a constant frequency for the loads. Then the Diesel is started and takes the load off the flywheel before it is totally discharged, followed by the long term power regulation shifting as much load as possible to the gas engines. If the gas engines are able to produce enough power for the facility, the Diesel engine is stopped after some time. In the case that there is more power required than the Gas engines are able to produce, the facility can be supplied by a combination of Diesel engine and Gas engines.

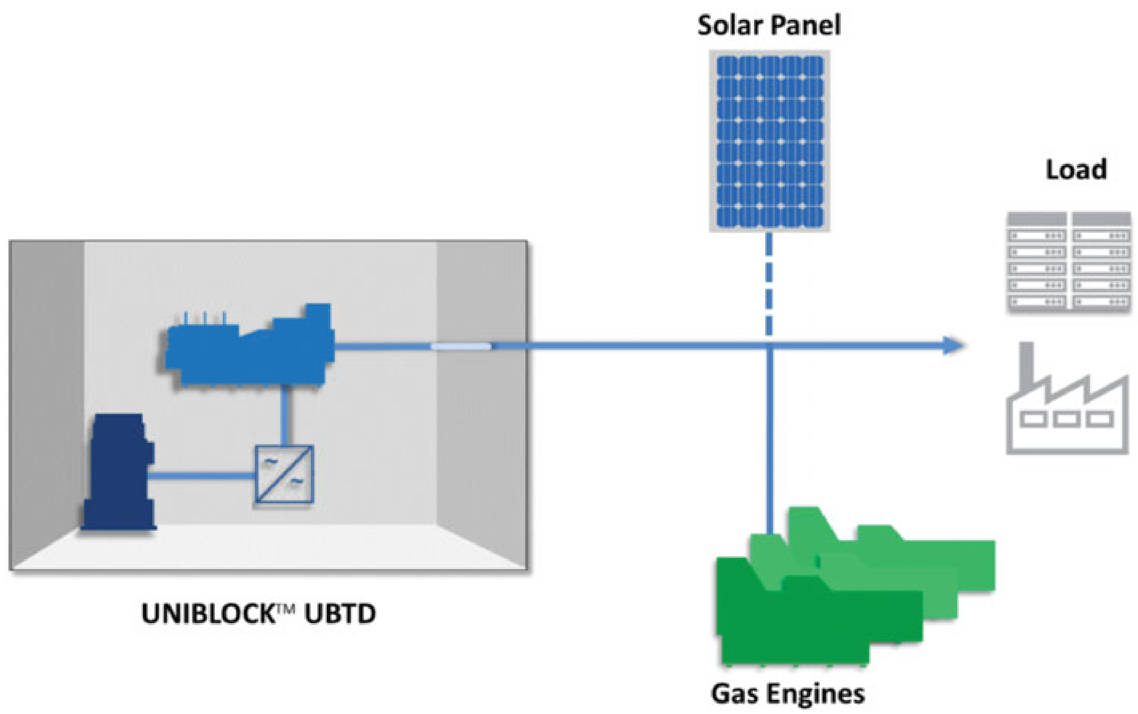

Fig. 8 Micro grid supplied by 3 gas engines, utilizing a PILLER UNIBLOCK™ UBTD for stabilization and for long term backup power.

6 Summary

The stability of electrical power supply networks is increasingly influenced by the extended use of renewable energy. There are special technologies and methods necessary to stabilise local supply networks in combination with on-site power generation. In this application, due to their robustness, their flexibility and high output power, rotating stabiliser systems utilising a synchronous generator are the first choice to guarantee a highly reliable power supply. In combination with bidirectional energy-storage devices, such as electrically-coupled flywheels, they are able to provide stabilization energy for every type of load or supply fluctuation and therefore ensure constant frequency even in island grids. The synchronous alternators of rotating stabilisers are also perfectly suited to operate in parallel with on-site power generation and to provide reactive power for voltage stabilization as well as to deliver additional short-circuit power to the network.

An optimized interaction between the stabilization unit and the power plant is able to ensure an island grid with an outstanding stability, which has been proven by multiple projects world-wide.

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