A research roadmap for engine power plants

Draft version 2 – 14.06.2016

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EUGINE works with EU and national institutions in order to help the European electricity system to meet the challenges of today and tomorrow.

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The role of engine power plants in the future energy mix

Europe's energy system is following a decarbonisation path. This includes that a constantly growing share of energy is generated from renewables. While the share of constantly available renewables is limited, the growth will mainly come from the use of volatile wind and sun.

The volatility creates a growing challenge for a steady reliable electricity system. A solution is needed that can quickly and on short notice fill the gap when wind and sun are not available or electricity demand exceeds the capacities. This flexibility is a new and growing requirement.

Most traditional power generation technologies in Europe have difficulties adapting on short notice or at least need to run on idle or low load to be able to react quickly. Modern engine power plants - normally operating with gas, may it be natural or e.g. biogas - can provide this flexibility better than all other power generation technologies. Similar to engines in transport they can start-up and shut down with almost no lead time. Compared to other thermal power generation technologies gas engines clearly produce less air polluting emissions and due to their high efficiency their carbon footprint is low.

Engine power plants are an existing technology. Compared with other flexibility options like large-scale electricity storage, the costs for providing flexibility via engine power plants in short as well as medium-term are low and would allow for a fast deployment. This would enable a further fast integration of more volatile renewables and the closing down of the most polluting coal-fired plants without endangering the security of supply and stability of the grid.

Why a research roadmap?

Engine power plants are using reliable well proven technologies. However, they have mainly been used in the past for different applications and their design was optimised for these applications. A typical task was the provision of emergency power for buildings, data centres, hospitals etc. Adapting to being the optimal solution as flexible back-up power plants in the electricity grid for the growing amount of volatile renewables is possible, but may need some additional design efforts to ensure perfect conditions.

The European engine power plant industry has gathered in this paper six challenges for which further research and innovation efforts are needed:

- A better use of the large amount of available data to ensure an intelligent steering and controlling of the power plant
- A further reduction of exhaust emissions and greenhouse gases
- A further optimisation of part-load operation
- An increased fuel flexibility, taking into account diverging gas qualities caused by the use of LNG or the addition of hydrogen
- An improved recovery of the waste heat generated by the engines to increase the overall efficiency
- A further improvement of start-up times

The six challenges and the specific R&I needs are described in the following chapters

Intelligent Controls

Compared to the electricity system of the past with few large central generation units running steadily, the new system, with an increasing amount of volatile renewable energy and a more decentralized smaller distributed power generation, is becoming more and more complex. An efficient management requires highly developed intelligent control algorithms and utilisation of large amounts of data to be able to run each individual power plant and the whole system effectively, providing highest possible value for the whole value chain in the most sustainable way.

Intelligent control of engine power plants, not only for electricity itself, but also for reserved capacity, heat, inertia and other ancillary services is needed. As the complexity increases, intelligent, self-learning control models must be developed. Decision making utilising big amounts of unstructured data is beyond human capability. Cognitive computing is the new technology to overcome this challenge. Research work how to utilise it in the power generation industry is required.

The sharing of information, as well as cyber security, becomes more and more critical to ensure safe operation in all circumstances. As the topic is extremely complex and at the same time the lifetime of the power plant is relatively long, a long-term vision as well as a step by step path are needed. Elements of the complexity and challenges are illustrated in the draft mind map (see attachment).

Specific R&I needs:

- Clarification of the specific needs and interconnections with the other parts of the grid

- Cognitive computing in power generation – As the system becomes too complex for normal control methods, we have to understand what possibilities cognitive computing can bring to solve this issue. This, however, is not only related to engine driven power plants, so the first step is to understand what is ongoing in this field and then define how engine driven power plant control can integrate to this
- Cyber security in a “big data” environment – When components in the power plant start delivering data in the internet (IoT), it must be ensured that the data is used exclusively for the intended purpose and by the authorized parties. However, when power plants and components in the power plants communicate with each other in the future digital power plant systems, closed communication is not an option anymore.
- Data models, communication protocols – This topic is in connection with the two above mentioned topics as the different equipment which communicates with each other must have commonly agreed data models and communication protocols
- Future network requirements (Network codes) – The main target for digital power plant systems (topics above) is to ensure stability in a network with an increased amount of distributed and renewable power. Requirements for this are defined in the network codes and these shall be studied and developed when developing more intelligent control for engine driven power plants.

Further reductions of exhaust emissions & greenhouse gases

While engine power plants contribute to an overall reduction of negative environmental effects by the energy system via avoiding excess generation, running on idle or intensive cycling, further improvements in the impact on local air quality and global warming can be achieved via further improving gas-engine based power plants. Emphasis should be put on reductions in CO2, CH4 and NOx, through both on-engine and exhaust gas after-treatment technologies.

In light of the changing operational profile of engine-based power plants towards intensive cycling & low running hours, the exhaust gas composition during and shortly after startup as well as during load transients is becoming more important. Multiple technology areas can benefit from improvements. Pre-heating for exhaust gas catalysts is one of these, as is integral (engine + after-treatment) emission control during load transients. Besides these, the topic of methane slip reduction remains high on the agenda, both using on-engine technologies as through catalytic conversion of methane in the exhaust gas.

Specific R&I needs:

- Catalyst preheating: mechanical embodiment, control and balance between (stand by) power consumption and startup emission reduction
- Transient emission control: improvements in engine control and mixture composition. Improved integration between engine and after-treatment controls, including feed-forward control.
- Methane slip reduction: lowering of engine out methane emissions through design optimisation, improvements to catalytic converters for methane (durability, conversion efficiency and price)

Optimising part-load operation

Optimising part load efficiency of engine based power plants should be done using a holistic (plant level) approach in general, but should focus on a number of different areas in particular. These particular areas are:

- The combustion air path, with emphasis on the turbocharging and charge cooling equipment
- Reducing frictional and other parasitic losses, the relative importance of which increases at lower engine loads
- Combustion system optimisation at low engine loads

This all needs to be done within a confined and shrinking window as throughout the years the power density of engines used for power generation has increased significantly. Therefore the tradeoff between power density, efficiency at full and efficiency at part load is now more complex as ever before. Progress though can still be made through the use of advanced modelling, model-based control and simulation techniques.

Specific R&I needs:

- Advanced turbocharging research to further improve turbocharger efficiency across the full operational window, including also improvements in engine integration and charge cooler design.
- Research on friction reducing technologies for main and conrod bearings, piston and ringpack to liner interaction and improved efficiency of ancillaries such as pump.
- Combustion research into further improving premixed and diffusion combustion modes as well as into advanced (mixed) combustion modes that promise high efficiency combined with low emissions but still pose a real challenge mainly in control and hardware utilisation (Pmax and dPmax/dT).

Increasing fuel flexibility regarding gas fuels

Natural gas is a product by nature and thus the gas composition varies depending on the gas source. In the past the different regions of the EU imported gas mainly from a defined region with a stable composition. The EU gas strategy foresees an internal EU gas market with gas flowing freely among the different countries. Additionally the EU tries to become more independent from certain suppliers, by importing gas from additional supply sources via new pipelines or LNG transport.

A second effect could be the injection of hydrogen to the natural gas grid by Power-to-Gas plants in the future. The production of hydrogen is an intelligent way of using excess energy from renewable sources. This hydrogen can be injected into the existing gas network, replacing part of the natural gas. This avoids costs for specific storage solutions and reduces the consumption of natural gas. The challenge of this approach is the fact that the rate of hydrogen in the net will vary along with the volatile generation by renewables.

Both effects lead to a fluctuating gas composition within short periods of time in future. Based on the gas composition the combustion process varies and thus the composition of the exhaust fumes.

Power output and exhaust fumes cleaning should stay stable independently from a varying gas composition. Thus the gas composition has to be measured online to adjust the combustion process immediately, too. At the same time the exhaust cleaning systems have to be controlled to guarantee a continuous cleaning of the exhaust fumes.

Specific R&I needs:

- Online measurement of gas composition and online adaption of combustion process to guarantee a stable combustion
- Adjust combustion process for a high content of hydrogen as combustion characteristics of hydrogen differ from those of methane

Waste Heat Recovery

Although reciprocating engines achieve a high efficiency of around 50%, there is still 50% waste heat that is lost to the ambient in case the heat cannot be used in a combined heat and power (CHP) application to provide heat or process steam. About half of this waste heat is available in the engine exhaust, while the other half is coming from the charge air coolers, jacket water and oil coolers, as well as radiation losses. Utilising the waste heat – especially the exhaust heat – by adding a bottoming cycle, similar to combined cycle gas turbines, can increase output and efficiency by up to 10%.

Operating costs are mainly driven by fuel costs, which represent typically more than 50% of the total operating expenses. For that reason efficiency is very important for gas-fired power plants and the use of free waste heat for power and efficiency improvement is major factor to improve this efficiency.

Several options can be considered for turning waste heat to power:

- Gas Engine Combined Cycles utilising exhaust energy of the engines to generate steam for a steam cycle similar to a Gas Turbine Combined Cycle.
- Organic Rankine Cycle (ORC) utilising the engine’s exhaust energy, or the engine cooling energy or both to generate additional power using an organic fluid in a closed cycle instead of a steam cycle.
- Turbo compound systems are using exhaust energy to drive a turbine similar to the turbocharger and generate additional power.

However, efficiency improvements based on waste heat recovery lead to more system complexity and they can have an impact on operating flexibility. With operating flexibility like fast start-up, low load operation and high cyclic capability being a key requirement for future installations of gas engine power plants it is required to optimise the integrated solution of gas engines with a waste heat recovery system so that there is no negative impact on the operating flexibility.

Specific R&I needs:

- Evaluation of suitable waste heat recovery concepts to support flexible operation
- Optimisation of waste heat recovery concepts to maximise efficiency and meet required operating flexibility
- Development of dynamic simulation models
- Investigation of the dynamic behavior of the integrated waste heat recovery system
- Field validation of highly flexible gas engines with integrated waste heat recovery system

Faster start-up for reciprocating gas engine power plants

Typical startup durations for a medium-speed gas engine power plant engine to operate from a standstill, pre-heated condition to 100% load are currently less than five minutes. Compared to other thermal power generation technologies like nuclear power plants, coal-fired power plants or gas turbines this is much faster – however, the dynamic behavior could be further improved. Significant potential is attributed to a number of technologies for which advancements in research and development are of essential value.

Reducing the startup time will allow enlarging the scope of application of gas engines, with resulting benefits in cost of ownership, emissions and carbon footprint. Reduced startup times would contribute to a more widespread field of application and enable further displacement of traditional base load power generation by renewable energy. At the same time, individual plant utilisation increases through more frequent starts and longer total operating hours, since starting the engines becomes more economically viable.

A widely adopted strategy to reduce emissions from large bore gas engines is the application of the Miller method, by which the intake valves of the engine are closed before bottom-dead center, in an effort to reduce peak combustion temperatures and hence emission of thermal NOx. To maintain engine power, advanced turbocharging techniques such as two-stage turbocharging are used. This emissions-centered strategy limits however results in drawbacks in transient performance unless countermeasures are used. A number of technologies have been identified and are partly already in use e.g. on marine engines which can help overcome the challenge of low transient performance towards faster startup times.

Specific R&I needs:

- In a first step, the transient response requirements for power generation in view of ancillary power services needs to be evaluated
- Evaluation of current and future technologies to meet above requirements such as
    - Mitigation strategies for mechanical limitations associated with high thermal transients
    - Valve control systems for fast startup
    - Turbocharger jet assist and electrical assist systems
    - Alternative future technologies
- Optimisation of control strategies for fast start of gas engines with regard to low emissions
- Development of dynamic 1D simulation models
- Single cylinder engine trials and comparison to / calibration of simulation results