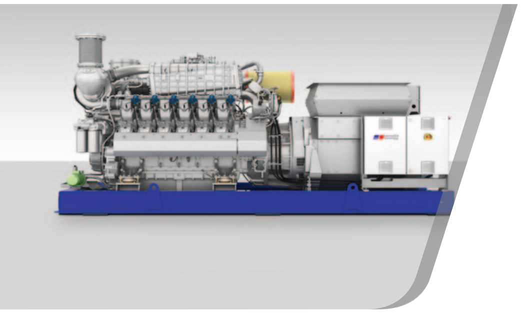
GAS ENGINE BASED POWER STATIONS IN COMBINATION WITH RENEWABLES

Renewable sources of energy with fluctuating output will be supplying an increasing share to the world's power grids. To support balancing needs, flexible and clean gas engine technology is expected to occupy a considerably larger role.



Authors:

Kapil Verma
ENSI – System Development
MTU India Pvt Ltd.- EARC, India
Kapil.Verma@mtu-online.com

Dr. Harald Gretscher
EDP – Power Plant Design
MTU Friedrichshafen GmbH, Germany
Harald.Gretscher@mtu-online.com

The rapid scale-up of many emerging power markets, at the same time as an introduction of higher levels of solar, hydro and wind renewables, can lead to a mismatch between local power needs and the capacity of the network to meet those needs. Simultaneously there has been a rapid expansion in the availability and extraction of natural gas, although many areas lack gas distribution network infrastructure.

Whether you are powering a single factory or an entire community, you need power you can trust. A quick recovery is also needed when local power consumption has unexpectedly overtaken supply and created high peak demands that threaten the stability of the national or regional grid.

Rolls-Royce Power Systems (RRPS) can provide an effective and efficient means to erect power stations based on reciprocating gas engines in more remote areas rich in gas, while producing significant levels of electrical power to support the national electricity need. In addition, the rapid start-up, quick shutdown and fast ramp rates allow for the quick response needed to meet the variable generation of non-hydro renewables in microgrids, while the use of multiple units enables high levels of plant turn down and availability throughout the year. The benefits become even clearer when seen within the framework of a modular power system where the use of pre-defined customizable modules allows specific site needs to be accommodated, and to keep down the overall plant lead time from order to commercial operation date.

GAS AVAILABILITY AND POTENTIAL REGIONS FOR GAS POWER AS A BALANCING FORCE

Gas is utilised as significant contributor to clean power and clean industrial production. In the context of a global forecast demand, the share of natural gas in the global energy mix increases from 19% in 2014 to 23% in 2040, drawing level with coal as the second largest fuel in the global energy mix after oil. (IEA, 2016)

The main regions pushing global gas demand higher are China, which will become a larger gas consumer than the European Union by 2035, and India. Gas plays an important role in mitigating coal use and related air pollution in these regions.

In 2014 the non-OECD Asia region was almost in balance with regard to gas production and demand. While there was a significant deficit between production and demand in China and India, there was an excess of production in countries such as Myanmar, Indonesia, and Malaysia. This left the area with a net import requirement of just under 2% of the demand. Overall regional demand is expected to grow at CAAGR of 3.6% up to 2040. (IEA, 2016)

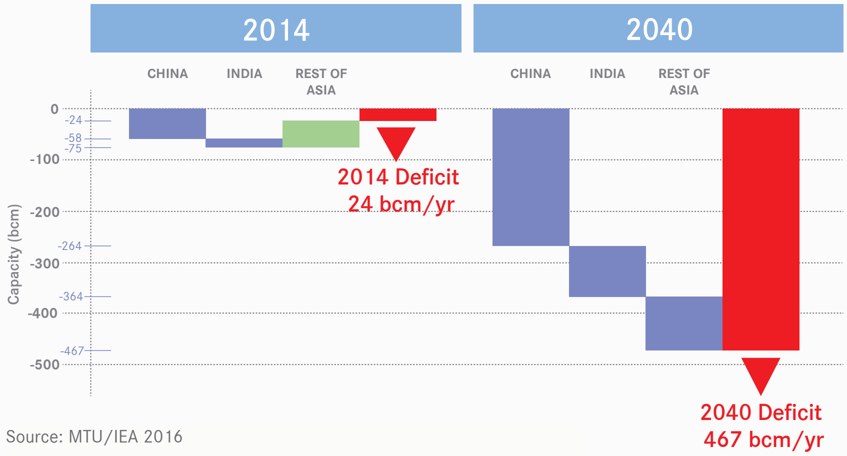
Fig. 1 shows the region wise gas deficit i.e. gas production minus gas demand. In 2014 China's gas deficit was -58 billion cubic meter (bcm) and India's gas deficit was -17 bcm making for a total gas deficit of -75 bcm around the region however the rest of Asia (excluding China & India) has an excess of gas production of 51 bcm. So the total gas deficit for non-OECD Asia in 2014 was 24 bcm. Similarly in 2040, China's gas deficit is predicted to be -264 bcm and India's gas deficit would be -100 bcm. The rest of Asia would also register a gas deficit of -103 bcm making the total gas deficit for non-OECD Asia 467 bcm until 2040.

The demand is driven by significant growth in all gas consuming sectors in China and India and the emergence of gas as a major fuel in the rest of the region. However, this is against an annual growth rate in gas production of two thirds the growth rate of demand. The result of these changing patterns of production and demand is that the regional deficit will grow to around 32% of the demand by 2040, leaving the region as a significant net importer of gas. (IEA, 2016)

The regional share of gas demand taken by power generation is expected to remain stable at around 37%. However, the gas share taken directly by industry will increase from 21% to almost 30%. This increase in share from industry, coupled with overall increased demand for gas and the large future regional deficit, presents a major challenge for economic development. It is a clear goal stated by many governments to reduce the carbon intensity of their expanding economic activity and to increase the geographical diversity of that economic activity. The addition of grid scale variable renewable energy (RE) to the network supports the first goal. Unfortunately the location of suitable sites for variable RE and the desirable sites for industrial expansion often do not coincide. If the electricity networks can be improved, it is practical to place the needed balancing power stations close by the new centres of electrical demand. In these cases the required gas pipelines can serve both the industrial and power generation need.

Here there are now two major and parallel infrastructure development programs to support clean economic development. The addition of RE as a commitment to control CO_2 emissions requires electrical infrastructure development.

FIG. 1 // GAS DEMAND DEFICIT PROJECTION FOR NON-OECD ASIA



Source: MTU/IEA 2016

The regional gas deficit and increased demand requires LNG (liquefied natural gas) importation terminals to be constructed and a gas distribution infrastructure to meet the needs of new industrial areas. Gas based power can operate at the convenient nexus between both of these developments, balancing the inherent instability of variable RE through the new electrical networks forming so called microgrids and drawing upon the new gas infrastructure being built for industrial growth.

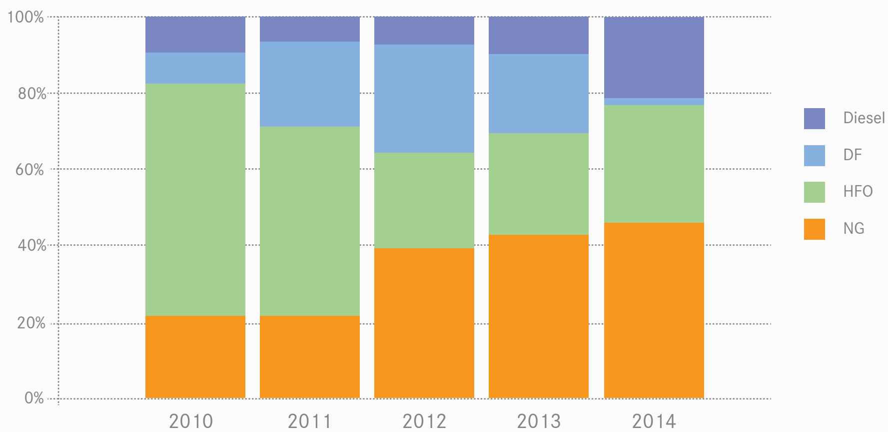
COMPARISON OF TECHNOLOGIES

Power developers of distributed generating systems as add-on to renewable energy sources have a choice between two primary power sources: gas reciprocating engines and gas turbines. Both are proven worldwide in thousands of pure power (simple cycle) and cogeneration (combined heat and power, or CHP) installations. Over the years, both technologies have steadily improved in efficiency, reliability, emissions performance and operating costs – and they continue to do so.

A most effective use of gas in Power Generation is as part of a reciprocating engine or a combined cycle gas turbine (CCGT) solution. As the reliable availability of gas has improved, the continuous power reciprocating engine market has shifted towards pure gas engines. In 2014, for the first time, the market share of pure gas reciprocating engines, in the largely continuous power market of >3.5MW units, exceeded the combined share of HFO and dual fuel engines, see fig. 2 (DGTW, 2015).

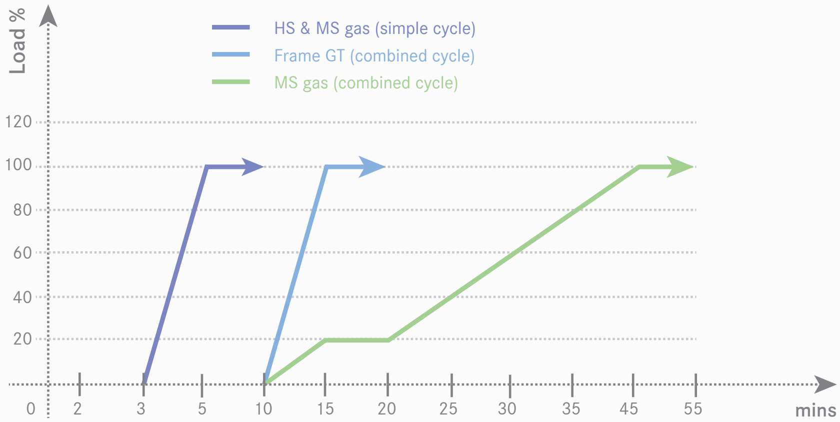
Many papers have been presented demonstrating the advantages of large reciprocating engine-based power and in an era of de-regulation and increase in the number of IPP projects, the 50-200MW market in the Asia/China/India region is well served by the technology. Typically this scale of power project replaces

FIG. 2 // FUEL SHARE OF GLOBAL RECIPROCATING ENGINE BY MW (>3.5MW UNITS)



Source: Diesel and Gas Turbine World 39th Power Generation Order Survey, 2015

FIG. 3 // RESPONSE TIME OF RECIPROCATING ENGINES WRT GAS TURBINE



Source: MTU Onsite Energy

existing high speed reciprocating power stations or provides for rapid additional local/ regional capacity. The final technology choice often comes down to a choice between combined cycle gas turbine plants and large reciprocating plants, in either simple or combined cycle.

It is the flexibility and cleanliness of gas engine based power that is attracting most attention in the market place. The improved turndown ratio of a plant running multiple smaller units versus one or two large gas turbines is well known. This comes from both the high levels of part load efficiency of the gas engine and a more simple mode of operation by simply switching off or on individual units as needed.

Modern high and medium speed reciprocating gas engines are able to start, synchronise, and ramp up to 100% load within minutes. This meets the requirements for secondary response level (SRL). Even faster start and loading is possible considering specific project conditions.

The plant can offer simultaneously with different engines tertiary response level (MRL) with simple or combined cycle, secondary response level in simple cycle through start from hot standby and shutdown, as well as primary response level (PRS) in simple cycle. The relatively flat fuel consumption curve across the power range allows for high levels of turndown in primary response without significantly degrading plant efficiency. The proportions of PRL, SRL and MRL offered for despatch can be adjusted in minutes to meet the ever changing capacity requirements and pricing structures.

Power stations that can be dispatched within minutes are important assets for balancing electric system loads and maintaining grid reliability. The generating technology affects the time required for a power plant to start up and reach full load.

The internal combustion engines can start and achieve full electrical output in less than 3 to 5 minutes for HS & MS engines to meet the stringent customer requirements – providing flexible, quick start capability. However combined cycle gas turbines can take over 30 minutes to achieve full electrical output, as shown in fig. 3.

In a recent public tender the benefits of the medium speed gas engine solution became clear when flexible 2-hour pulse cycles and 8-hour peaking cycle performances were required alongside the more regular 24-hour and 72-hour 100% running. The pulse cycles can be considered a form of SRL and MRL.

Referring to table “comparison between heat rate for different operating cycles”: Due to the start stop cycles for the CCGT steam system both the pulse and peaking cycle must be run in simple cycle. As a result the overall plant efficiency suffers. It is only when the plant runs for extended periods that the steam system can be brought on line and that the efficiency improves to better than the gas engine plant. The comparative combined cycle heat rate for 72 hours for the medium speed plant would be 7,263 kJ/kWh, almost matching the efficiency of the CCGT plant.

BENEFITS OF GAS ENGINE BASED POWER STATIONS

With more gas becoming available in the Asia/ China/India region, either piped or transported as LNG and regasified, it is set to increase as a share of energy consumption in the region from around 8% today to 13% by 2040 with a compound growth rate of 3.7%, well ahead of the overall Power Generation energy consumption growth rate of 2.5%. (IEA, 2016)

Here are some of the main advantages of gas engine based power stations:

// RAPID BUILD AND COMMISSIONING

Once financing is in place and notice to proceed given, time becomes critical. In a recent Indian

COMPARISON BETWEEN HEAT RATE FOR DIFFERENT OPERATING CYCLES

	SIMPLE CYCLE MS GAS RECIP PLANT	COMBINED CYCLE GAS TURBINE PLANT	CCGT HEAT RATE VARIANCE FROM MS
2-hour pulse cycle	7,870 kJ/kwh	7,870 kJ/kwh	+26%
7-hour peaking cycle	7,945 kJ/kwh	8,112 kJ/kwh	+2%
72-hour running	7,945 kJ/kwh	7,263 kJ/kwh	-8%

Figure 4:
Two engine pipe modules loaded to 40ft standard trailer for shipping
(Image: Rolls-Royce Power Systems AG)

Figure 5:
One engine set of table coolers per 40ft container
(Image: Rolls-Royce Power Systems AG)

public tender, two developers offered reciprocating solutions with a project timeline of 14 months to commercial operation date (COD) whereas the CCGT solution required 18 months. Where regions suffer from irregular power supplies the reduced timeline can allow for faster local economic development.

The shorter lead time of the core reciprocating engine reduces project duration. However, it is the use of repeated modular elements for the plant design that enables parallel working at site to reduce build duration. The use of pre-tested modules shipped to site reduces on-site construction time and the risk of extended plant commissioning duration. Furthermore the size of the individual power units means that major items such as auxiliary modules, chimneys, cooling and charge air systems can be completed and tested in a factory environment, broken down for shipping in standard 40ft containers and delivered to site ready for installation and operation (see figs. 4 and 5).

// PHASED DEVELOPMENT

Financing remains a major challenge in the region particularly for IPP. Using a phased development approach can allow an IPP to gain experience while providing better matching of capital expenditure to revenue. This improves cash flow and provides a stable base for fur-

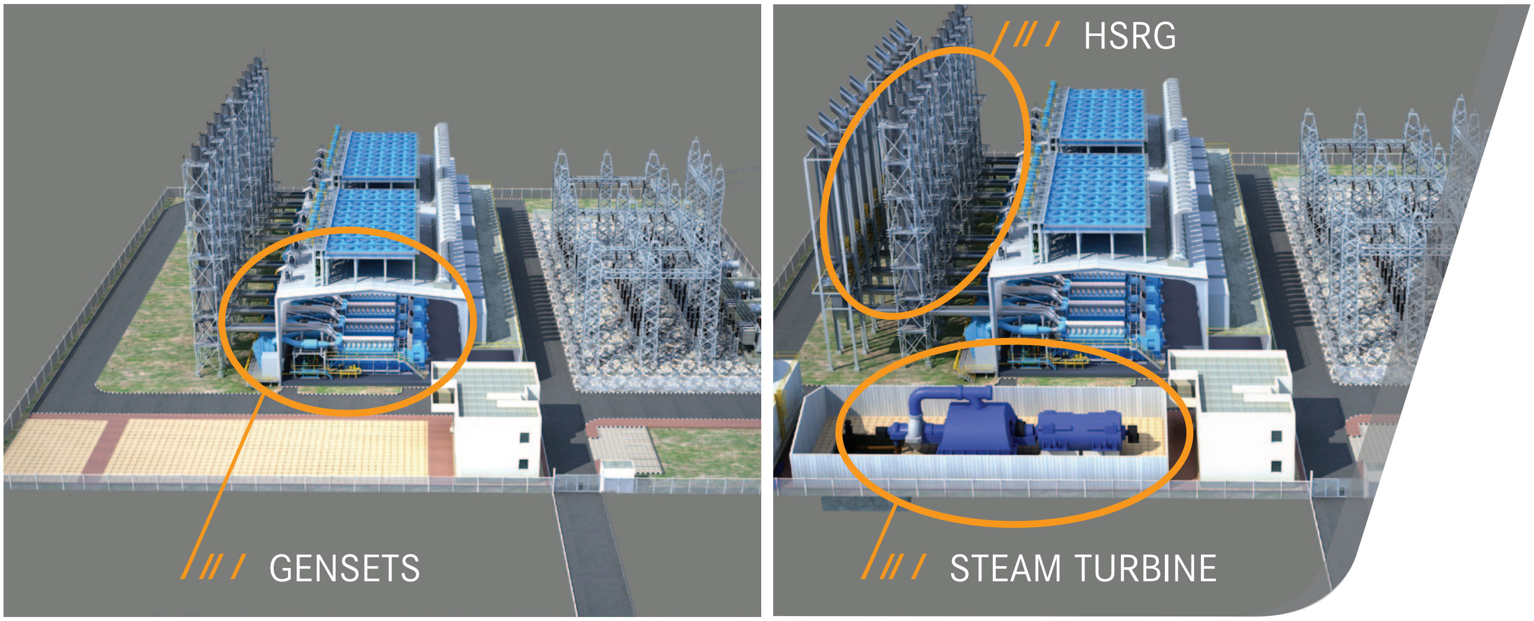


Figure 6:
Modular development in three stages (1: five gensets; 2: additional five gensets in phased construction; 3: heat recovery steam generator and steam turbines complete combined cycle)
(Images: Rolls-Royce Power Systems AG)

ther expansion. Fig. 6 illustrates for a medium speed reciprocating plant a phased approach with construction in 2 to 3 phases each consisting of 3 to 5 engines. The phasing may be dictated by the capacity of local grid connections, the gas supply and allocation or simply by the financing risks. With relatively small additional investment at the outset of the project, suitable sites can be developed with this phased expansion capability built into the site and power plant infrastructure. Such foresight allows for the engineering phase to be largely removed from the later phases and commencement of dispatch in as little as 8 months after contract.

Gas engines exceed 48% electrical efficiency and as a result they are entirely practical for baseload applications where they replace existing simple cycle gas turbines or high speed engines, with engine efficiencies of 35-45%.

As total efficiency becomes more critical than capacity, the addition of combined cycle steam turbines as a further development phase can lift the plant electrical efficiency to more than 50%. In CHP applications the overall plant efficiency can easily reach more than 95%. Planning for this upgrade at the start of the project allows for the space and services and has small additional cost (see fig. 6).

PARTNERING GAS RECIPROCATING ENGINES WITH RENEWABLE

The power sector is undergoing one of the most profound transformations since it began. Developing economies are now dealing with rapid industrialisation and the associated need for increased electrical power. Domestic and industrial consumers across the region are also demanding cost effective, reliable access to power. Many countries in the Asia/China/India region are starting from a low basis of power demand and must satisfy the triple challenge of capacity growth, transmission infrastructure development and distribution penetration.

Overall electrical capacity annualised growth rate around the world can be expected to be 2.3% up by 2040. Of this a 3.5% growth in low carbon and renewables allows for a much slower growth rate of 1.5% in fossil fuel capacity. Within this change there is also a shift in the share of fossil fuel demand towards gas, see fig. 7 (IEA, 2016).

The capacity growth rate in the Asia region excluding China and India is expected to be around 4.0% with an impressive growth rate of 5.5% in low carbon and renewables. (IEA, 2016) Many of those countries have low levels of electricity penetration and lack a nationally interconnected grid infrastructure. This makes it doubly difficult to grow variable renewable energy (RE) faster than the overall electrical capacity growth. In these cases large scale off-grid renewables can be a means to quickly bring power to consumers, although the delivery of stable capacity and the future integration into a national network must be carefully planned.

The microgrid concept will be a natural fit between the reciprocating engines and renewable source of energy, supported by battery storage. Such a pairing increases system efficiency because:

1) When e.g. the sun is shining and the solar panels are producing electricity, the fossil fuel generators do not need to run. As well, the batteries can be charged. This reduces fuel costs, emissions and generator maintenance needs.
2) When the sun is not shining, the customer has alternative sources of energy to ensure reli-

ability. The reciprocating engines are flexible, can run anytime on fuel and are not limited to daylight hours when the sun shines. Shorter periods can easily be bridged by batteries without starting the reciprocating engines.

The trend towards alternative and sustainable energy sources has led in recent years to the widespread use of photo-voltaic solar farms. Solar energy is eco-friendly and literally inexhaustible but is not continuously and predictably available. Darkness and weather conditions can lead to fluctuations in the energy supply. One answer to this problem is provided by fossil fuel generator sets that produce energy reliably around the clock. Working together with project partners, RRPS and MTU Onsite Energy can offer its clients bespoke solutions that combine the advantages of e.g. photo-voltaic solar arrays, battery storage and gas power plants to create a reliable and sustainable system.

Beside little space requirements, reciprocating engine generators are also valued in a microgrid for their ability to ramp up quickly. This speed-to-service not only minimizes or negates power outages, but also assists in microgrid optimization. Optimization refers to the ability of an advanced microgrid controller to leverage the micro-grid's various resources for best economics. Sometimes referred to as the "brain" of the microgrid, the advanced microgrid controller is the software that orchestrates all of the microgrid's resources and enables it to disconnect and re-connect to the central power grid.

The controller constantly calculates the best or optimal mix of resources for the microgrid to use based on energy prices, fuel availability, weather and other factors. Because the reciprocating engine can start and stop quickly – and typically has a ready source of fuel – it's a flexible tool the controller can leverage. For example, the reciprocating engine generator might be quickly called into action if there is a sudden drop in solar or wind generation. It also may serve as a tool for peak shaving or other forms of demand management. (Microgrid Knowledge, 2016)

Regardless of the pace of increase, it is clear that the scale of variable renewable capacity will increase and it is likely that the share will also increase. A rule of thumb is given that there is an economic and operational ceiling on the maximum capacity share that can be provided by variable renewable energy that is roughly equal to the capacity factor (Jenkins, 2015). While there is much discussion around this suggested maximum economic and technical ceiling, the impact of the variable renewable capacity, at much lower levels of penetration, is already being felt on networks around the world.

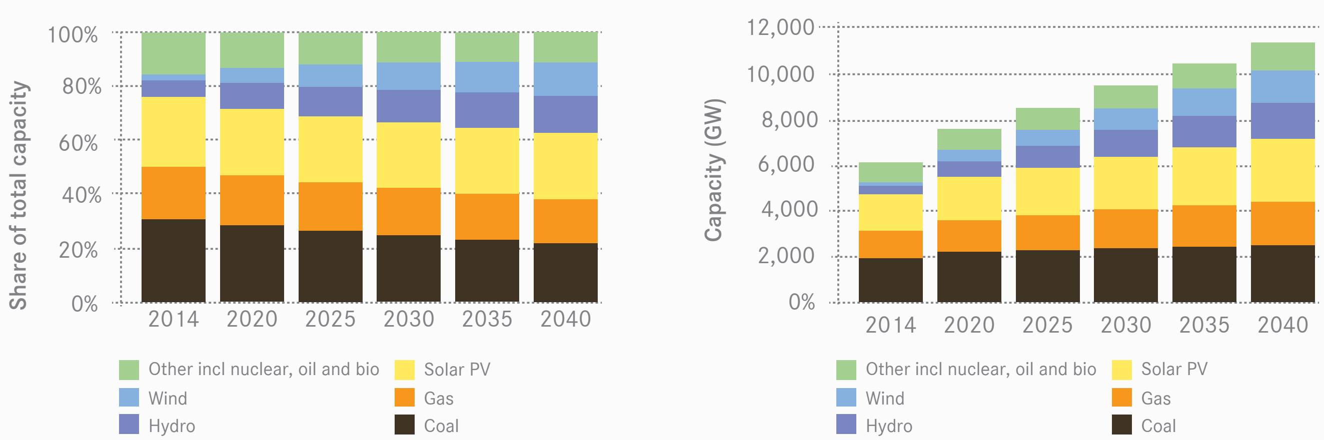
The flexibility of gas engine technology is expected to occupy a considerably larger role in maintaining grid stability. Transition from big, centralized peak power stations and gas turbines to smaller units suggesting more engine-based power plants in the future.

The expectation of increased demands for flexibility and efficiency, lower emissions and lower costs is set to increase technical demands on gas engine technology.

Flexibility in the power system to integrate more renewable wind and solar, seems to be the top priority and need of an hour. And also the demand of electricity is less stable than before. It's getting more and more peaky. And to follow those peaks as precisely as possible, we need fast and flexible generation, and this is what the reciprocating engines are capable of.

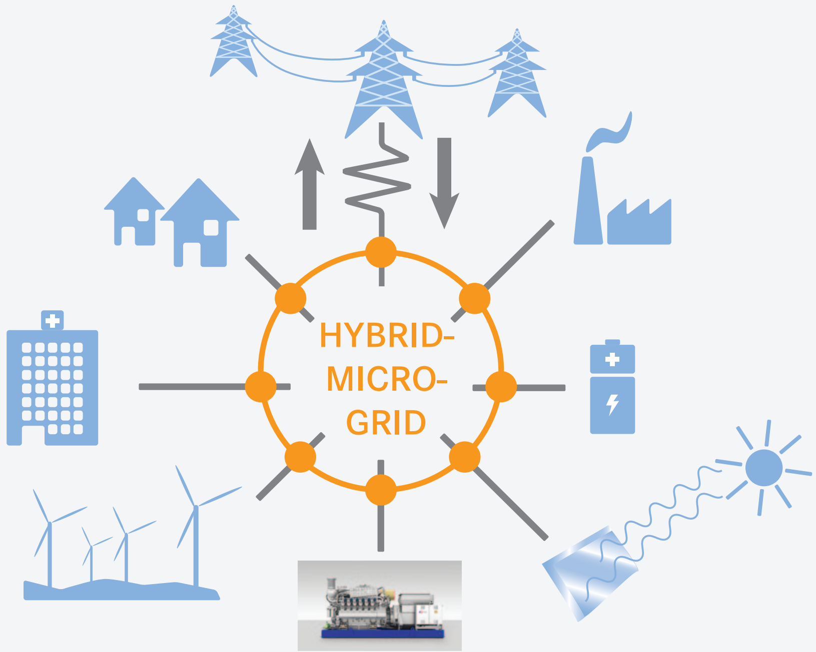
Hybrid power plants that combine the advan-

FIG. 7 // FORECAST CAPACITY GROWTH AND SHARE DEVELOPMENT AROUND WORLD



Source: IEA 2016

FIG. 8 //
MICROGRIDS ARE DISTRIBUTED ELECTRIC POWER SYSTEMS WITH LOCAL GENERATIONS



tages of gas generators and photo-voltaic solar arrays are a reliable and efficient answer to the challenges of using renewable energies in regions without power grid access. Natural and renewable energy sources are not always constantly and predictably available. In such cases, gas gensets can quickly and economically ensure power supply availability.

MTU Onsite Energy gensets are ideally suited to such tasks. With their especially good low-load capabilities, their economical fuel consumption and their outstanding load uptake characteristics, they offer customers maximum economic benefit combined with maximum supply reliability.

CONCLUSIONS

Based on current government policies there is expected to be a rapid and sustained growth in overall power generation capacity within Asia/China/India region over the next quarter century. Variable renewable energy (RE) such as wind and solar will provide an increasingly larger share of the capacity. The addition at scale of variable RE can exacerbate network stability problems due to the inherent mismatch between the capacity that they provide and the demand on the network. The progress made to stabilise regional networks and to reduce frequency excursions can be threatened unless suitable balancing capacity is added to the network to handle variable RE-driven instability.

The characteristics of balancing capacity are well defined in developed economy grid codes and it can be expected that similar requirements will emerge in regional grid codes as they are developed. To handle the required power flows that variable RE imposes there is also a significant upgrade required to the transmission & distribution networks. The upgrades are well known but must be carefully planned as part of an expansion and robustification program.

Gas is well suited as fuel to support balancing needs. However, over the next years the region will become a major importer of gas as consumption grows at a faster pace than production. To achieve the joint goals of increasing geographical diversity of economic activity, and a reduction in the carbon intensity of the economy, significant gas infrastructure will be required to be built alongside enhanced electrical network infrastructure to dispatch variable RE to industrial centres. The decentralized power generation approach is in favour of gas-based balancing power stations to be located at new industrial zones, while balancing the effects of variable RE. In combination with e.g. batteries for energy storage, high efficient microgrids are formed. As a further advantage, such microgrids can be established much faster to ensure reliable energy supply to these areas instead investing in long lasting and expensive transmission & distribution network projects.

For gas-based balancing, pure gas engines offer a path to delivering quickly new capacity in remote areas. The modular design and construction of gas engine power plants allows for better matching of financing and revenues while being able to deliver the needed grid support services. The start stop and loading performance as well as the high level of part load efficiency even in open cycle enable this type of plant to match the needs of the region.

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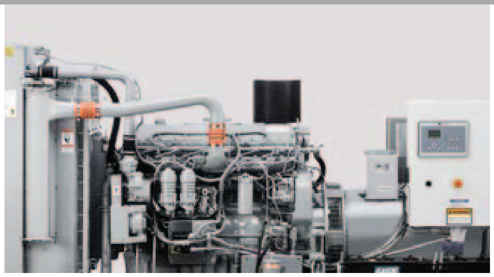

MTU Onsite Energy is a brand of Rolls-Royce Power Systems. It provides diesel and gas-based power system solutions: from mission-critical to standby power to continuous power, heating and cooling. MTU Onsite Energy power systems are based on diesel engines with up to 3,250 kilowatts (kWe) power output and gas engines up to 2,530 kW.