BROWNFIELD vs GREENFIELD PLANNING IN TURBINE REPLACEMENT PROJECTS

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Hartmut Walter
Innomotics GmbH
Nonnendammalle 72
13629 Berlin
Germany
Ht.Walter@innomotics.com

Gijs van Maanen
Innomotics GmbH
Prinses Beatrixlaan 800
The Hague
Netherlands
Gijs.van.Maanen@innonotics.com

Bart Sauer
Innomotics Inc.
Adress
Norwood, OH
USA
Bart.Sauer@innomotics.com

Abstract - As an effective way for carbon reduction the brown field turbine replacement has picked up in the recent years. However, the planning for the replacement often follows the usual and well-known Green filed planning line, often lead to miss the turnover date. This paper will show the difference for project planning for Brown Field vs Green Field planning. Topics as “determination of power and speed”, “Foundation”, Coupling and Torsional”, “Operation on an Electrical Grid”, “Financials” as well as “Technology” will be discussed and proposed.
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Index Terms — Turbine Replacement, planning, CO2 reduction, Brownfield, Greenfield.

I. INTRODUCTION

This paper builds on a previous PCIC paper [1] that presented high speed (HS) solutions for turbine replacements with a focus on technology and another PCIC paper [2], where CO2 Emission Reduction in Chemical and Petrochemical Plants by Steam and Gas Turbine Replacement projects were discussed.

This paper is now focusing on turbine replacement projects specifically, based on the best technology.

Additionally, the usual challenging topics are discussed, including interfacing with the existing plant environment, details related to current environmental and sustainability issues, including carbon footprint reductions and finally how to meet the required reliability level compared with the very reliable steam and gas turbines to be exchanged. For the larger applications (e.g. cracker services) reliability topics are even more important based on the huge impact of these installations. Ultimately important for smooth project execution is the timely consideration of the necessary adaptations for auxiliary equipment, e.g. lubrication oil provisions, air provisions for electrical equipment in hazardous areas and applied cooling provisions of the motor and Adjustable Speed Drive (ASD).

The climate change discussions have finally led to the Paris Agreement and later based on it in the EU to the Green Deal. Here, the 27 EU Member States aim to become climate neutral by 2050. As a first step, greenhouse gas emissions are to be reduced by at least 55% by 2030 compared to 1990 levels. The heart of the Green Deal is the EU Climate Law, which sets the goal of greenhouse gas neutrality by 2050 and increases the EU climate target for 2030 to at least 55 percent greenhouse gas reduction compared to 1990. Also, many companies and corporations have inhouse programs for a NetZero Goal by 2050.

To reach those goals, the exchange of mechanical drives by electrical drives plays a major role. Nevertheless, this exchange is technically challenging and need well planning as the replacements will take place in running production sites in a so-called brown field environment.

II. TURBINE REPLACEMENT CHALLENGES

A. General

The mechanical drives subject to exchange are usually driving critical equipment necessary to keep the process and production in the respective plant up and running. To exchange those drivers in a short period of plant shut down and start up with a new electrical driver has risks what need to be considered.

Usually, such drivers and compressors are selected, designed, purchased, manufactured and commissioned in green filed projects with the usual planning from Pre-Feed, Feed to execution and the typical purchase routs down from End User EPC OEM to vendors.

Now, the plant is already an asset and earning money, so when doing Brown Field exchange the planning and execution need to be adjusted to this different situation.

B. Timeline

First, we need to have a look at typical project lifetime. In contrast to Greenfield project, a turbine replacement project is characterized with a fixed turn around date coupled to an overall plant overhaul. Not keeping the date means no project. This means that the project needs to be started well in advance. It is advised the equipment ready to order 2 years prior to the turnaround.. This also means that, in cooperation with the user, with the OEM and/or the EPC, a fully clarified offer needs to be in place .. As discussed in this paper, some of the planning and engineering processes differ much from a green field project and require a significant time for clarification, such as power and speed requirements and foundation fit.

Summary: start the project preparations 3 years in advance at least, in order not to endanger the project: Think 3 years ahead!

After the turn around the plant will start up and go back to production. Each delay led to financial losses. As for the general plant overhaul, many parties are involved, a shift of this date is usually not possible. If the turnaround for the driver is delayed, in many cases the next opportunity is 5 to 7 years later, and the benefits of a turbine replacement like efficiency increase, operational benefits and carbon taxes or similar cost on CO2 emissions need to be paid.

Due to the trend for electrification in the industry, delivery times, for example for transformers, E-Houses and couplings, can be longer than expected. And the clarification period to define the necessary equipment is usually longer and comes with different challenges compared to a green field project.

The trigger to start projects differs also from Green- to Brownfield. The projects are often triggered by the plant operation or the service groups as they oversee the installed equipment. But usually, those parties are not familiar with the engineering, design or purchase of electrical drive systems, even often not knowing what the available portfolio on the market is.

*Fig 1*and Fig *2* showing the typical timelines for Gren- and Brownfield projects.

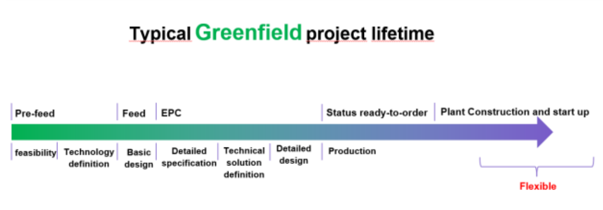


Fig 1 Typical greenfield project timeline

Fig 2 Typical brownfield project timeline

C. *Power and Speed*

The first challenge when exchanging a mechanical with an electrical driver is, to define the required power and speed of what the electrical drive should be designed for. The installed drive train is often more than 30 years old and so is the existing documentation. There are name plates with ratings on the driver and compressor, data sheets and sometimes recordings of the actual power consumption over time. All data often are inconsistent regarding rated power and speed, over speed, speed range or different working points to be covered. Also, the driver and or compressor might have been upgraded or the process requirements changed over time, what might be not reflected in the existing and available data sheets.

Basically, the engineers designing the motor need a torque speed curve of the compressor, whilst the data sheets of the compressor usually show compressor curves with diagrams pressure over volume flow. To derive the speed torque curve out of the compressor curves is task of the OEM or EPC, usually the vendor of the electrical driver can and should not do this.

Fig 3 and *Fig 4* showing measured field data what can be used to support the decision on required power and speed for the electrical driver.

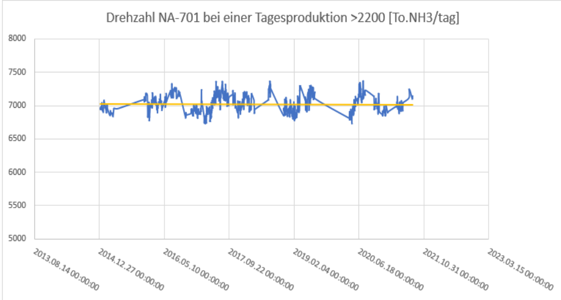


Fig 3 Measured speed variation over one day

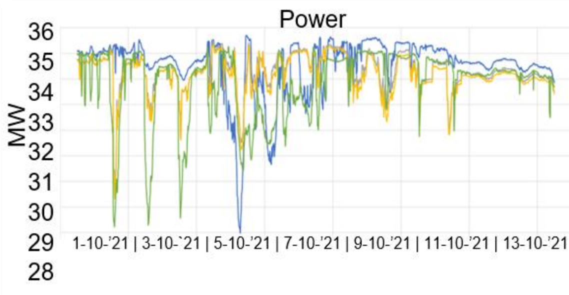


Fig 4 Power variation of the turbine over half a month

Fig 5 and *Fig 6* showing typical data from the compressor data sheets. Often, the data are not consistent, as often the safety margins or other details, what has lead to the rating of the compressor and the related mechanical driver are not known any more.

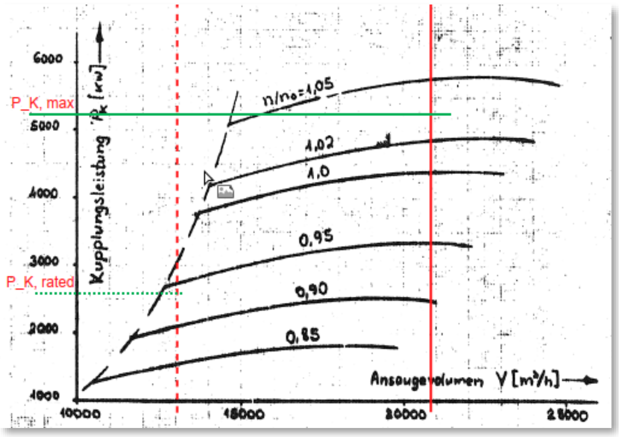


Fig 5 Power at the coupling versus suction volume

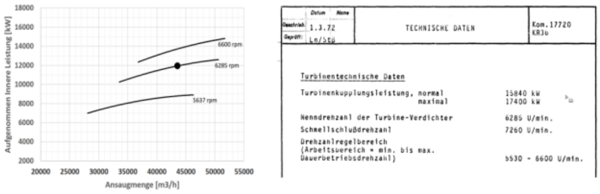


Fig 6 Compressor curves and turbine data sheet, stating different speed and power

Also, it is often not known what tolerances and safety factors were used when designing the driver. The best way here is to have a compressor OEM involved to define the torque speed curve for the electrical driver and the end user to add possible need to improve or expand his process. Typically, this clarification takes around 2 to 5 months but is the most important one and should be done first, before evaluating technical options for the driver.

In addition, the outlook from operations perspective need to be included in this evaluation, ensuring that the compressor-string is running smoothly and most efficiently for the next 20 - 25 years.

Summarizing: in order to define the base electric drive package rating, determine the desired operating speed range. This can be done by Power @ Speed information on the rating plates, by field data verification or by data sheets. The recommendation is to include the Compressor OEM plus an Engineering, Procurement & Construction company to establish the electric drive package rating

D. *Foundation*

The mechanical driver already exists and so does the foundation where the driver is installed on. That means, the available space and the conditions of installation, such as accessibility or crane loads already exist. With this, the existing foundation defines the possible technical solutions when replacing the mechanical driver.

As the mechanical driver is usually elevated on table foundations (*Fig 7*) it becomes obvious that the electrical driver system should not exceed the dimensions of the existing turbine. For steam turbines, the power density of a turbine and a motor are in a similar magnitude, so a direct drive turbine is to be most likely only possible to be replaced by a direct drive high speed motor. This selection is only determined by the dimensions and weight restrictions but also highly recommended to keep the excitations from the rotating machine into the foundation in the area, where the foundation originally was designed to. When using a gear and adding with this a new excitation frequency due to the lower speed of the motor, eigenfrequencies of the foundation might be excited. (*Fig 8* and *Fig 9*) For Gas Turbines, turbines with all the necessary auxiliaries usually need more space than the electrical driver, so basically geared solutions might fit on the foundation. The constraint here is, that with a gear the driver will have an off set to the original mechanical driver's location, leading to an uneven foundation load or to an overhang of the driver. Also here, a direct drive to keep the original center line and dynamic foundation load is recommended.

Another topic is the adjustment of the shaft height of the electrical driver to the compressor. Experience shows that for smaller steam turbines up to approximately 15MW, the motor shaft height us usually smaller than the steam turbine shaft height. In this case, adapter plates to align the shaft height must be foreseen. For steam turbines in the higher power range up to approximately 22MW, the motor might just fit with its shaft height, for higher power, the motor shaft height might exceed the steam turbine shaft height, and the motor must be specially designed to meet the conditions. This can be for example, motors with a longer shaft, what then often need extra efforts to meet rotodynamic requirements. This alternative might introduce significant risks, based on change of the 'proven' motor design, which means 'first-of-its-kind' application for the most important and challenging part of the drive train. Another solution can be tandem solutions, with two smaller motors in a row, if the foundation space allows. The third solution is mostly not a real option: raising the shaft-line of the compressor to lift the level the shaft height for the motor. This is usually ruled out by OEM, EPC and/or end-customer as it required too much interference with existing pressure pipes. Such modification typically is too risky and increases the required Turnaround schedule.

If possible, before evaluating any options, a visit on site with vendor, OEM and EPC is highly recommended, followed than by a fast budget design of the motor to see in a very early stage, if the motor fits in well or if there are special measures to be considered regarding shaft height, crane load, installation and, not to be forgotten, space for VFD and transformer installation as well as cable tray options.

In any case, the new electrical driver will change the properties of the dynamic system foundation plus equipment, as it will have most likely a different weight and additional excitations and foundation loads.

The weight is a static load and can be usually easily checked and evaluated referring to the information found on the foundation drawing. The dynamic load, as concerns the forces introduced by the rotating shaft, they are in the range of the dynamic load of the previously installed turbine. The difference is dynamic load caused by a possible short circuit. For this, the bolts to the foundation must be designed for. For the foundation itself, the short circuit load can be considered as a short static overload. The main impact of a short circuit is on the coupling and torsional load of the string.

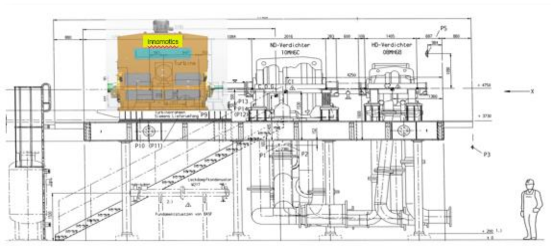


Fig 7 Typical table foundation

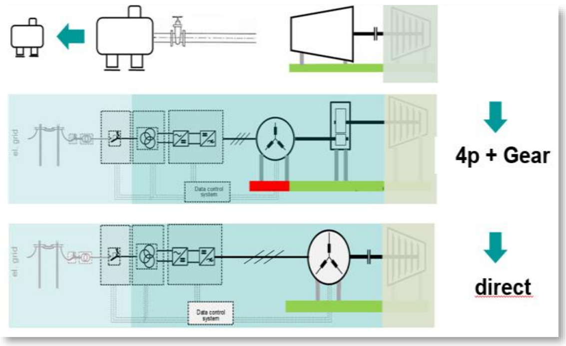


Fig 8 Possible driver arrangements

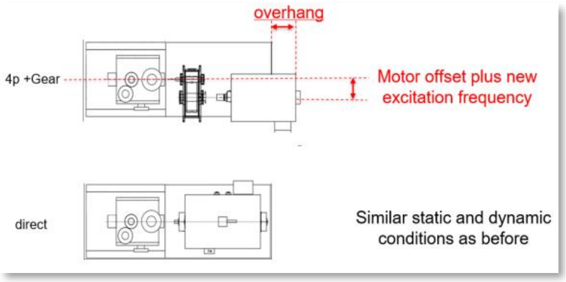


Fig 9 Possible driver arrangements

E. *Coupling and Torsional*

When replacing a mechanical driver, the options of the replacement scope can be either to replace the complete train with a new compressor and an electrical driver, or, only to replace the mechanical driver (*Fig 10*). For the first option, usually the new package is than ordered through the compressor OEM, and all topics related to the coupling and the torsional analysis are done by the compressor OEM as in a green field project. In the case of the second option, the coupling and torsional analysis need to be taken care separately and it need to be decided, which party involved will take care about torsional analysis, coupling selection, coupling purchase and coupling installation. Also, the timeline to do all those steps must be considered separately, as it is not included in the compressor OEM package as usual.

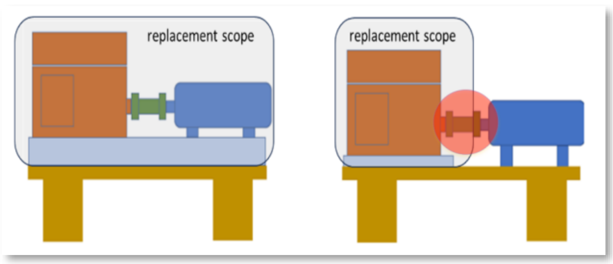


Fig 10 Replacement scope options

Torsional Analysis and Coupling Parameter Specification can be done by EPC

The torsional analysis can be done generally by all involved parties, the user, the EPC, the vendor of the electrical driver or by a consultant, such as engineering companies or a compressor OEM. The efforts in time and cost to do the torsional analysis depend very much on the existing documentation of the existing train. In the best case, the report on torsional analysis containing the calculation mode and the calculation results is available in the plant documentation. As example see *Fig 11*.

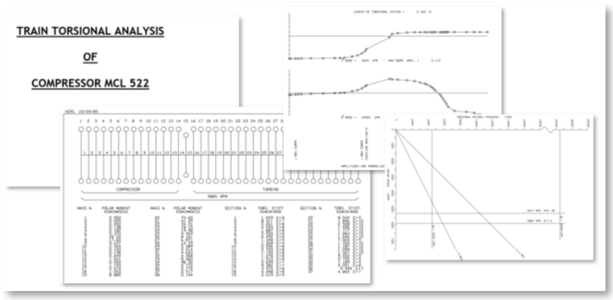


Fig 11 Report and results of torsional analysis of an existing train

In this case, only results analysis needs to be verified with the calculation of the todays used tools for the analysis, the torsional model of the mechanical driver replaced with the torsional model of the electrical driver, recalculated and the coupling parameters set in a way what satisfy the needs (*Fig 12*). The torsional data of the new electrical driver are the mass of the rotor, its inertia and torsional stiffness as well as the excitation with a 2- or 3-phase short circuit. All those data are already available in a decent precision, so that first check on the possible required coupling can be done already in an offer stage by the user.

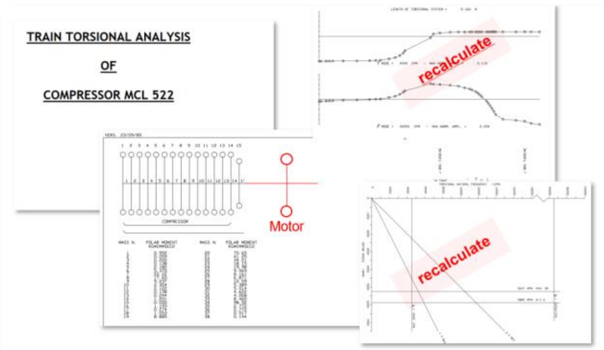


Fig 12 Torsional Analysis data with updated torsional model

However, the experience shows that those original torsional reports are rarely available, either not stored from the beginning, or lost during the digitalization of documentation decades ago. In this case the torsional model must be retrieved either from existing drawings of the compressor shaft and the coupling or from spare shafts (*Fig 13*). This can be done by the compressor OEM or by specialized engineering companies but take extra cost and time effort and is usually done after the decision to do a replacement and after the PO to the parties involved in the replacement. In this case, the time needed for the buildup of the torsional model and the analysis, as well as the delivery time for the new coupling, must be considered in the project planning of the user or EPC. Usually, the analysis takes around 3-4 months, the delivery time of a new coupling can be up to 1.5 years. Also in this case, the scope of torsional analysis and coupling selection can be in the user, EPC, OEM or electrical vendor scope. The purchasing and installation of the coupling however typically is in the OEM or EPC scope. The decision which party has the purchase and install the coupling should be done in an early stage and not been forgotten.

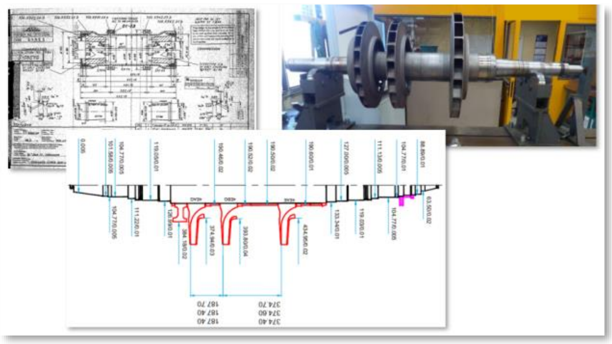


Fig 13 Possible sources to retrieve information to build up a torsional model, drawings or original parts

A difference in the torsional behavior of a train driven by a mechanical or an electrical driver are the additional excitations an electrical driver can have. One additional excitation for all electrical drivers independent of the technology used is the excitation by a short circuit. This excitation needs to be considered for the coupling selection to make sure the forces in case of a short circuit are not transversed to the compressor coupling hub, resulting in a possible slipping of the hub or damage in the compressor itself. Usually this is done by calculating the resulting torque based on a short circuit at all relevant locations in the string, compared to the allowed torque inclusive safety margin (refer to 6 - G)

F. Technology

The motor and the VFD should be selected to ensure safe start up, long uninterrupted service and low maintenance requirements possibly without the need for motor re-balancing in the field.

Generally, all motors, low and high speed are composed of the same type of components, rotor, bearings, stator, frame and accessories (*Fig 14*). The main components what need to be designed differently are the rotor, as it turns at a much higher speed than standard motors, and the frame, what need to hold the rotor and should be dynamically stiff in the complete speed range to ensure low vibration. All other components are standards components. This is also true for sleeve bearing, although they might be special to be used for motors, but the bearings for high speed are standard in the turbine and compressor application. This is also the reason why usually the existing oil supply system for the turbine can be used also for the motor.

The frame is usually a special design with welded fabricated steel and very similar at all motor manufacturers offering high speed solutions. The main difference in technology however is in the rotor design, here every motor maker has its own special design.

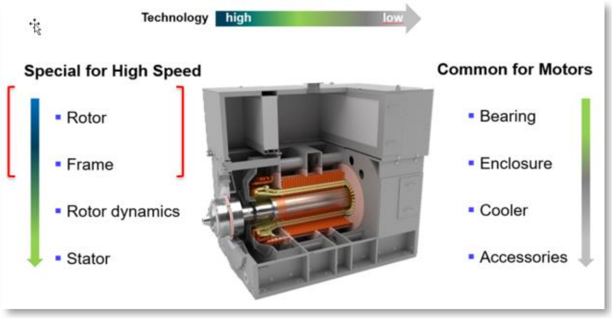


Fig 14 Main typical motor components

The main rotor designs used in high-speed motor technology are depicted in *Fig 15*. One possibility is to go with the conventional design, laminations shrinked on the shaft, with special retainer rings to cope with the high centrifugal forces on the short circuit ring. This design is due to material properties not available for highest speeds.

For high power applications of approximately 35MW and higher, high speed synchronous motors are typically used with a cylindrical shaft.

In the smaller power range and sometimes in integrated design, where the compressor and motor are in one common pressurized housing, and where the efficiency is not the main issue, reluctance massive shafts are used.

Also shafts with permanent exited magnets (PEM) are used in high-speed applications. Often the reason is because in PEM designs the electrical losses on the rotor are very small, but this advantage is usually made void due to higher stator losses as the air gap in high-speed motors are relatively big to ensure the cooling flow in the air gap. The PEM design is subject to aging as the magnets are held with a bondage composed of organic material. The magnets can lose the magnetic properties in case of overheating. Finally, handling and service of a fully magnetized PEM shaft in the Megawatt range is very challenging.

The maybe best solution is a massive shaft, where all components are bonded 100% together and no moving parts due to centrifugal or thermal influence are present. Such a design, once produced and balanced, will stay stable and keep the vibrations on the required low level over the lifetime of the motor.

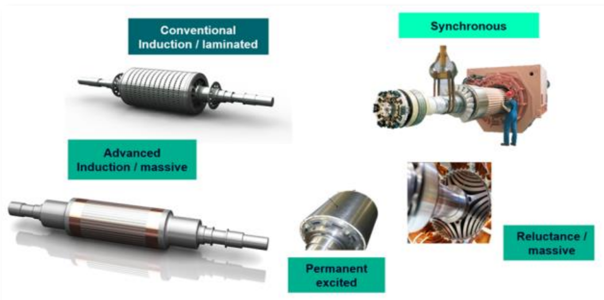


Fig 15 Different possible technical solutions for high-speed motor rotors

To run the motor a VFD is required. The VFD's used are typically established product lines used in the Oil & Gas industry. A current and voltage wave form close to sinusoidal is preferred to reduce any possible losses in the rotor and not to have torsional excitations. Redundancy options might be added or a hot standby considered.

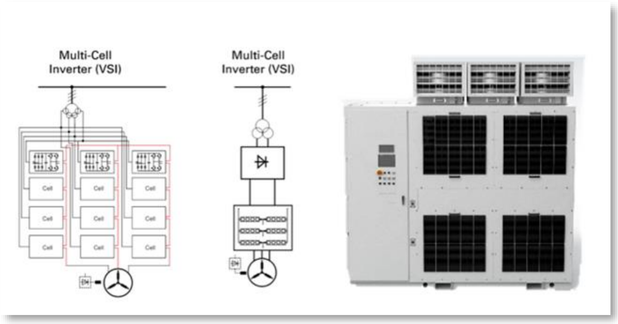


Fig 16 Example of a VFD with cell-based topology

G. *Variable Frequency Drive*

Applied drive train technology for turbine replacements typically consists of a transformer, VFD, motor, cooling system and, ultimately, VFD system integrated in an E-house, ready to be integrated on-site prior to the turn-around period. Eventually, additional switchgear equipment and low voltage distribution too.

Selection of the VFD technology should have the highest priority: one of the goals after the replacement is a system as reliable as before the replacement at least. Reliability is of the highest importance, not only the first years of operation, but rather for the lifetime of the equipment.

Although it is not obvious that the selected VFD topology might influence the long-term drive train behavior, having a closer look at the details regarding VFD induced torque pulsations provides the understanding that any ripple will impact on the mechanical drive train components that were originally designed for ripple free torque behavior, like for a steam turbine. This is especially the case for components that were initially designed to transfer the torque from the motor shaft to the compressor shaft, like the compressor coupling hub, the compressor shaft-end and the compressor itself.

The standard VFD topology used in this field of technology are 3-level or 5-level VSI drives. Such kinds of drives induce a high number of harmonics in the output waveform, which in turn results in increased output torque pulsations. Such torque pulsation might reach 3%-4% of rated output torque. It is not obvious that this relative low value will influence the coupling behavior instantaneously, however with the knowledge that these pulsations are active for the next 25 years of operation, it is obvious that this might cause a significant risk. Contrary, selection of the VFD topology where the output waveform is built with a superposition of different 5 level voltages (the so called multi—level technology, M2C or MMC and H-bridge, ref *Fig 16*) provides an almost sinusoidal output waveform. Depending on several factors (e.g. output voltage level and redundancy requirements), the number of output steps might reach up to 49 voltage-levels, which represents an almost perfect sinus.

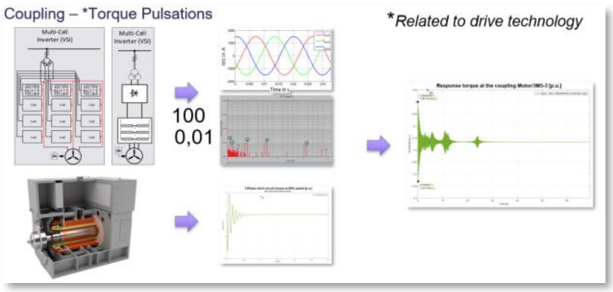


Fig 17 Torsional analysis, VFD torque excitation input and motor short circuit excitation input

This can be achieved by the application of so-called 'cell-based' drives, where typically the output voltage is being built by the number of cells per phase (H-bridge) or arm (M2C). With such technologies, it is possible to reduce the VFD induced torque pulsations significantly by a factor 30, typically below 0,1% of nominal torque (ref *Fig 17*).

H. *Operation*

When changing from steam or gas turbines to electrical drivers, also the reliability of the electrical energy source at site needs to be investigated (*Fig 18*).

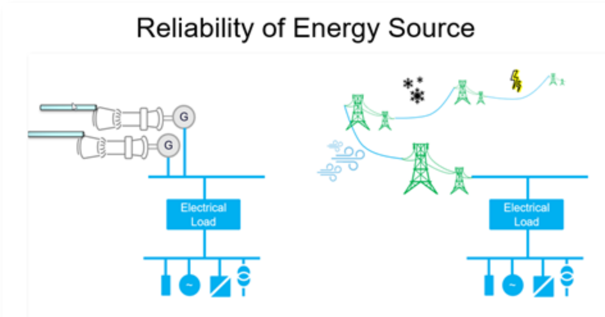


Fig 18 Gas Turbine-Generators or Electrical Grid

There can be unforeseen disturbances such as heavy weather influencing the power supply or short circuits, but also standard disturbances such as voltage fluctuation or voltage dips exceeding the voltage fluctuation.

Such scenarios can be studied based on available site data of the grid and for example "VFD Voltage Dip Ride Through" with the planned equipment calculated to ensure that the compressor or the plant does not trip.

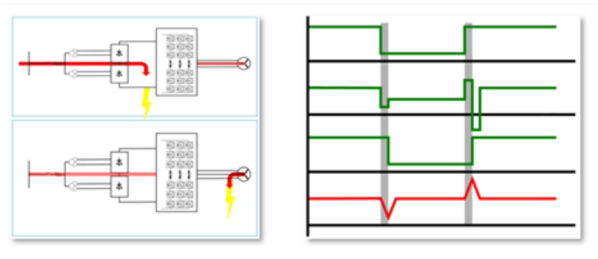


Fig 19 Schematic of a short circuit before and behind the VFD and of a voltage ride through scenario

With the 'voltage dip ride through' capabilities in the VFD, it might be ensured that the VFD will remain in service with short spikes or voltage dips. Since these events can happen quite regularly, depending on the location and the connection to the grid, such functionality is solving most of the grid disturbances.

However, if the voltage disturbance is a 'dip'-character (between 0% - e.g. 60%) and/or longer (> several milliseconds), generally the VFD might remain in service too (ref *Fig 19* and *Fig 20*). However, based on the absence of input power, the VFD will not be able to provide output torque (i.e the firing pulses to the semi-conductors are blocked for the time-frame of voltage absence). When the voltage is re-established, this will be recognized by the VFD control after which the VFD needs to be synchronized on the still running motor. Torque needs to be re-established in a controlled way, in order to ensure a smooth re-acceleration of the compressor string. If the acceleration is too fast, this might be problematic for the compressor/coupling, therefore smooth transition from torque-less period (deceleration) into active driving phase up to full torque availability is required. Such transition phase might need to be discussed with customers and compressor OEM in advance in order to prevent surprises during the time-critical commissioning phase in the Turn-Around.

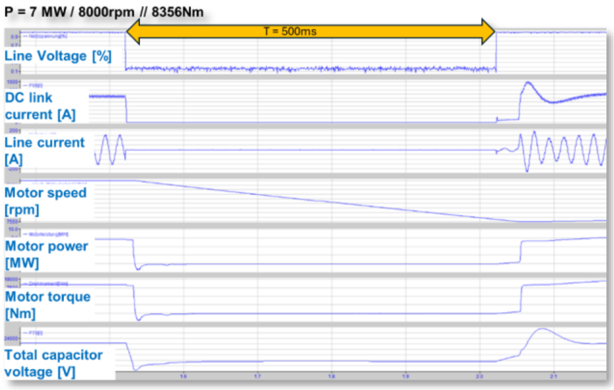


Fig 20 Example 500ms Voltage Interruptions and VFD behavior

Having the VFD configured in such a way that it will survive grid interruptions and other voltage dips, it is not 'guaranteed' that the process will survive such events in all cases. After the input voltage disappears, the firing pulses to the VFD will be blocked and the driving torque to the motor will go to zero. From that moment onwards, the compressor string will decelerate based on several factors, such as string moment of inertia, the point in the compressor operating map and the process reaction as a result (ref *Fig 21*).

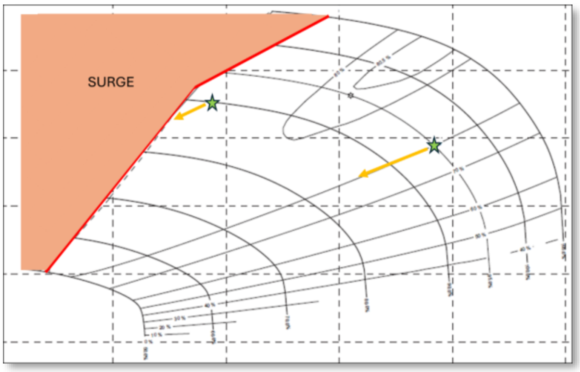


Fig 21 Typical compressor operating map

If the operating point is in the left hand side of the map, the compressor might go in surge in case of fast deceleration. If the compressor is on the right-hand side of the map, the steep decline of speed (depending the time-interruption) might cause subsequent processes to be disturbed, causing a stop of the compressor. In any way, such kind of interactions need to be evaluated and defined well in advance.

Another way to investigate the system response on power interruptions, is running 'Hardware-in-the-Loop simulation. The HIL simulation tool allows for simulation of the complete process, including all possible grid-behaviors but also including complete train inertia and if required process data (ref *Fig 22*).

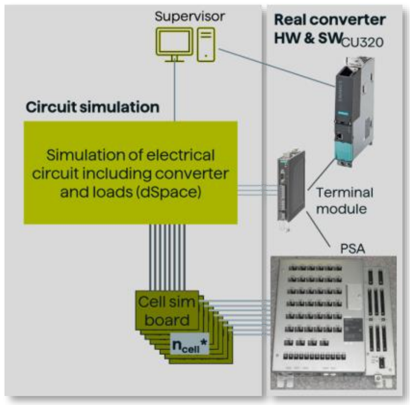


Fig 22 Example setup for HIL simulator

In such a way, all possible fault scenario's but also load conditions can be simulated and system can be prepared and parameterized accordingly. Final goal of such simulation is running cold and hot commissioning of the VFD off-site, only requiring some final verification checks on-site. Time consuming tuning and power interruption measurements and subsequent optimization can be avoided, with ultimate time-efficient commissioning as a result.

I. *Financials*

The main benefits on the commercial side in a steam turbine replacement are

1. Emission TAX reduction down to 0%
2. Efficiency increases up to factor 2
3. CO2 Emission savings up to 94%
4. OPEX reduction up to 20%
5. Clean water savings, thousands m3/day

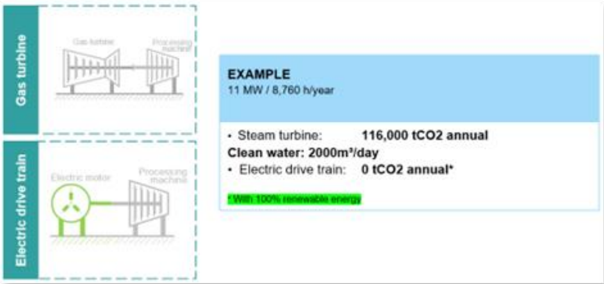


Fig 23 Steam turbine Replacement benefits

Refer to *Fig 23*, this is an example of emission reduction by exchanging 11MW steam turbines (here it was multiple smaller ones). Steam turbines are generally operated around the year, running uninterrupted for 5-7 years. Again, this is highly customer specific, but general thumb of rule is a saving of 116000 tons co2 emissions per year. Precondition for this number is the grid condition, this number requires an emission factor of 0% (actually 100% green energy, like in Norway). In general, in European sites, the emission factor is still around 25-35%, but decreasing rapidly.

Here the emission saving is a result oof lowering or completely eliminating the steam generation process. Considering the base efficiency of a boiler system, this is typically less than half of the efficiency compared to a gas turbine replacement, therefore steam turbine replacement is the first choice to electrify

Another important saving is water consumption. This water must be clean water, and in turn is counting for emission savings (not included in the basic equation….), ref *Fig 24* and *Fig 25*

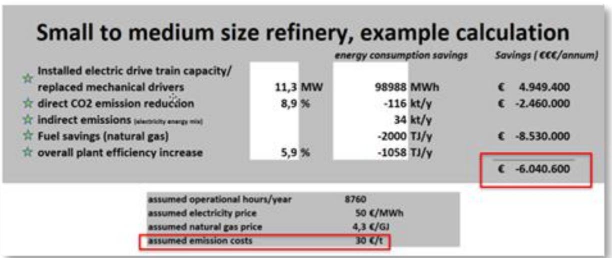


Fig 24 Steam turbine Replacement savings

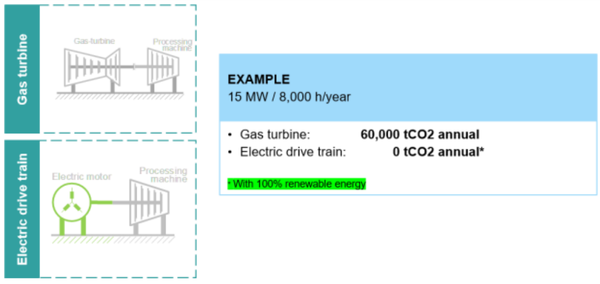
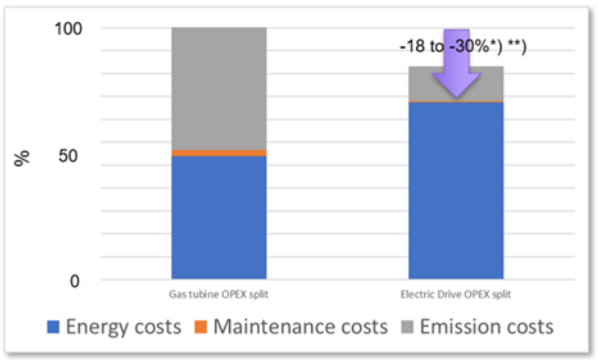


Fig 25 Gas turbine Replacement benefits

Looking at operational costs, *Fig 26* shows a base calculation, in this case for a standard gas turbine. As previously said, the savings for a steam turbine are even much higher. These are the relative cost contributors in the comparison of a base gas turbine with a comparable electric drive system. . For the gas turbine, operational costs are fairly distributed over fuel costs and emission costs. Approximately 50%/50% distribution. Whereas for the electrical drive, the emission costs are generally going down significantly. Another factor which is highly interesting: the yearly maintenance costs required. The gas turbine requires a downtime once a year, where an electric drive is running for 5 – 7 years, only requiring some wearable exchange like fans and batteries. In order to allow for long term operation without any interruptions, it is typically advised to implement remote monitoring of the drive train. This allows for timely reaction in case of disturbances, timely recognizing cooling topics and environmental conditions of involved components like motor, VFD and transformers. In addition, this allows for condition-based maintenance and even further improvement of the required interventions duting the coming turn-around periods

As is depicted, significant saving applies in this calculation. Depending on the GT size the savings can be in the range of 3 to 10 Mio EUR per year



OPEX cost distribution
**) depending on energy mix at power generation*
***) for an 18MW Turbine this is arround 2-4MioEUR/a*

Fig 26 Gas turbine Replacement OPEX savings

As we see in both calculation examples, the benefit is in savings on operation cost of the plant after the exchange. This means for the invest calculation that the Brownfield FID should consider „Investment vs. Cost Savings „and not as in Greenfield FID „Return on Investment “. The benefit is not in getting out as much as possible from a low investment but save as much as possible by installing the correct technology to ensure the savings from day one after commissioning without losing money due to delayed or stopped production.

FID Planning should be based on OPEX versus Savings and not on CAPEX versus the earnings

II. CONCLUSIONS

1. Increased Emission Reduction Requirements push for Mechanical Drive Replacement Projects
2. Early and in-depth Consideration of Base Technical Interfacing Parameters are required for successful Project
3. High Reliability and long Operation Schedules are possible with correctly selected Equipment
4. Typical challenging Aspects in Turbine Replacement Projects are manageable if considered in-time, de-risking factors are applied and Equipment is selected accordingly

REFERENCES

[1] PCIC-2015 Electrification of Alkylation process with high-speed motor drive systems in a refinery, S. Dixon, T. Salazar, S. Singhal

[2] PCIC 2022 DE-50, CO2 Emission Reduction in Chemical and Petrochemical Plants by Steam and Gas Turbine Replacement with Electrical Drives, Walter, H., Sauer, B., Tyer, T., Kitchel, J

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III. NOMENCLATURE

VFD Variable Frequency Drive
FID Financial Invest Decision
OPEX Operational Expenses
CAPEX Capital Expenses

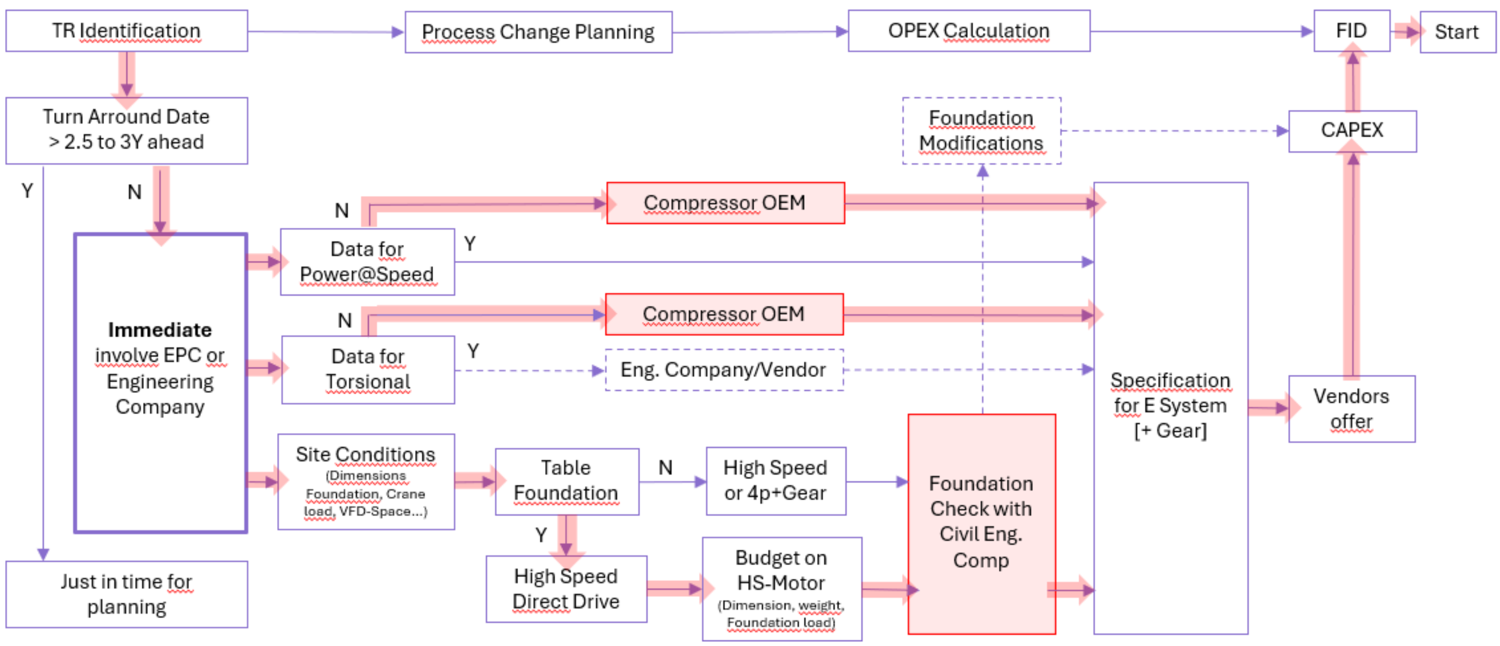
IV. VITA

First Author Hartmut Walter graduated from the Technical University in Berlin in 1996 with a Master's degree in Engineering Science. After graduation he joined Siemens (now Innomotics LLC) Nuremberg/Germany. Since 2018 he is working on developing solutions for turbine replacements, currently within Innomotics.

Second Author Gijs van Maanen graduated from The Hague University of Applied Sciences in 1995 with a Bachelor's degree in Electrical Drive Systems Technology. After graduation, he joined Siemens Large Drives in the Netherlands. In his current role, he is responsible for Global Project Development, key area Turbine Replacement Projects within Innomotics.

Third Author Bart Sauer graduated from Case Western Reserve University in 1989 with a Bachelor of Science degree in Mechanical Engineering. He has been an employee of Siemens (now Innomotics LLC) at the ANEMA motor plant in Norwood, He has been an author on four previous IEEE papers and is currently a member of the IEEE / API 541/546/547 committee.

V. APPENDIX


TR Identification
Process Change Planning
OPEX Calculation
FID
Start
Turn Arround Date
> 2.5 to 3Y ahead
Foundation Modifications
CAPEX
Y
N
N
Compressor OEM
Data for Power@Speed
Y
N
Compressor OEM
Immediate involve EPC or Engineering Company
Data for Torsional
Y
Eng. Company/Vendor
Specification for E System [+ Gear]
Vendors offer
Site Conditions
(Dimensions Foundation, Crane load, VFD-Space…)
Table Foundation
N
High Speed or 4p+Gear
Foundation Check with Civil Eng. Comp
Y
Just in time for planning
High Speed Direct Drive
Budget on HS-Motor
(Dimension, weight, Foundation load)