



SOLUTIONS TO REQUIREMENTS ON ELECTRICAL DRIVES IN O&G APPLICATIONS

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ABSTRACT

Variable-frequency drives (VFDs) are being increasingly employed in oil and gas (O&G) applications due to their better efficiency, reliability and process control when compared to conventional drives. In comparison with conventional industrial gas turbines, electrical drives result in at least 7 to 10 more production days per year. The requirements on variable-speed drives (VSDs) keep rising, including stricter regulations and the need for higher efficiency. Due to the wide range of different compressor/pump applications (upstream, midstream, downstream) used in the O&G industry, different requirements are placed on the electrical drive systems for each application. For high power applications ranging from 1 MW up to 100 MW medium-voltage (MV) VFDs are the preferred solution. This paper provides an overview of the application-specific requirements on MV drive systems, and matches these requirements with state-of-the-art MV VFD solutions. This paper complements the process and mechanical knowledge that

the O&G industry has with essential electrical background on medium-voltage drive systems.

ELECTRICAL DRIVES FOR OIL AND GAS

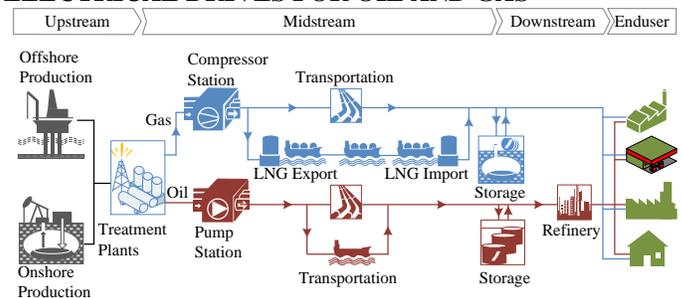


Fig. 1: Overview of O&G applications

To extract, transport and process oil and gas (Fig. 1), high pressures are frequently required to refrigerate the medium. Therefore, turbomachinery rotating equipment such as compressors and pumps are used to achieve the required pressure and flow. Electric motors are used to drive these machines. The motors can be supplied directly from the line supply (DOL motor) or can be supplied from a variable-frequency drive (VFD). The following are the key advantages of employing VFD fed motors,

- Higher process flexibility can be achieved by varying the speed and torque of the driven equipment along with a lower energy consumption.
- VFDs increase the process reliability by decoupling the motor from the disturbances in the line supply or grid.
- They are employed to start big motor or gas turbines without high inrush currents and transient pulsating torques when operating under load.
- VFDs can also feed energy back into the grid while operating the process with a variable speed.
- Higher speeds can be achieved by feeding the motor with a higher frequency than the line supply frequencies. This can eliminate the need for gearboxes, which are subject to high mechanical stress and require regular maintenance.



Tab. 1: Key requirements on VSDs depending on the installation sites in O&G industry

Installation site	Onshore	Offshore	Subsea
Load machines	Compressors / Pumps		
Criticality of process interruptions	Medium	High	High
Long cables required between drive and motor*	Low	High	High
Spatial flexibility required	Low	High	High

Tab. 2: Key characteristics of O&G applications that influence the VSD system specifications

O&G Applications	Upstream					Midstream			Downstream			
	Artificial lift		Multi Phase Pumps	Enhanced recovery		LNG	Pipeline	Storage	Refinery	Petrochemical		
Process	Gas lift	ESP		Water injection	Gas injection					MR, PR, Booster, BOG, ...	Pipeline compressors	Storage compressors
Power range in MW	< 4	< 1.5	< 4.5	< 20	< 50	< 80	< 40	< 15	< 30	< 20	< 40	< 60
Criticality of process interruptions	o	+	+	o	o	++	o	o	++	++	++	o
Long cable requirement*	o	++	++	o	o	+	o	o	+	o	o	o
High speed	o	+	o	o	+	++	++	++	++	o	o	o

* Cable length between motor and drive less than 80 m is normal (o), cable lengths up to 500 m can be considered long (+) and output cable lengths up to 25 km and above can be considered to be very long (++)
o – Less; + – Medium; ++ – High

The different applications and processes in the oil and gas industry, lead to various requirements placed on the VSD. Tab. 1 and Tab. 2 summarize the most common oil and gas applications employing medium-voltage (MV) drives and their specific characteristics influencing the VFDs. Using electrical drives for O&G applications to improve the process should have no negative impact on the process reliability and availability. This requires drives with integrated redundancy to keep them functioning also in the unlikely case of a component failure. The drive should also have ride through capabilities in case of line side disturbances. They should be nearly maintenance free and simple and fast to repair. All these key requirements that may have to be taken into account will be discussed in the following chapters.

As each application and project environment have their own specific requirements, good cooperation between electrical and mechanical engineers to utilize developments in their respective fields becomes vital in the oil and gas industry.

MEDIUM-VOLTAGE VARIABLE-FREQUENCY DRIVES

A VFD is the most common technology in the oil and gas industry to vary the speed of rotating equipment driven by motors. The speed and torque flexibility of the compressors and pumps lead to a higher degree of process optimization. For loads with power requirement higher than 1 MW, medium-voltage (MV) drives are the most widely employed drive solution. They have input and output voltages ≥ 1 kV. Depending on the output power, several different topologies of

MV drives are available on the market. A short overview of the existing topologies will be provided. In particular, the modular multilevel topology, which can meet most of the requirements related to the oil and gas industry, is presented in this paper.

Overview of VFD topologies:

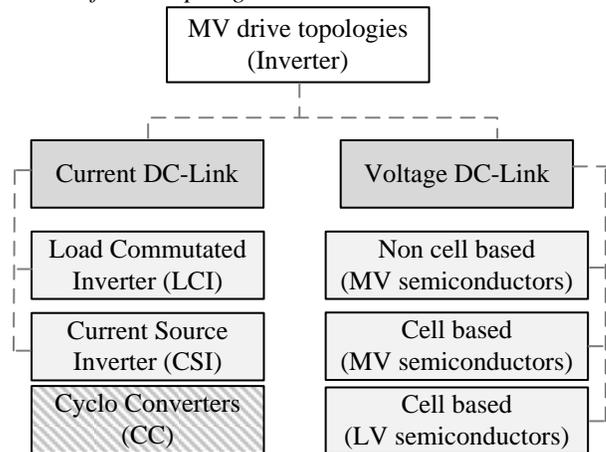


Fig. 2: Overview of medium-voltage drive topologies

Fig. 2 shows the main medium-voltage drive topologies for high power ratings in industrial applications. Over the last few decades the Voltage DC-Link commonly termed as voltage source inverter (VSI) topologies have become the predominant converter technology. This is why this paper only focuses on these topologies. Nevertheless, thyristor converters are still frequently used for higher power ratings and to address special



applications (Hiller et al., 2008).

MV drives can be divided into two major categories based on the type of DC link used, these being the current and voltage DC link drives. Current DC link drives have a reactor in the DC link to filter the rectified DC current. This is then modulated to create a variable-frequency AC current by the inverter. This can be further divided into the well-known LCI and CSI topologies. Cycloconverters (CC) are similar to LCI drives but they do not have a DC link, and therefore convert the AC directly into a variable-frequency AC supply. They are only used for very low speed applications with a maximum output frequency not exceeding half the input supply line frequency. As a consequence, cycloconverter drives are not normally used for oil and gas applications.

The drives with voltage DC link have a DC link capacitor to store the rectified DC voltage. The inverter generates the variable-frequency AC voltage at the output. These inverters can have various topologies, and can be divided into conventional non-cell-based and cell-based topologies. The non-cell-based MV drives use medium-voltage semiconductor devices. Both the non-cell-based and cell-based topologies are multilevel inverters. A drive is multilevel if the number of levels (steps) in the output phase to the neutral point voltage is higher than two. The cell-based drives can either use MV semiconductor devices or LV semiconductor devices. The main difference between these is the magnitude of the output voltage steps. Drives using LV IGBTs have relatively small voltage steps at the output. Another decisive intrinsic characteristic of drives with LV IGBTs is the high level of redundancy. This is not possible with the cell-based drives using MV semiconductor switches.

Considering the power requirements for MV drive systems in the oil and gas industries and to limit the comparison to comparable topologies, this paper only considers water-cooled MV drives starting with an output power of 4 MW. For oil and gas applications, where regeneration is normally not required from the process viewpoint, diode bridge rectifiers are the most suitable line side rectifier configuration. Occasionally, dynamic braking choppers are required to quickly stop the process. Conventional multilevel converters using medium-voltage semiconductor devices capable of blocking voltages higher than 4.5 kV have been discussed in depth in several previous publications (Sommer, et al., 1999, Kouro, et al., 2012). Modular multilevel converters (M2C) using LV IGBTs are briefly explained in the following section.

Modular multilevel converter (M2C)

The modular multilevel converter (see Fig. 3) is the latest topology to enter the high power, medium-voltage drive market. Depending on the motor voltage and the corresponding number of cells, the M2C is a 7-level up to 17-level drive. It uses simple, two-terminal cells equipped with 1.7 kV IGBTs and state-of-the-art polypropylene film capacitors. These devices are well established in the low-voltage converter

industry. Since the low-voltage drives market is 80-90 % of the total drives market, these components are manufactured in very high quantities. This ensures the highest possible quality at reasonable costs. Furthermore, all new technologies (e.g. new IGBT and diode generations, new module technologies with higher load cycling capabilities) are first introduced into the LV market. All these developments are driven by high volume applications, such as the wind power industry requiring very high quality standards. Therefore, MV drives using LV technologies can benefit from these applications, leading to a long-term availability of spare parts, fast innovation cycles and high reliability.

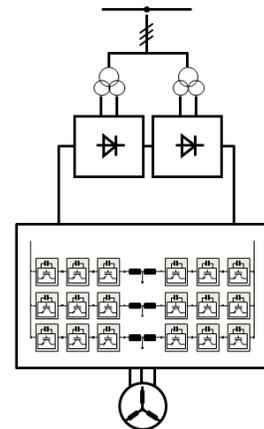


Fig. 3: Modular multilevel converter (M2C) topology

On the line side, the M2C can be connected to any conventional 12 to 36-pulse diode rectifier using press-pack diodes and RC snubbers. This technology has been employed for many decades and has reached a very high quality standard.

Due to the modularity of the M2C topology, redundancy can easily be implemented in the motor-side inverter. By adding 6 (or 12) additional cells and bypass switches to all of the cells, an $n+1$ (or $n+2$) redundancy can be realized. This kind of redundancy covers a complete cell including semiconductors, capacitors, heat sinks, PCBs and power supply. Having this type of redundancy, the drive voltage and current capability does not have to be reduced in case of a cell failure. One advantage of cell-based topologies that should be noted is that a cell bypass allows operation with reduced power, even if no redundant cells have been implemented, which allows the process to remain operational.

REQUIREMENTS PLACED ON VFDS IN THE OIL AND GAS INDUSTRY:

This section explains how the key requirements of the oil and gas industry can be met regarding the electrical drive systems. Each of the requirements and its influence on the electrical drive system will be explained, and the behavior of the M2C-based drives will be discussed.



1. High-speed drives

Gas pipeline and storage applications are tending towards high-speed motors to avoid mechanical gearboxes and hydraulic couplings. The newly developed compressor concept with integrated motors is designed for high speeds to eliminate mechanical gearboxes. It is becoming common that gas turbines (GTs), driving the process compressors and nearing the end of their lifetime, are being replaced by electric drive systems. High-speed drives will eliminate the need for gearboxes and hence may fit better in the available space. The higher speed requirement places certain challenges on the electrical drive system.

Definition of high-speed drives

The term high-speed drive refers to motor speeds normally higher than the speeds equivalent to the line supply frequency. For example motors for a 50 Hz power supply with an operating speed higher than $n_{syn} = 50 \text{ Hz} \cdot 60 = 3000 \text{ rpm}$ can be termed high-speed motors.

Tab. 3: Key data of high-speed motors (current market values)

MOTOR TYPE	SPEED IN RPM	OUTPUT POWER LIMIT IN MW (APPROX.)
Synchronous	3000 to 3600	90
Synchronous	3000 to 6700	55
Induction	5000 to 15000	15

These higher motor speeds require a special motor design (Walter, et al., 2007 and Walter, et al., 2014). The VFD characteristics also have a significant influence on the motor design.

Motor design:

The stator design is similar to that of a standard converter motor. For high-speed motors, the rotor design differs considerably to conventional high-speed motors. The mechanical stress and the rotor dynamics are the major influencing factors for the rotor design.



Fig. 4 High-speed rotor designs

The maximum feasible peripheral speed (material-dependent value) is in the range of 200 to 250 m/s. This limits the possible rotor diameter. This is calculated using the following formula.

$$\text{Rotor diameter} = \frac{\text{Peripheral speed}}{\pi \cdot \text{speed}}$$

For a given peripheral speed value the diameter of the rotor decreases with the increasing motor speed. This leads to a very compact design.

Advantages of the M2C type drive for high-speed applications:

High-speed motors can only be operated by converters as they require high frequency (> line supply frequency). Among the available MV drives, the cell-based drives with LV IGBTs are the most suitable drives for high-speed applications. Their advantage for high-speed motor applications is as follows

a) Fewer losses in motor

The modular, multilevel converter topology results in a very high number of smaller output voltage steps, resulting in an almost perfectly sinusoidal waveform (see Fig. 5). This reduces the additional losses due to harmonics in the motor.

b) No special insulation or output sinusoidal filter required

Another advantage is that the motor does not need any special insulation for converter operation due to the almost sinusoidal waveform characteristics of M2C drives. The M2C-based drive, due to its very small voltage steps, does not need any output sinusoidal filter. Sinusoidal filter normally implies additional restriction in the maximum possible output frequencies. They also result in additional losses leading to a decrease in the overall system efficiency.

c) Torsional resonance frequencies of drive train are not excited:

Due to the higher output steps (levels) the air-gap torque is almost equivalent to that of a direct online motor (motor connected directly to the line supply). The air-gap torque is free from any lower order torsional pulsating torque excitations. The M2C drive uses vector control and pulse width modulation (PWM) with a constant switching frequency. This eliminates any risk of white noise associated with modulation techniques employing a random switching scheme. Hence, the M2C drive has no restrictions when it comes to selecting the operating speed range, rated frequency and number of pole pairs. This provides a high degree of freedom to optimize the motor design to make it suitable for higher speeds.

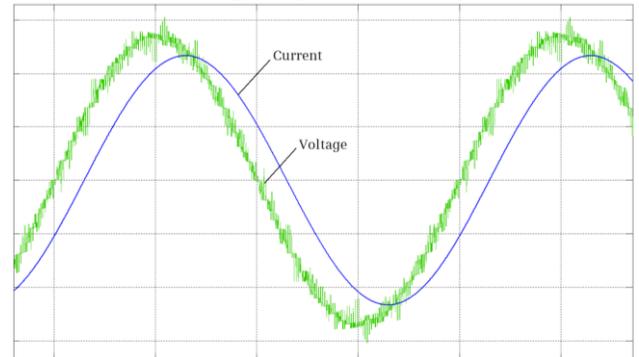


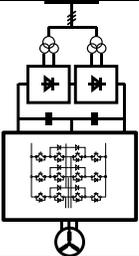
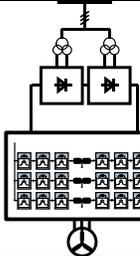
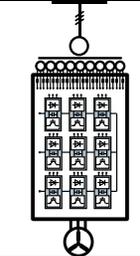
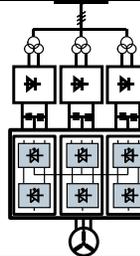
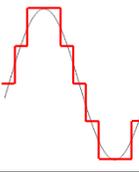
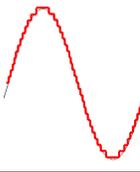
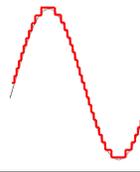
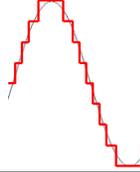
Fig. 5: Measured output voltage and current waveforms of a M2C drive

d) *No or only low drive derating required for high-speed operation*

In variable-frequency drives, the variable sinusoidal voltage output is achieved by switching between different DC voltage levels. In order to achieve a reasonable fundamental sinusoidal output voltage waveform, the switching frequency of the semiconductor devices should be at least 3 to 5 times the fundamental frequency. The higher motor speeds require higher VFD output frequencies and hence higher switching frequencies. This may lead to higher switching losses and hence require higher output current / power de-rating. This means higher losses and lower efficiency, which may require larger drives. Also additional cooling is required to dissipate the resulting losses in the drive. This not only increases the cost and space of the drive, but also the operating costs due to the increased power requirement resulting from the reduced efficiency.

Due to their inherent higher effective switching frequency, the proposed multi-cell-based topology using LV IGBTs does not require any (or only little) output derating. This means the M2C-based drives have higher efficiencies even at very high output frequencies. This results in better drive utilization, with a more compact design and higher efficiency. As a consequence, operating costs are reduced and less cooling is required.

Tab. 4: Theoretical comparison of the output voltage characteristics of common MV VSI drive topologies (6.6 kV output voltage)

3L-NPC	M2C	2L-SC-H-BRIDGE	3L-SC-H-BRIDGE 5L-ANPC
			
			
Number of levels in the output phase-to-phase voltage			
5 levels	25 levels	21 levels	9 levels
Highest voltage step			
5 kV	1 kV	1 kV	2.5 kV

e) *Braking chopper:*

High-speed motors mostly use active magnetic bearings (AMB) due to their advantages over sleeve and ball bearings. The use of AMBs eliminates the requirement of lubricating oil, therefore making this solution more environmentally friendly.

The AMBs also give more freedom in controlling the lateral vibrational characteristics of the drive train. AMBs require backup bearings for the unlikely event of the AMB power failing. Ball bearings are used for this backup system. The rotor will land on the backup bearing in case of an AMB failure at high speeds. The backup bearing is only dimensioned for short time operation where it is expected that the motor comes to a standstill in approx. 20 sec. If this braking cannot be provided by the process, the drive should be capable of actively stopping the motor. This is normally achieved using braking resistors. As the M2C technology combines the multi-cell-based technology with a common DC link (see Fig. 6), the braking resistors can be simply connected in the DC link, and the active braking can be controlled using the braking chopper in the DC link. This feature is normally not possible with conventional multi-cell-based drives.

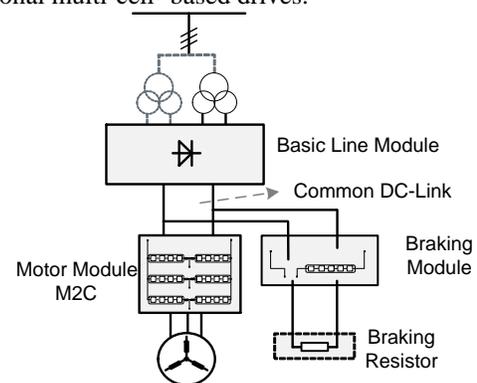


Fig. 6: Drive system with braking chopper at the common DC link with the braking resistor

2. *Integrated compressor*

Integrated compressors are compressors that combine the motor and compressor in the same housing as shown in Fig. 7. Due to the compact integrated design, they are normally of direct drive type without any gearbox. AMBs are employed in integrated compressors to make them oil free.

They have the following advantages over conventional compressor trains with separate motor, compressor and shaft couplings,

- No gearbox
- Oil free, environmentally friendly and also low maintenance
- Shaft seal systems are not required
- Couplings are not required between the different shafts

Due to their higher speeds, drives for an integrated compressor should meet the requirements specific to the high-speed applications explained above. In addition to those requirements, it has to be considered that the motor for these applications is an integral part of the compressor, and therefore their nominal voltage and current values cannot be freely selected. This means that the drives should be customized for the predefined electrical parameters. It is also important that the motor windings are not stressed with higher voltages due to the drive

switching behavior. A higher harmonic content in the drive output current may lead to higher additional losses in motor, therefore complicating the motor design. The proposed cell-based M2C drives can meet all these requirements without requiring one insulated bearing.

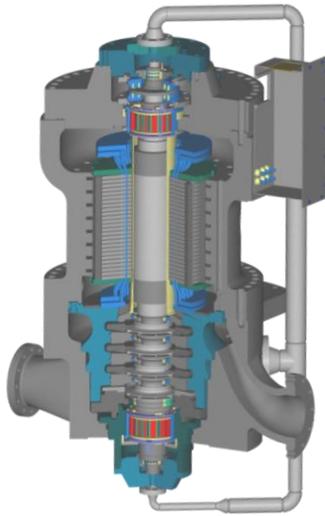


Fig. 7: Compact integrated compressor with electrical motor with an output power of 6 MW.

3. Long output cables to motors

Depending on where the motor is installed, the drive may be located remotely from the motor. Applications requiring long cables between the VFD and the motor:

- If the motor is installed in a hazardous zone
- Subsea application where the motor is installed in the seabed
- ESP applications where the motor/pump is installed in the oil reservoir.

Long cable lengths ($80\text{ m} < \text{cable length} > 1\text{ km}$):

In most of oil and gas projects where the motor is installed in a hazardous zone, the length of the cable between drive output and motor can be up to 1 km. The longer cables may cause transmission waves and also lead to higher parasitic capacitor charging currents. Depending on the drive topology an output reactor or dv/dt filter is required to overcome the above effects. The important drive characteristics influencing these effects are the highest voltage steps and the dv/dt . The cell-based M2C drive has inherently very small voltage steps, and hence does not need any additional measures in the form of reactor or dv/dt filter for long output cables.

Very long cable lengths ($> 1\text{ km}$):

Having very long cable connections from the VFD to the motor requires high output voltages from the VFD in order to minimize the transmission loss and the voltage drop in the

cables. For long cable connections between VFD and motor, transmission effects have to be taken into account. It has to be ensured that the VFD output frequency spectrum does not intersect with the natural cable resonance frequencies. The impedance characteristics of the output cable depend on the electrical cable parameters and its length. If a cable resonance gets excited by the output voltage component, that particular voltage harmonic component may be amplified to higher amplitude when reaching the motor terminals. This may stress the motor insulation and damage the motor insulation. The longer the cable the lower the first resonance frequency - and it may be excited by the output voltage harmonics of the drive. LC filters are used at the output to avoid this. The low-pass filter alters the output impedance characteristics so that the higher frequency components are attenuated instead of being amplified.

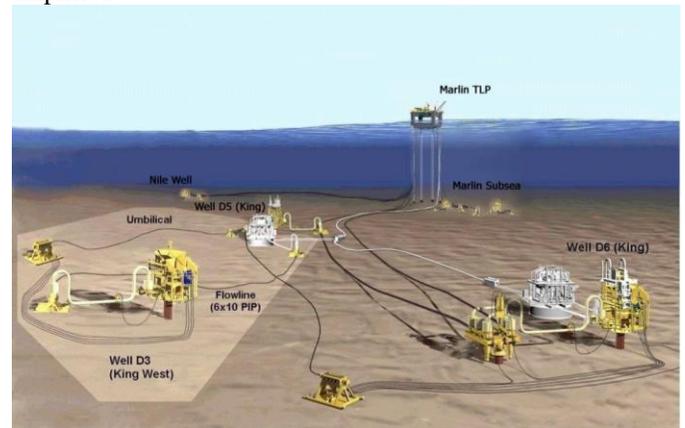


Fig. 8: Subsea application showing the use of very long cables between the drive located on a platform and the motors on the sea bed.

The well-defined higher effective switching frequency of the cell-based M2C drives with LV IGBTs makes the filter design simple and straightforward. The clear base band without any harmonics helps to optimally select the first natural frequency of the filter.

For very long output cables, step-up transformers are required to compensate the high voltage drop that occurs along the long cable. Due to the sinusoidal output voltage and current waveform of M2C drives, these transformers can be easily dimensioned and designed.

For applications involving long cables, employing the proposed M2C drives results in a compact solution for the output filter and step-up transformer when required.

4. Input and output side flexibility

The flexibility at the input and output of the VFD is very important for oil and gas applications due to the wide range of possible installation environments, for example platform, subsea or onshore. Flexibility at the input means the freedom to select any type of drive transformer, oil filled or dry type depending on the installation location and the availability of

cooling resources. This also means the freedom to select between different pulse numbers (12, 18, 24, 36 or even higher), which influences the line side harmonic current injected into the line supply by the drive.

Most MV drive topologies available on the market can offer a separate transformer. The only exception is the SC-2L-H bridge drives (see Fig. 10). Generally, these topologies have an integrated transformer. Especially in the low power range (often air-cooled drives power range) this is a benefit as it allows easy integration according to the maxim “three cables in - three cables out”. But this concept is limited especially in the high power range, where often water-cooled drives are employed. Oil-filled transformers are the best choice for high power and high input voltages. This is not practical for water-cooled 2L-H bridge drives. Even in cases where the plant has restricted space, with this concept is not easy to locate the transformer elsewhere (e.g. outdoors).

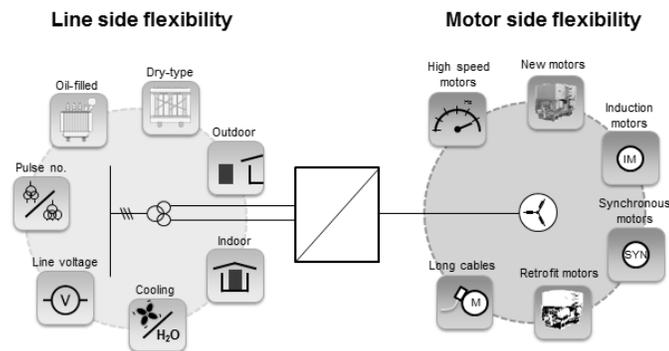


Fig. 9: Important factors for line and motor flexibility

A restriction of the SC-3L-H-bridge topology is that the input side always requires 6 secondary transformer windings. Generally, this results in low harmonics on the line side. But this drive does not provide the flexibility to change the pulse number in case of cable resonance around the 35th harmonic component. It also limits the flexibility, especially in terms of place (size, space) restrictions.

With the proposed M2C drive, any type of transformer in conjunction with a project-optimized pulse number can be selected without any restrictions.

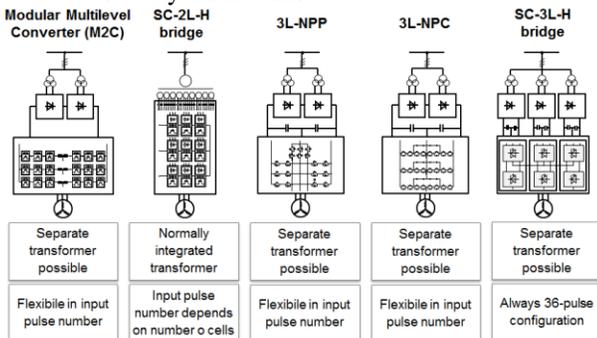


Fig. 10: Comparison regarding line side flexibility and possible restrictions

On the motor side, thanks to its almost sinusoidal output waveform, the M2C drive can also be used for retrofitting existing DOL motors. Further, any type of motor (induction, synchronous or permanent magnet) can be supplied without any restrictions.

5. Scalability of drives for different power ratings

The better a drive product can be scaled over a wide power range, the better is the maintainability. This is because this lowers the number of different spare parts, but also ensures that development costs for different drive products can be reduced. Changing the drive topology to achieve higher power ratings will always lead to differences between the drive characteristics, and normally leads to higher costs of maintainability.

With growing power demand the optimum drive voltage will also grow (normally in a range of 2.3 up to 13.8 kV).

Cell-based topologies using LV components often have an advantage in scalability as, with just one cell design, they can cover a larger range of output voltages. This is possible due to their smaller output voltage steps compared to drives using MV components.

The cell-based M2C topology is truly scalable over a very large voltage range, and hence power range. This is demonstrated in HVDC applications, which operate with 400 kV output voltages and therefore use more than 200 cells per arm. The following example better explains the scalability. An M2C cell with a 1.2 kV phase-to-phase output voltage could be scaled as follows:

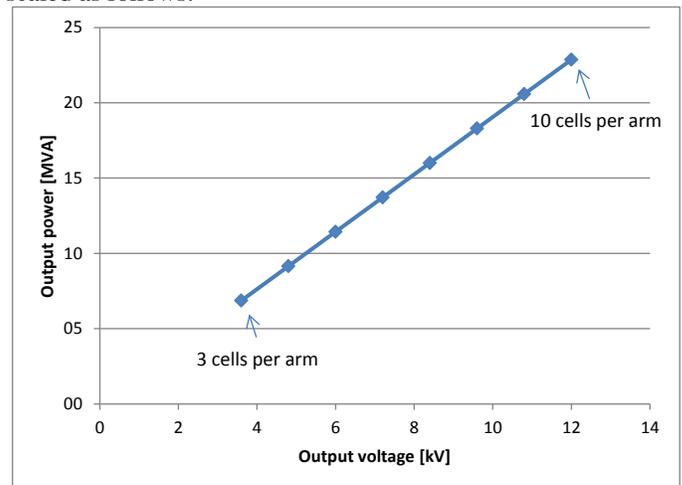


Fig. 11: Theoretical output voltage and power scalability of a single M2C drive using the same 1100 A cell type achieved by connecting 3 to 10 cells in series in one arm.

Drives for an output power range of 6 to 23 MVA could be covered by employing just a single type of cell. The power range can even be doubled if two motor modules feed one motor (connecting the motor modules in parallel to increase the output power). This means a lower range of different spare parts and also the number required. Further, if a plant has drives comprising two different cell types, due to their unified



modular design, all available central drive components such as control boards, bypass switches, bus bars, and water connectors are the same. This means common spares for these components can be used for drives, even if they are equipped with different types of cells. This helps keep the reliability, quality and more importantly the maintainability.

The benefits of such scalability are that the footprint normally increases only by the space required for an additional rack of cells. Furthermore this concept allows cell redundancy to be very simply implemented.

Tab. 5: Power rating, silicon area and FIT rate of the 6.6 kV water-cooled MV drive topologies being considered (w/o line-side rectifier diodes)

Topology	Nom. motor voltage [V]	Nom. motor current [A]
M2C	6600	1200
SC-2L-H bridge	6600	1250
3L-NPP	6600	1100
SC-3L-H bridge (IGCT)	6600	1250
SC-3L-H bridge (IGBT)	6000	1925

6. Reliability of the drive

Interruptions of "critical-to-service" processes can be expensive if they happen unexpectedly. Because of this, reliability and availability are often two of the most important criteria in oil and gas industry to consider when specifying and selecting equipment. In general terms, the reliability states the probability that the drive will perform its intended function for a specified amount of time without failure. On the other hand, the availability is an indicator for productive uptime.

Normally the comparison of a product feature expressed in a numerical value such as weight is a simple task. Unfortunately, the same does not apply when comparing MTBF values provided by different vendors. This is due to differences in the evaluation method and the possibly different assumptions made during the calculations.

To avoid the above mentioned problems, (Busse et al., 2015) used the same methods and assumptions for all topologies when comparing the main medium- voltage VSI topologies for high power compressor applications.

In the case of compressor drives in the power range 10-15 MW, the predominant motor voltage is 6.0 to 6.6 kV, which is the cost optimum for the complete drive system comprising switchgear, line transformer, converter, cables and motor.

Hence, the MV drive systems comprising water-cooled drives with a nominal motor voltage of 6.0 or 6.6 kV that are available in the market - and which were available for a motor power of 11 MW - have only been considered for comparison purposes – and most importantly the maintainability.

The benefits of such scalability are that the footprint normally increases only by the space required for an additional rack of cells. Furthermore this concept allows cell redundancy to be

very simply implemented. Tab. 5 gives the reliability relevant data for the selected drives.

Fig. 12 shows a comparison of MTBF values of the compared drives without any redundancy. A service interval of five years has been assumed. When comparing the MTBF of the drive concepts without redundancy, all drives have a comparable system MTBF (without redundancy) – the differences are negligible. Fig. 13 shows the MTBF values taking the redundancy into account for the compared topologies. Implementing an (n+1) redundancy significantly increases the MTBF of the cell-based drive systems (except for the SC-3L-H bridge drives, where redundancy is not possible in the power section).

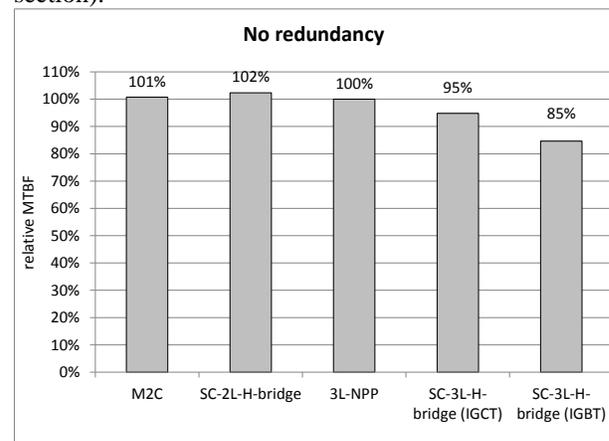


Fig. 12: Relative MTBF for different drive topologies (no redundancy)

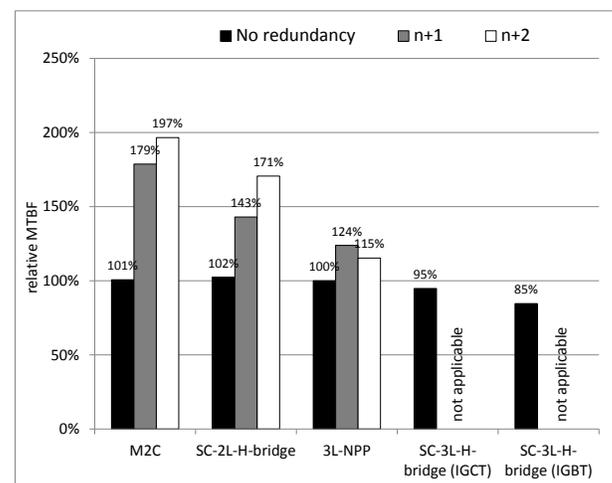


Fig. 13: Relative MTBF for different drive topologies (including cell/IGBT redundancy)

The benefit of an (n+1) redundancy in the 3L-NPP concept is limited. This is because of the limited reliability of how redundancy is actually achieved. Example: In a series connection of IGBTs in the 3L-NPP concept, redundancy is only successful in case of a short-circuit (conduct-on-fail) of the IGBT itself. In the case of a malfunction of the associated

gate unit, redundancy is not necessarily successful, i.e. there is a certain probability that the drive will trip.

Beyond the associated costs, the step from (n+1) to (n+2) redundancy does not significantly increase the reliability of the cell-based concepts. In other words, the benefit of (n+2) redundancy does not significantly exceed the disadvantage due to the increased component count.

In the 3L-NPP concept, the effect of the reduced total reliability due to the increased component count already exceeds the theoretical advantage of the (n+2) vs. the (n+1) redundancy. This is why the MTBF for the (n+2) is lower than for (n+1) redundancy.

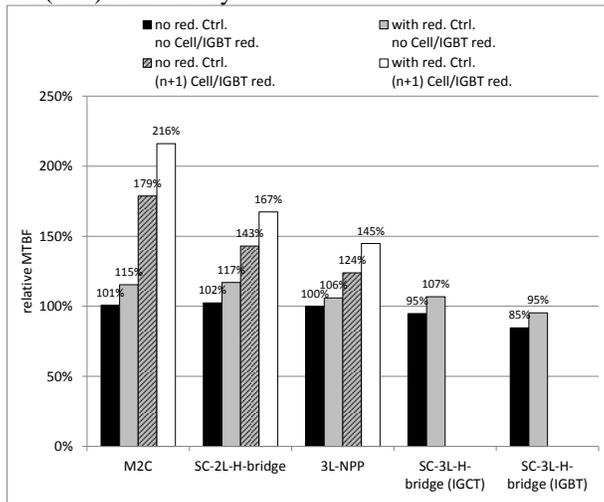


Fig. 14: Relative MTBF for different drive topologies (including (n+1) cell/IGBT redundancy and redundant control)

Fig. 14 shows the influence of a redundant converter control including redundant CPUs, interfaces between control and power section, current and voltage sensors, power supplies etc. According to extensive field experience with state-of-the-art control electronics, the reliability of such components is already very high. Theoretical calculations (e.g. acc. to IEC 61709) result in very conservative reliability data, whereas field data show results that are better by a factor of 5-10.

CONCLUSIONS

This paper has summarized the important requirements on electric drive systems for O&G applications. This further explains how the proposed M2C topology-based drive will be best suitable for O&G applications. In doing so, the paper tries to address the requirements of process engineers regarding state-of-the-art MV drive systems to meet their foremost requirements.

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