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DIGITALISATION IN MEDIUM VOLTAGE VARIABLE SPEED DRIVE SYSTEMS TO INCREASE PRODUCTIVITY IN OIL & GAS APPLICATIONS.

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ABSTRACT
In this paper we talk about influence of digitalization in process industries and how it can be adapted to Medium Voltage drive systems. Various aspects of digitalization like monitoring, preventive maintenance and using detailed simulations will be discussed in details.

Data logging and monitoring of critical parameters will give clear picture of the drive system conditions. Automated analysis of this data can be used to prevent any unplanned shutdown. Detailed information about medium voltage drive train analytics will be provided.

Simulation models can be used to analyse complex drive system topics such as Voltage dips or protective measures in case of short circuits which can not be tested physically in the field. Also simulations can be used to reduce the risk during commissioning by performing pre commissioning studies. This helps to identify the project specific drive system parameters prior to commissioning. Examples of each of these simulation cases and their advantages will be discussed.

INTRODUCTION
Oil and gas industry continues to struggle with cost reduction both in capex and opex to remain profitable due to lower prices than what the industry got used to in the recent years. Lower oil and gas prices continues to demand higher operating efficiency on both brownfield and the greenfield projects. Amid this uncertainty and challenging environment, everyone is expected to provide disruptive solutions that can help transform the industry.

One such disruptive technology in oil and gas industry is the use of digitial technologies that has the potential to make significant impact in both capex and opex reduction. The effective use of digital technologies in the oil and gas sector could reduce both, capex and Opex without compromising on safety while enhancing productivity and reliability through predictive capabilities.

This paper discusses the key requirements of process industries in future and how these demands translate into enhanced reliability and efficiency from VSDS in the O&G industry. To better meet the higher operating efficiency while continuing to improve both reliability and availability, digital solutions in the VFD system easily accomplishes these objectives as compared to fixed speed or low efficiency fluid coupling solutions.

INDUSTRY 4.0 / DIGITALISATION / INTERNET of THINGS
The term Industry 4.0 encompasses a promise of a new industrial revolution, i.e. the fourth revolution - one that marries advanced manufacturing and operating techniques with the Internet of Things to create a digital enterprise that is interconnected to and communicates, analyzes, and uses information to drive further intelligent action back in the physical world. Industry 4.0 / Digitalization / Internet of Things is the enabler to increase availability, improve performance and optimize serviceability for plant components. A step towards Industry 4.0 also means that each component in the process plant has to be communication capable and intelligent. For drive trains, this means that all components of drive train are communicating with higher level automation system conveying the status information, A high level schematic of this is shown in Fig.1 below.

The possible negative or positive impact of annular seal on rotordynamics of compressors and steam turbines is discussed. The nature of destabilizing forces that can be developed by a see-through@ and interlocking labyrinths is discussed.

Figure 1: Communication in a digitalized process Industry

DRIVE TRAIN ANALYTICS

Critical applications in Oil & Gas & Petrochemical plants like Extruders, Main Refrigerant compressors in e-LNG or Gas process compressors are typically driven through electrical drive systems comprising of gear units, big capacity motors and variable frequency drives.

Trouble free operation of the production plant is the top priority and hence it is crucial that inspection and maintenance activities for motors, converters and gear units are condition based. Only this approach allows you to identify optimal time to balance your production requirements with necessary maintenance and repair activities.

As such, the key is to detect faults at an early stage and to develop maintenance schedule based on this information. Before a motor fails, in most of the cases, the trend is seen weeks before in deteriorating values of critical parameters such as vibration, temperature etc. This is where Drive Train Analytics (DTA) comes in to play as a flexible system monitoring the complete drive train with connection to a cloud.

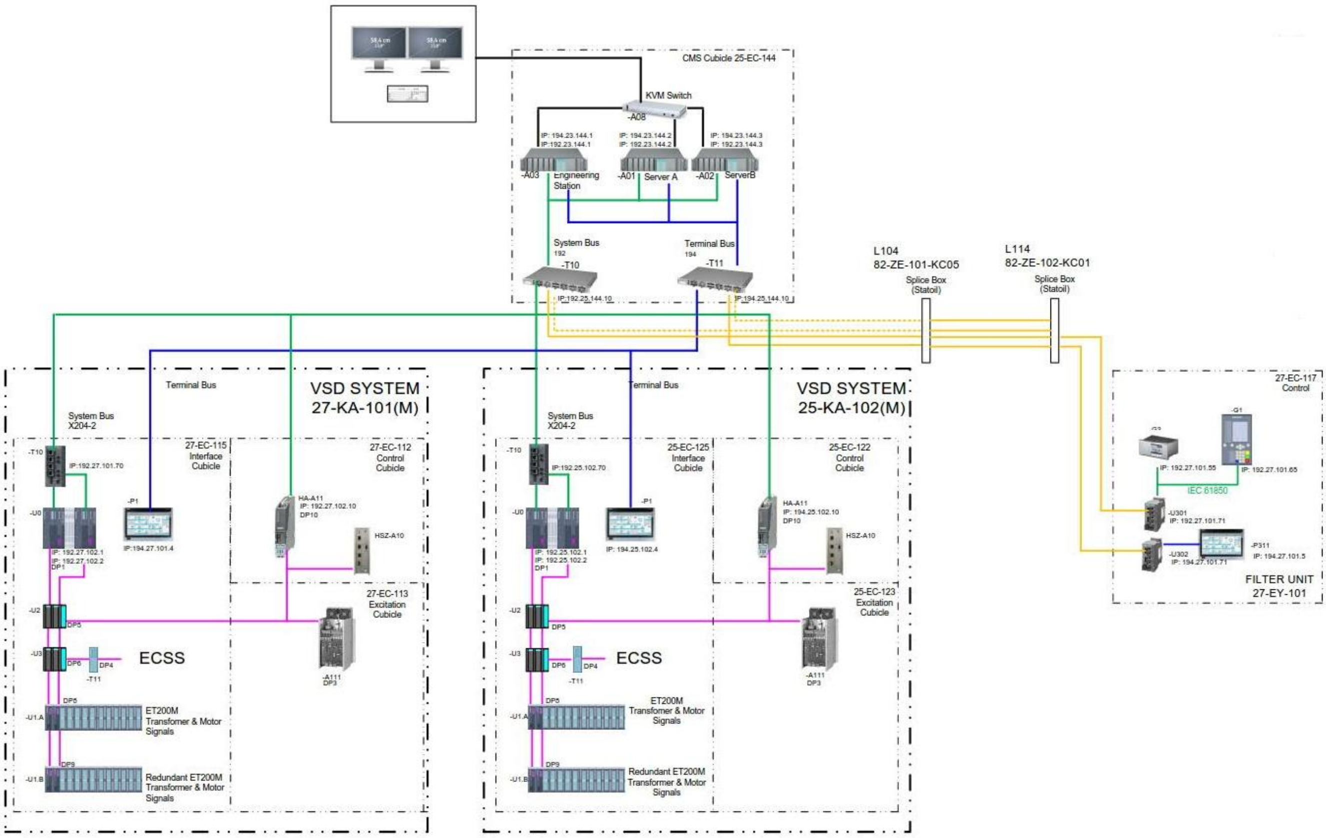

Figure 2: Automation involved for making Drive train communication capable from an installed base reference.

With DTA you continuously monitor and evaluate the data from your drive train and are in a position to detect the faults looking at data trends before they occur allowing you to react in a timely manner and plan and implement suitable measures to avoid failures. DTA is the analysis of the complete drive train with manufacturer's expertise sitting in the cloud.
For successful implementation of DTA, we have to make components of the drive train communication capable. In the single line diagram below in Fig. 3, you can see a typical automation involved on the existing drive train to make it communication capable is shown.

Continuous monitoring of critical parameters provides a steady supply of data about the condition of components of drive system such as motor, drive, filter unit, transformer etc. This data is then transmitted to an external server through a firewall. The data on the server is then evaluated by certified OEM experts and in most cases trend analysis carried out. Generally, before any faults occur in mechanical equipments, they are visible through trends in temperature or vibration. Trends of critical parameters are monitored and maintenance managers are notified in a timely fashion so that they can initiate countermeasures to avoid the impending failure. Frequency and nature of monthly and annual reports can be agreed with the end user.

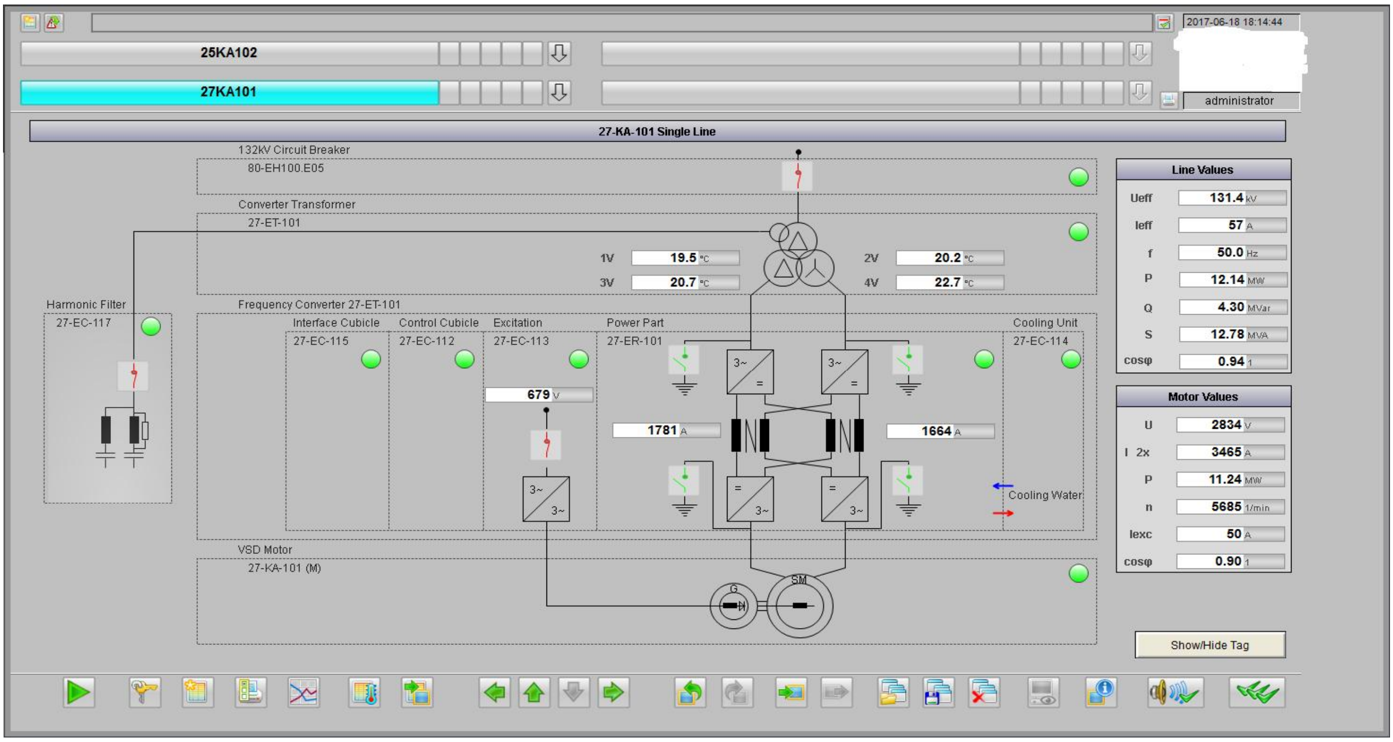

Figure 3: Monitoring devices in drive train.

As you can see from the Figure 3, for a critical turbomachinery application, motor, converter, thyristor temperatures, cooling water temperatures, harmonic filter, control & excitation cubicles can be monitored continuously. The screenshot above is of an installed system where all requisite monitoring devices have been installed and displayed in local control room. This huge amount of data is then relayed through a firewall via VPN tunnel to an external server.

Table 1 below indicates typical parameters in a drive system which could be monitored to notice the trends and alarm the user with a potential upcoming failure.

Table 2: Partial list of typically monitored parameters in Drive System

Motor	VFD	Transformer
Motor input currents	Semiconductor device Temperatures	Actual winding temperature
Winding Temperature	Cooling water temperatures	Main tank Oil temperature
Bearing temperature	Power quality at input of VFD	Partial discharge monitoring
Cold Air temperature	Power quality at VFD output	Input & Output Voltage & Currents (Differential protection)
Warm Air temperature	Harmonic Filter cubicle temperature	
Bearing vibration	Excitation Panel cubicle temperature	
Partial Discharge Monitoring		

Smart Motors

Most of the motors installed on the field are direct on line (DOL) applications without any VFD. Components such as motors, couplings or gear units are frequently subject to high stress, resulting in different levels of wear depending on the period of use and the loading. Frequently the stress is invisible to the naked eye even after a longer period, resulting in unexpected failures and unscheduled downtimes with unbearable financial losses. It is therefore important to be able to correctly estimate the state of the components at all times.

Smart Motor concept is an example for digitally enhanced electrification in an effort of transition towards Industry 4.0. Smart Motors will be the ones which will be connected to higher level cloud network with the help of a sensor box mounted on each motor. These sensor boxes are integrated vibration, magnetic flux and temperature sensors which enables them to communicate the corresponding status to cloud directly. This naturally reduces down times and enhances plant availability and reliability and optimizes operational efficiency. With this capability, maintenance and servicing activities can be planned in advance to avoid any down times. For example a maintenance manager can receive a message on his mobile device that Tag No. XYZ has overheated. Upon entering the tailor made app, he can find out the current, voltage and temperature values on the go. Upon physical inspection, he can immediately take an informed decision to correct the impending failure.

Electrical Drive systems simulation

As mentioned before, digitalization further brings availability of 'Digital Twin ' for high capacity critical application motors. Digital twins are digital replica of the physical product that are extremely useful in simulation of predictive studies to study the response in case of unbalanced supply or step overloads or other probable process perturbations. For critical applications, a complete drive system is simulated using drives system model.

Introduction

Variable Frequency Drives (VFDs) are increasingly employed in oil and gas (O&G) processes due to better efficiency, reliability and process controllability compared to conventional drivers. The requirements on the VSDs keep rising with increasing demands, stricter regulations and the drive for efficient production.

The development in the field of computer simulations in the last decade allows us to optimize the drive systems by performing simulations of complete drive train. They can be used to reduce the risks in the complex system configurations involving a combination of electrical, mechanical and process technologies. A schematic of the drive train is shown below in Fig.4.

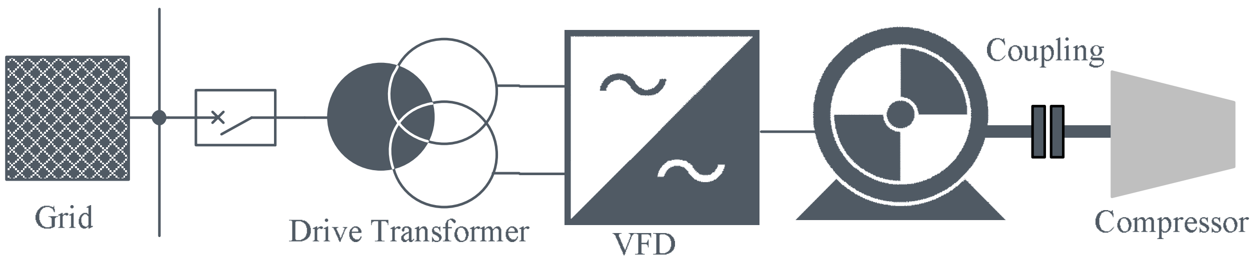

Figure 4: Basic components of a drive train with VFDs considered for simulations.

Simulations techniques:

Depending on the goal of performing a simulation different types of simulation techniques can be used. Some of the common simulations are :

- High level software simulation
- Software In the Loop simulation (SIL)
- Hardware In the Loop simulation (HIL)

Schematic of the high level software simulation is shown below in Fig 5 :

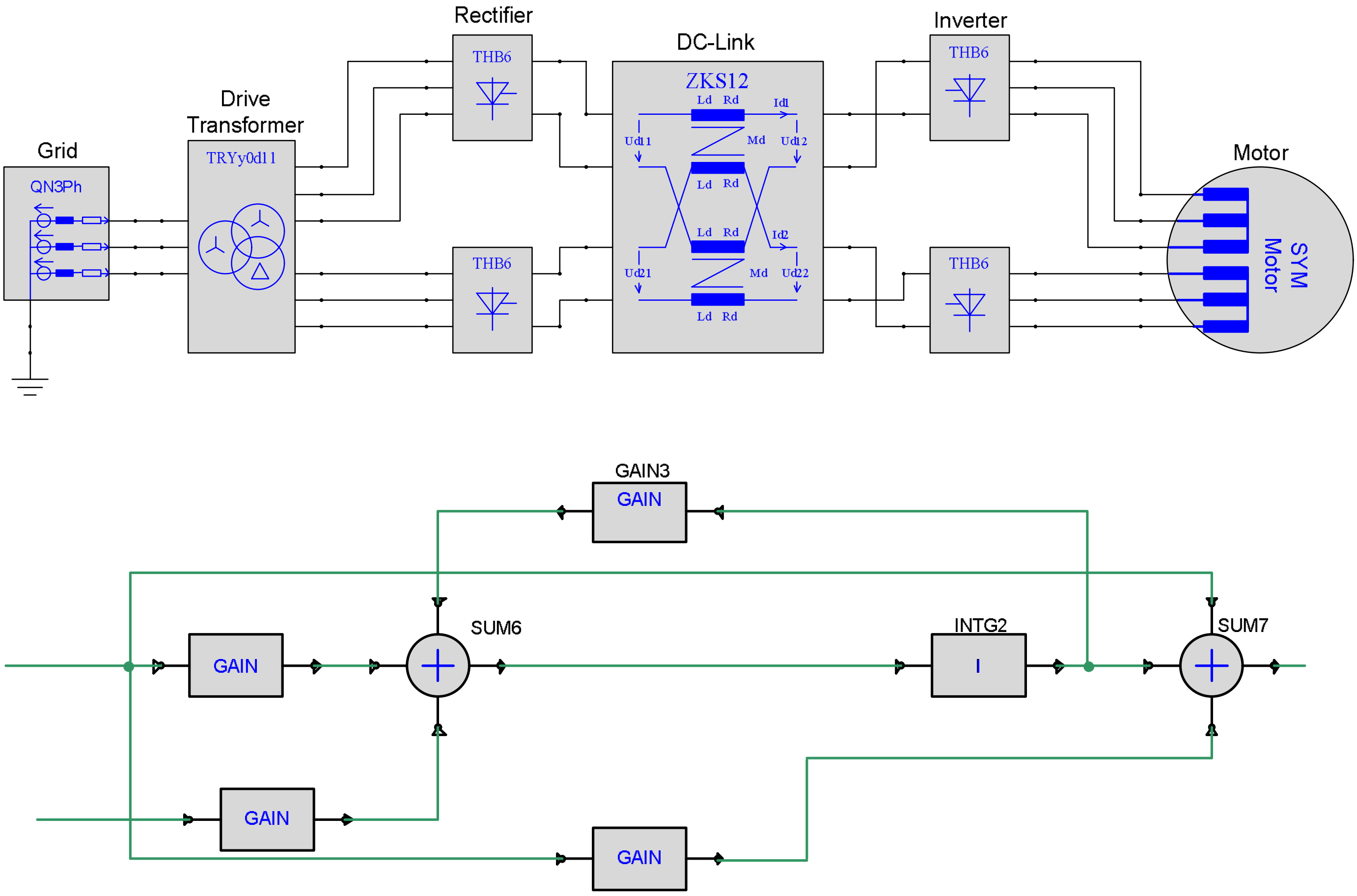

Figure 5: Example MV drive system model in a high level software environment

In the software simulation a mathematical model based simulation is carried out. All the components are modelled mathematically in a high level software environment. This involves a higher degree of simplification. Software like Matlab, Ansys-symplorer is well known commercial tools with good model libraries for electromechanical components.
They are mostly used for simulating the overall system to verify the basic concept and functioning in the technological level. They are easy to model and use.

Schematic of the Software In the Loop (SIL) simulation is shown in Fig 6 below :

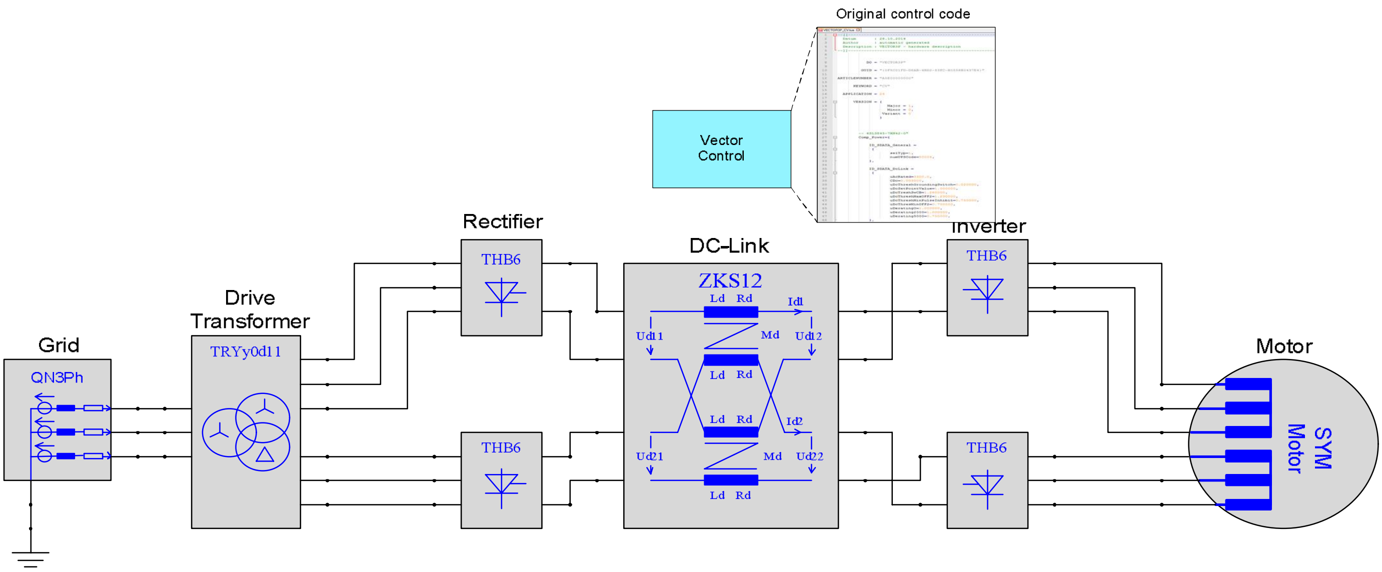

Figure 6: Example MV drive software in loop system model

As shown in

Figure 66, in software in loop simulations the original control codes used in the drive is incorporated with in the high level simulation.

It allows a simulation of electrical circuits interacting with the actual Variable Frequency Drive (VFD) control. The advantage of this simulation technique is the higher correlation with reality achieved by using actual VFD control code. But this comes at a price of longer simulation times and complexity in modelling.

Schematic of the Hardware in the loop simulation (HIL) is shown in Fig. 7 below :

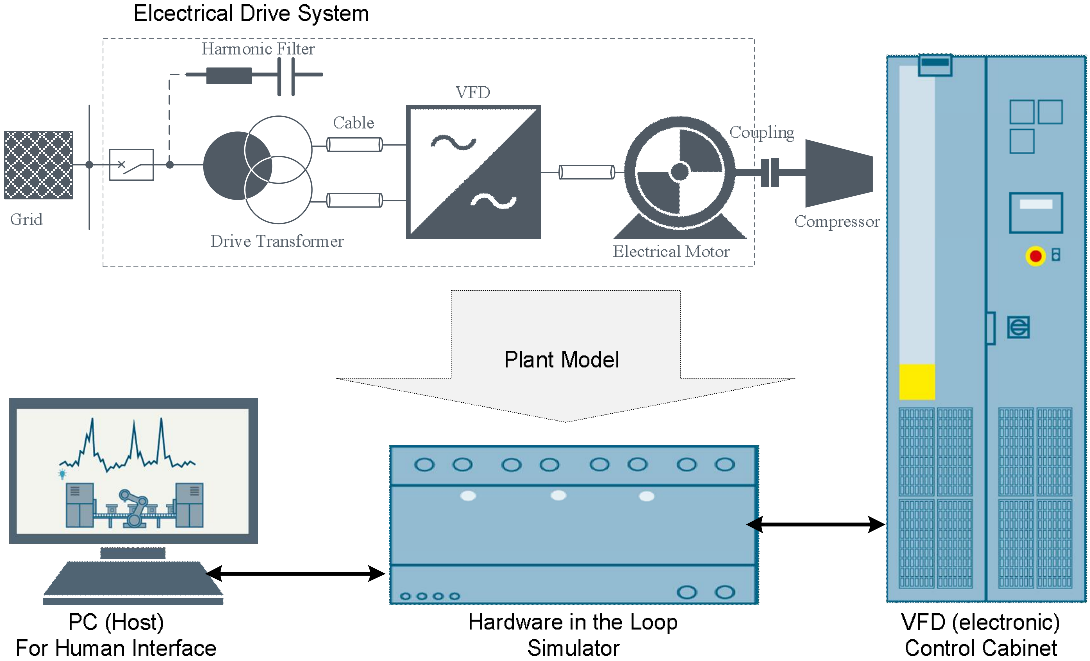

Figure 7: Hardware In the Loop simulation model - principle

HIL is a powerful simulation technique which uses real electronic control hardware of the VFD in combination with electrical and mechanical plant models of the drive train running in real time on a HIL-simulator. This type of simulation has the following advantages

- Almost exact behavior of the drive system, identical to the real plant behavior
    - All delays and discretization included automatically
- Real time simulation → means fast simulation
- Parameters from HIL can be imported into drives control in plant and vice versa → this helps faster testing of plant conditions with their original parameter settings.

These advantages come at the cost of high level of effort required in such HIL models. The models require additional hardware development (electronic). HIL simulation also requires a complete commissioning procedure involving the complete system parameters.

Electrical drive system simulations in O&G applications

Drive system simulations have been typically used in O&G applications for analyzing the following topics

- the air-gap torque of VFD driven motor
- line side current and voltage → to analyze the harmonics injected by the drive into grid
- SSTI – Sub Synchronous Torsional Interactions → to simulate the reaction of VFD system with the Gas Turbine (GT) driven generators supplying them.
- Effect of long cable in applications like subsea production, ESP applications
- Voltage dip ride through behavior of VFD driven systems (**Fehler! Verweisquelle konnte nicht gefunden werden.**)
- Pre commissioning of drive systems

Root cause analysis in case of unlikely failures

Table 2: Summary of different simulation techniques available for medium voltage drive system. The pros and cons of each technique have been shown relative to each other.

Arguments	High level software	Software In the Loop	Hardware In the Loop
Correlation to reality	O	+	++
Simulation time	+	O	++
Simple to use	++	+	O
Cost involved	++	+	O
Typical applications	Overall system simulations, Concept verifications	Drive control development, Detailed control behavior simulations	Pre-commissioning, failure analysis, safety concept, routine and type testing

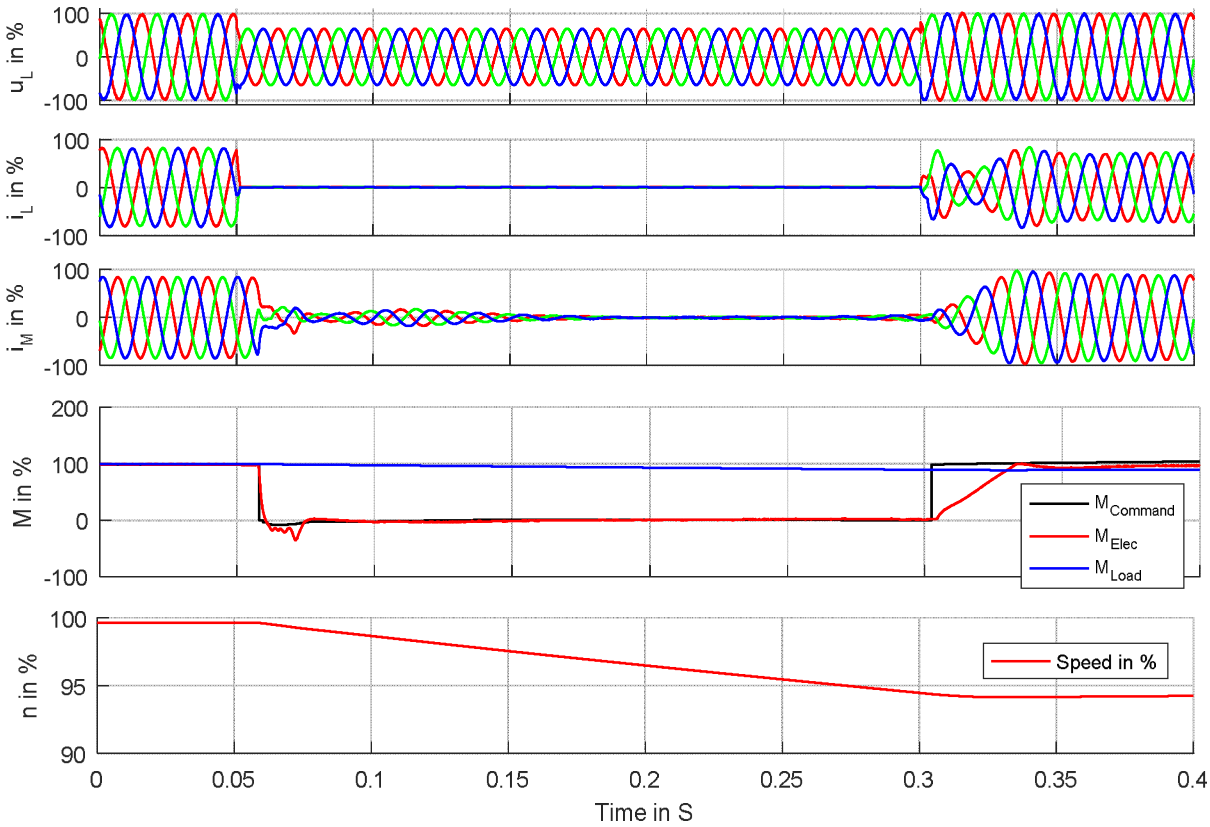

Figure 8: Results of drive system voltage dip ride-through behavior simulation using HIL.

Conclusion

As explained above, Electrical Drive System, simulation capability offers unparalleled advantage of estimating the response of the complete drive system in the event of system faults. This possibility is a tremendous advantage to the customer in improving the plant reliability and availability while taking advantage of better operating efficiency. This advantage is not available when customer is selecting mechanical speed variation equipments like variable speed fluid couplings.

Due to its modular design, Drive Train Analytics can be flexibly tailored to meet specific drive requirements. Whether one wants to monitor a component or the entire drive system, a solution can be tailored that will grow with demands and continuously monitor installed components. The use of this solution optimizes the previous inspection intervals and the resulting downtimes, enabling one to focus fully on your core business. With all these components working together optimally, Drive Train Analytics helps to significantly reduce lifecycle costs and boost availability & productivity.

NOMENCLATURE

VFD = Variable Frequency Drive

VSDS = Variable Speed Drive System
O&G = Oil & Gas
DTA = Drive Train Analytics
e-LNG = Electrically powered Liquified Natural Gas (process)

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