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MAINTENANCE FOR OPERATIONAL SUPPORT IN A CHANGING LANDSCAPE

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Over the last few years, Siemens has offered and started to deliver advanced service solutions to a number of operators of its medium-sized gas turbines. Such solutions contain more guarantees than classic solutions and often include remote product monitoring. They may also include extensive sharing of data on future production requirements and technical details on predicted and observed parts characteristics that are normally considered classified data at the supplier, operator or both. Examples of maintenance concepts related to such solutions are CBM, RCM, RBM, TQM and TPM. In order to make such solutions possible, changes on technical, business and contractual level might be required to ensure clear division of responsibilities between supplier and operator, and to ensure that the risk and profit splits between the parties are sufficiently transparent and, of course, acceptable to both parties. The paper will discuss challenges and benefits from a supplier perspective and show some examples of how the changed business setup might affect both supplier and operator.

Introduction and background

Many concepts exist, today, to improve maintenance from traditional, plan based preventive maintenance to more cost efficient and production-oriented maintenance. Some commonly suggested improvements concepts are Condition Based Maintenance CBM, Reliability Centred Maintenance RCM, Risk Based Maintenance RBM, Total Quality Management TQM, Total Productive Maintenance TPM and Asset Performance Management APM. Each of these methods can improve performed maintenance, and to some extent judge what maintenance should be done when acting on a stable market with fixed goals. Advanced services go beyond these concepts and aims at using maintenance and a deep product understanding to improve production in close cooperation with the operator. This paper presents an OEM maintenance perspective on advanced service contracts where maintenance is considered a tool for operation optimization, and where 100% perceived production availability is the ultimate goal.

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What is an advanced service contract?

A long-term service agreement LTSA is a Product-Service System PSS, where hardware (products) are supplied to the customer (operator) together with certain services – installation, transportation, requalification for further use through inspections and certain guarantees. Remote support and further guarantees can be parts of the agreement. An advanced service is defined by Loasby [1]: “Advanced services are propositions, where the provider (the manufacturer) engages in in-depth customer interaction and extensive capability integration, and through a co-creation process delivers functional values to that customer.” According to the definition therefore, if the target is to provide advanced service, the contract needs to be centred around the operator’s production and be an aid to allow the operator to at all times run the production facility in line with requirements. This of course means that maintenance in itself is not an entity of itself but a tool to ensure production, and as a consequence, maintenance needs to be performed when operation is not needed, or when maintenance is the least harmful to production. This development can further be explained as a transition towards servitisation, a phenomenon spreading across different businesses [2]. This often includes a transition from a product centered approach towards offering more extensive services for improved economic gain while staying competitive in a changing market environment [3].
The three immediate consequences of this production focus are: The gas turbine should, if possible, never force the production facility to stop because it has maintenance needs; The maintenance needs to be tailored specifically for each equipment unit - even if there are multiple gas turbines of the same model at the same production facility, their maintenance can be quite different. Finally, the service and maintenance needs to be worked out in close cooperation between maintenance provider and operator and also give provision to change management should conditions change during the term of the contract.

Why advanced maintenance?

As perceived from the maintenance supplier perspective, there are several main drivers why operators are looking for advanced contracts. The strongest driver seems to be **predictability** of both when maintenance takes place and how long it takes to carry out the outage. With such predictability, gas turbine maintenance is co-scheduled with other production facility maintenance and, if possible, placed during times of the year with fuel deficiencies, low demand or cyclic fuel price spikes. Time frames are usually firm and can be extended only at considerable cost. This strong drive for predictability is first and foremost applicable for applications where the power from the gas turbine is business critical, i.e. there is not sufficient redundancy at the system level to compensate for a gas turbine failure.

Cost leads to the next driver, namely **guarantees**. Since the gas turbine is a small yet vital part of the production facility, it needs to deliver. The main driver doesn’t seem to be the cost of the equipment or its potential non-conformance but to ensure the maintenance provider will fix problems ASAP to maintain production. Standard guarantees are given for corrective maintenance with or without cap, and requests for performance, degradation, reliability, response time, down time are common. Guarantees can be provided both directly or indirectly - if service payment is partly paid based on production this is an implicit production guarantee.

Guarantees relate closely to **risk** management. In a high value production chain, some sort of risk management strategy is usually in place. In a cooperative environment within an advanced service contract, such data can be provided upfront as well as dynamically updated, as operation progresses and changes in operation together with new observations (positive and negative) are added to the data pool.

Some customers experience problems maintaining sufficient technical **competence** to optimize their production with in-house personnel. This can be due to either being new to gas turbine technology, or due to retirements and / or organizational changes. Outsourcing parts or complete scope of the maintenance through an advanced contract can be an option. To get an optimum service solution, this may mean that less advanced maintenance activities (e.g. plumbing of the complete gas turbine package) are included in the contract as well. It will depend on the skillset of the remaining on-site and support staff and how the skillset evolves over time.

For customers with need for periodic or continuous **overfiring** it is normally expected to result in shorter maintenance intervals, either generally for the entire service interval during which overfiring takes place or based upon amount of overload and time at higher ratings. While it is sometimes the case, the actual impact of overfiring can vary considerably dependent on circumstances like frequency, level, site climate and outage timing. There are also customers that have a desire to continuously maximize energy output, usually with fixed outage windows.

For complex production facilities, especially with multiple power sources and where gas turbine output is used not only as electricity but also to generate process steam, compressed air or heat; continuous trimming of the power production for maximum energy efficiency, reliability or other goals can provide major advantages. A skilled service provider can provide **dynamic operations optimization** advice, provided that enough of the production facility can be analysed and modelled with sufficient detail. In addition to short term optimization, long term consequences and impact on long term operation and maintenance need to be considered. A similar need can arise from short term electricity price spikes, where short term profit can be considerable provided that it does not have too high impact on long term maintenance scheduling.

Dependent on payment models, fair and **flexible pricing** may be a reason to go for advanced contracts as well. Production based payments in combination with special clauses, in case of considerable underutilization of equipment, can allow operators to partially compensate for market swings and sudden changes in production needs. The above development could support to drive the aftermarket into a more customer centered focus where the supplier should act as an aid to allow the operator to at every time run the production facility in line with requirements. Often, as Cohen says [4] “time and material contract relationships have the potential to misalign incentives (“pay me when it is broken”), whereas Performance Based Contracts can act to align incentives, (“pay me when it works”)”.

How to deliver advanced maintenance?

The cornerstone of advanced service contracts is a thorough understanding between the parties, and within the parties, about what is the purpose of service and the interaction required between the parties. The prime goal with all services provided, both from the service supplier and the operator's own organization, is to ensure smooth operation of the facility or facilities in question. For the mathematically interested, the needs and goals can be divided into boundary conditions and optimisation goals, where boundary conditions describe what needs to be fulfilled (e.g. positive cash flow for both parties; minimum X GWhrs of power produced between November and April; fulfillment of emissions permit of X amount of NO_x and Y amount of CO_2 per calendar year; planned maintenance in October every four years; response time on-site 4 hours Monday 6 am through Friday 6 pm and 24 hours during weekends) and goals (e.g. maximize uptime from Monday 6 am through Friday 6 pm except in March, April and October; Maximise profit per hour over a 10-year contract period). Goals and boundary conditions from both operator and service supplier need to be considered, directly or indirectly, in the contract setup. Figure 1 shows a rough overview of which functions that are typically needed during the different phases of the contract preparation and execution.

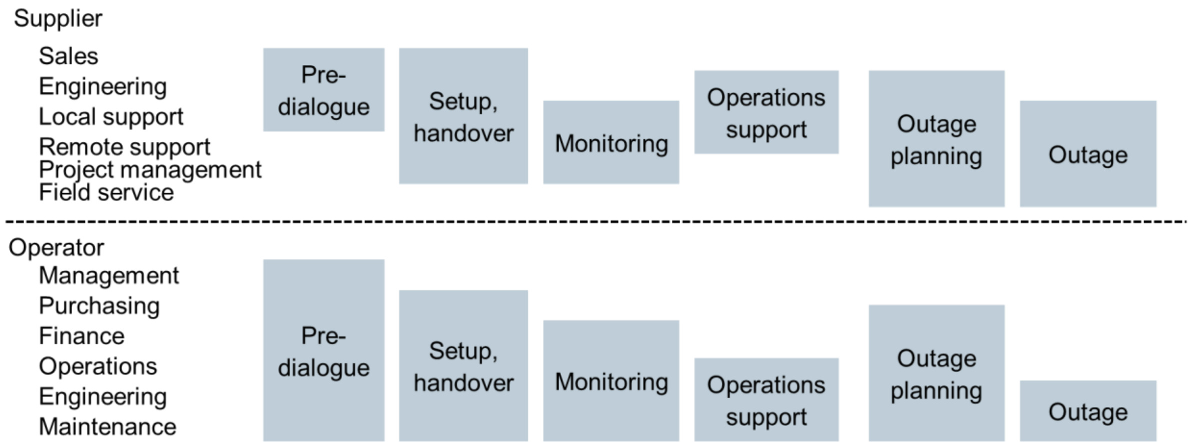

Figure 1: Advanced service contract Phases and Involved parties

Once a contract has been negotiated it needs to be set up. That includes communication to all involved roles with information on the special features of the contract. Technical and software setups also need to be completed. Points of contact need to be established, training needs to be carried out and new staff members may need to be hired. This applies in particular to the supplier local support organization that will need to know a lot of specifics about this customer. The knowledge of the contract needs not only to be distributed once but also maintained over the term of the contract, on customer as well as supplier side. If this is not done, a lesson learned is that both supplier and operator boundary conditions are at risk.
In order to prevent mixing up advanced contracts with classic contracts it is suggested to use different terminology where possible.

The fundament of advanced services is, first and foremost, the people working together to set up the contract terms and later keeping them updated with any important changes. From a technical point of view, there are also some critical functions necessary to make the entire system work, providing relevant and accurate date to decision makers and ensuring transparency between functions and organizations. A key system overview is shown in Figure 2.

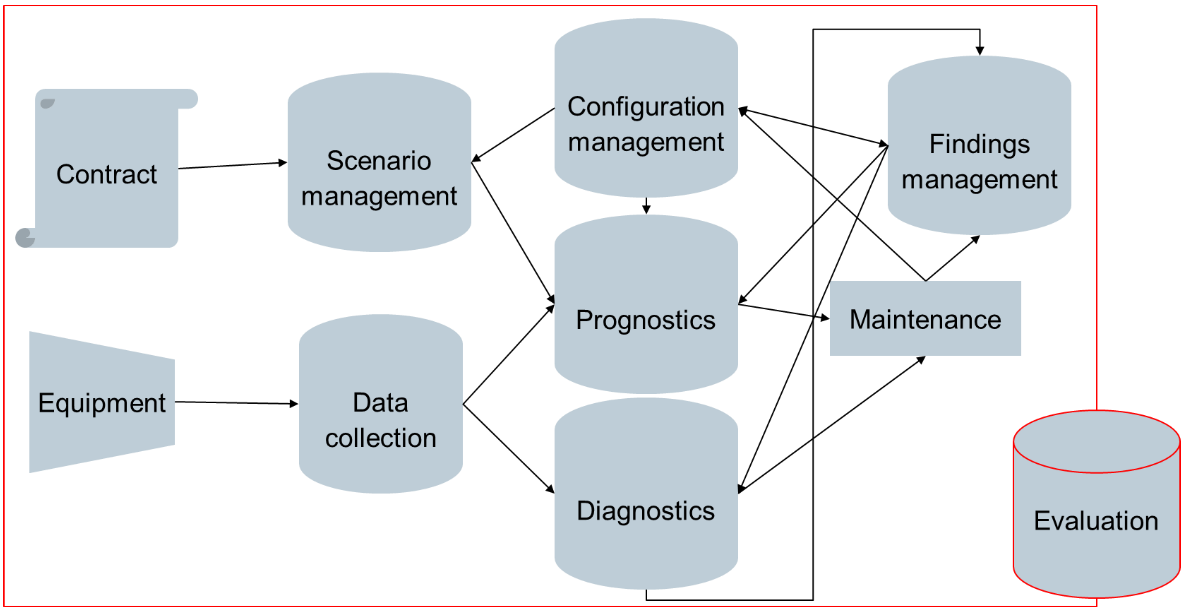

Figure 2: Key systems needed for an Advanced service contract. Maintenance provider perspective

Please notice that Figure 2 describes the service provider view, on a very high level. Please also notice that since the purpose of service is to improve operator production, the continuous evaluation will, in addition to be an ongoing activity within the service provider's business, does also need to consider possible changes in the operator's long- and short-term business goals and needs. This also means that the evaluation is actually the decision-making point – no decisions should ideally be made without considering the business perspective of potential changes. This of course requires the support systems to be correct, customer adapted and connected. It is Siemens view that the key elements to provide advanced gas turbine services is in-house capabilities for Scenario management, Configuration management, Prognostics, Diagnostics, Findings management and Evaluation. This is because systems for the other functions are generally available on the market, and their detail specifications are not critical. Regarding Configuration management, although such systems are available on the market they will need special functionality to cope with extended Prognostics and Diagnostics data and to match the needs for Findings management. Although in-house maintenance is helpful, as long as maintenance is specified according to requirements from the other modules it can at each outage be carried out by a sufficiently qualified mix of customer, supplier and external crew.

The setup of an advanced service contract relies heavily upon **Scenario management**, since the contract terms will be linked to one or more scenarios that describe a range of possible operation profiles that can realistically happen and describe the production that the operator wants to achieve. The scenarios are used as a basis of Prognostics pre-sales calculation and to predict operation during remaining operation time once the contract is up and running. Experience shows that an approximate idea of the planned operation together with a few extreme-case analyses will provide enough data to determine outage intervals, pricing and exception clauses. Exception clauses are used to prevent both parties from entering situations where the business boundary conditions can no longer be fulfilled, e.g.

when the operator's business has changed so much that the production goals need different metric to be managed.

If well prepared, monitoring an advanced contract is very simple. Data will flow between the systems, the service provider will collect data, track and plan necessary actions and discuss with the operator any business related decisions. From the operator perspective, questions regarding short term decision making are sent to **Evaluation** where the big picture is best understood, and sorted out jointly with the service provider. It is also possible to provide decision support software that can e.g. use prognostics and diagnostics data and predict on a short term basis the optimum way to operate the plant. Long term operation can also be analysed – however experience indicates that while the output will be good enough to predict e.g. average characteristics and suitable outage intervals with reasonable accuracy, detailed predictions of impact on replacement scope and whether maintenance intervals will be affected in the long term is possible only with very stable operation. The main reason is that while a single short term special situation usually hasn't a dramatic impact on future maintenance, reoccurring events may. If these events are quite different in nature, possible combinations of events need to be evaluated one by one to get a reasonable view of the consequences. The complex challenge is to find the balance between acceptable risk and equipment utilization. It is therefore always an advantage to tie the operating parameters to the current design models. This lays the foundation of understanding the impact from an event or a time series of operation. By only evaluating the data patterns the strategy must be decided on beforehand: maximized utilization with increased risk for failure or risk control with less priority on utilization.
With the combined input the potential of identifying the optimum balance is far greater.

Prognostics deserves some further comments. Siemens introduced its 1^{st}-generation prognostics system for marine fast ferry applications in 1999. The purpose of the system was to ensure safe operation of gas turbine rotors and analyses each load cycle using rainflow counting plus some additional characteristics to distinguish e.g. between different ramp rates. The cycle is then sorted into one of a fairly high number of different types, and a type characteristic damage is assigned to the total count. Please notice that damage is traced separately for each failure mode on each maintenance driving part.
In the early 2000's, a 2^{nd} generation of prognostics methods was developed. Instead of classifying operation into types, this system used continuous response functions, using selected measurable operating parameters (speed, temperature, etc) to calculate the relative damage of each operation instant, whether cycle or time unit, on life. Due to data requirements, and partly due to difficulties to define good service products, this generation was only used internally.
The current 3^{rd} generation prognostics was developed in the early 2010's. It is essentially an extension of our 2^{nd} generation prognostics but with the ability to also predict probability of occurrence of future events over time. It also predicts how both inspections and replacements affect reliability of all monitored parts. As a stand-alone tool, 3^{rd} generation prognostics also provides performance and degradation predictions. Altogether these capabilities allow a good overview of operational risk and sufficiently good data to predict impact of changes in operation on these parameters on relevant operator KPI's.

The new 4th generation tools are expected to be available within two years. They will integrate maintenance, performance degradation and emissions to allow considerably stronger decision making and a more complete support for dynamic decision making. It is also expected to increase both prediction horizon and prediction stability.

A key driver to improve prognostics systems and maintenance, and to ensure that improvements and lessons learned not only result in advanced technical solutions but also direct value to operator and maintenance provider, is **Findings management**. With 3rd generation or later prognostics systems that can predict probability of occurrence for findings, allow both good (should have seen damage but didn't) and bad news (shouldn't have seen but did) to be used together. This allows not just changing of life times but also changes of prediction functions e.g. "scatter is higher than predicted but average is about right" or "damage is not observed as early as predicted but it comes faster and the average life is less than we thought". Additionally, pattern analysis can reveal that certain damage always comes together, although theoretically there should be no link. If this can be modelled, it can be used to improve diagnostics, prognostics algorithms, inspection guide lines and maintenance instructions. However if only one of them is changed without considering the others, either a very conservative approach is needed or the outcome of the improvement may be an uncontrolled change in risk. Since it is likely that such connections are highly configuration dependent, they need to be linked to relevant product configurations only. This further emphasises the need for the maintenance provider to have deep multi-disciplinary product knowledge.

Remote **Diagnostics** is a standard service offered by all OEM's and is carried out independently by some customers. In the standard case it is used primarily for machine protection and used to detect potential issues and their root causes well in advance. In an advanced service context this is still the case – but the focus of recommendations needs to change somewhat from protecting machine integrity to identify the best way to keep production at the best possible level. Advanced service priorities may therefore result in equipment in more deteriorated condition but with production goals better met, if this is more profitable for the operator.

In conclusion, supplying advanced maintenance contracts requires acknowledgement and acceptance from the supplier that customer operation is the primary goal, and transparency with current and predicted condition – to a relevant level – between the parties is vital for success. Contract and payment structure that promote improved operation are desired since it creates a positive connection between operation and income for the supplier, and it works as a kind of insurance for the operator that there will be no pay for no gain and no payments for work that does not improve operation.

The future of gas turbines and the need for flexibility

In the changing energy landscape it is a relevant question to ask for how long gas turbines will still be used, and what the applications will look like. According to the latest World Energy Outlook from the International Energy Agency IEA, who presented their New Policies (NP) and Sustainable Development (SD) scenarios in late 2018, the use of natural gas as a source of electricity will grow at least until 2030, and for general energy production until 2035. From then the development depends on the scenario. According to the predictions there is no steep decline in the foreseeable future.

Regional variations are strong. While the use of natural gas in Asia will continue to increase independent on scenario, there is some long-term global decline in the SD scenario. In North America, at 2040 a growth of 25% from 2017 is expected with NP scenario but a 40% decline with SD. In economies like Germany, with renewables already reaching 35% of the production according to Clean Energy Wire, it has also been analyzed how combined cycle power plants will be operated. Until 2040, the average load factor is expected to be reduced on a relative basis by 25 – 30%, making plants with low efficiency non-profitable with today's business models. Customers on such markets are likely to need a high level of flexibility in their contracts, paying less for the average hour yet being able to operate as needed to maximize income during price peaks. Advanced service contracts should be able to provide this and allow operators necessary support to make the best out of the continuous changes. Operators that cannot meet the flexible needs are likely to have a very hard time, and may be subject to replacement by others that have the ability to adapt to the new realities.

Conclusions and summary

Siemens has started to deliver advanced service contracts and there appears to be an increased need for such contracts in the future. This development is not isolated to the gas turbine aftermarket business The basis of these contracts is to put customer operation in the center and to see service as a method to maximize the utilization of the gas turbine and other equipment to allow optimum operation from all relevant perspectives. First and foremost, that means that as far as possible, maintenance should be scheduled outside operation, or together with other production process maintenance, resulting in theoretically 100% availability from a production perspective. This requires commitment, openness and sharing of more data than ever before between the parties and a production operation perspective from all involved personnel. Support systems need the flexibility to cope with user specific data types and user specific processes without compromising confidentiality and speed. Main lesson learned is that if the key factors Strong commitment, Openness with necessary data and Production focused decision making are met then production performance can be increased considerably.

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