

Review On-Design of Load Filter for Medium Voltage Drive Used in Submersible Pump

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ABSTRACT: VFD are increasingly used for high-power electrical submersible pump (ESP) wells. Due to long length cable in ESP system harmonics is produced in system due series harmonic resonance occurred so the load filter remains to be a critical component in such applications. The design of load filter with different length of cable and different type of configuration for MVD (medium voltage drive) and two typical configurations for ESP systems is discussed. Three scenarios (no load filter, with an improperly designed load filter, and with the load filter designed using the proposed method) are discussed.

KEYWORDS: Electrical submersible pump (ESP), frequency response characteristics Load filter, medium -voltage drives (MVDs), neutral point-clamped inverter, parallel resonance, series resonance.

I. INTRODUCTION

As the oil reserves on the mainland have decreased, the oil companies started to extend their oil research area to offshore, thus offshore power systems have become enormously important. However, pumping oil from deep water is facing with different challenges related to the power system components.

A VFD can control the electrical submersible motor to a speed that better produces the well and keeps the ESP within its best efficiency range. VFDs also offer soft motor starting for ESP systems and reduce impact to power grid during the motor start-up [1] now Variable Frequency Drives (VFDs) are widely used in offshore-oil pumping systems[2]-[6]; due to the several advantages they offer to offshore oil pumping systems. Firstly, VFDs are important for motor starting issues. Cross-line starting and reduced voltage starting are traditional ways of motor starting. Neither of these traditional methods offers flexible starting for motors. Especially with cross-line starting, large amount of stress is applied on the motor due to the highest inrush currents as compared to the other methods. However, VFDs offer more flexible starting for motors with a constant volt per hertz method. In this case, voltage and frequency applied to the motor are started from smaller values and increased correspondingly; the ratio between voltage and frequency stays constant. Thus, this soft starting reduces the possibility of drawing sand in and cracks on the shaft. Another advantage of VFDs is being more efficient than throttling control valves in order to adjust the pressure in the oil well. Moreover, the dc bus capacitor allows the system run through during the case of a voltage sagging. However, the systems with VFDs contain some harmonics which cause resonance issues. especially if the system has subsea cables [8]. Depending on system configuration, series or parallel resonances could cause higher harmonic distortions in the system.

It has been long recognized that a series harmonic resonance at the output circuit of the drive in an ESP system due to the capacitive reactance equal to the inductive reactance of the series circuit can be excited by harmonics introduced by the drive. Such resonance results in the amplified voltage and high voltage distortion in the system [14], [15] which could cause insulation failure at the downhole cable and the ESP motor within short operation time [16]–[19]. Thus the system should be optimally designed in order to avoid undesired problems such as series resonance, high harmonic distortion, motor starting difficulty, etc. The harmonics generated by the VFD could coincide with the resonance frequency of the cable, and cause high voltage spikes on the motor terminals which curtail the isolation of

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the motor windings. Therefore, the system should be designed properly to reduce the drawbacks of VFDs and umbilical cable.

Much effort has been carried out on how to mitigate the series harmonic resonance in ESP systems by conducting the harmonic analysis and designing load filters at the drive output circuit [2]–[6], [20], [21]. The LC filter is a commonly designed filter type connected directly at the output of the inverter [22]–[26]. In this paper, a load filter design method for MVD applications in ESP systems is proposed, which is suitable for various types of MVDs and with various lengths of cables in ESP systems. Show the basic diagram of system

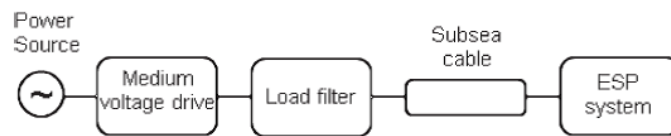


Fig 1. Load filter applications for MVDs in ESP system

In fig 1. A Load filter is connected in between medium voltage drive and subsea cable system to avoid the harmonics generated due to subsea cable. The load harmonic characteristics and spectra produced at the output of MVDs are investigated based on PWM techniques and carrier/switching frequencies, which will serve as the theoretical foundation for choosing the resonance frequency of the load filter using the proposed design method

II. MEDIUM-VOLTAGE MULTILEVEL CONVERTERS

Medium-voltage (MV) drive found widespread applications in ESP, production plants, and process industries. Only 3% of the currently installed MV motors are controlled by variable-speed drives [7]. The design of controlled MV drives is faced with a number of challenges that relate to the topologies and control of line- and motor-side converters, as well as power Semiconductor switching devices show the classification of multilevel inverters [7].

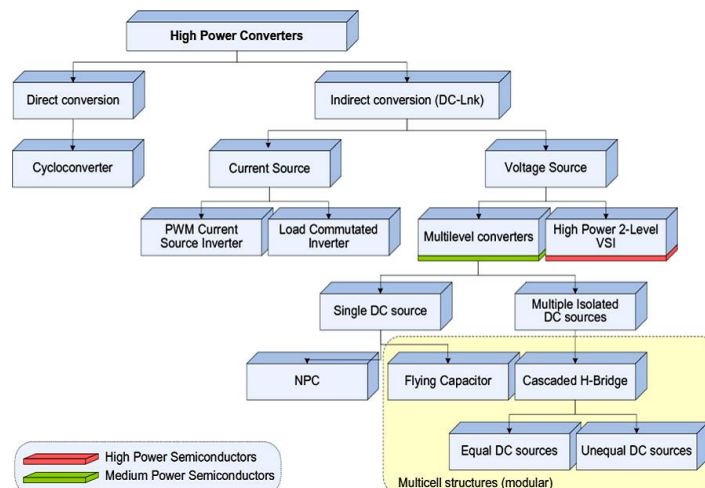


Fig. 2. Tree diagram different classifications of multilevel inverters

There are so many designs for medium-voltage VSI drives, but the NPC inverter [8]–[10],[12] and cascaded H-bridge inverter drives [12],[13], are the most common ones in the market and are currently used for ESP systems in oil field facilities. The NPC inverter uses one dc link subdivided into a number of voltage levels by a series string of capacitors [8]–[10], [12]. The configuration of a three-level NPC inverter is shown in Fig.3[8]

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If a way could be found to produce medium voltage by combining several low-voltage IPWM converters, it should be cost-effective. Such an approach would take advantage of the high manufacturing volume of low-voltage devices, and would yield several other benefits to be described [13].

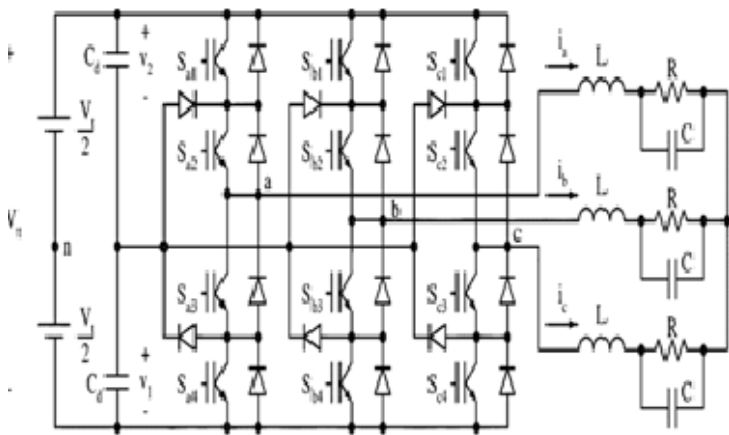


Fig 3. Three-level NPC inverter

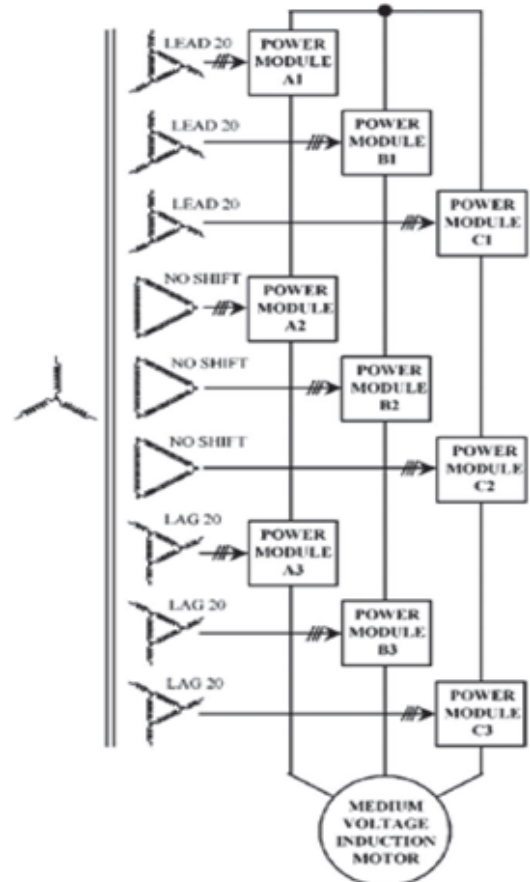


Fig 4. Topology of a 9-module 18-pulse cascaded H-bridge inverter MVD [13]

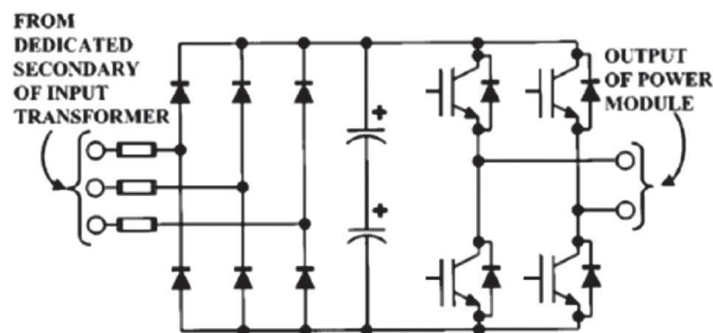


FIG 5. TYPICAL POWER MODULE OF A CASCADED H-BRIDGE INVERTER MVD [13].

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Show the cascaded H-bridge inverter is made up of series connected single-phase full-bridge inverters, each with their own isolated dc bus [12]. Fig.4 shows a configuration for an 18-pulse cascaded H-bridge inverter motor drive system [13]. Each phase has three power modules in Fig. 4. The power module for a cascaded H-bridge inverter drive is a static PWM power converter as shown in Fig.5

III. APPLICATIONS OF SUBSEA CABLES AND TECHNICAL CHALLENGES

Subsea cables are very common in the electrical submersible pump (ESP) systems for offshore platforms. Challenges of VFDs in the system combined with long cables may cause serious issues depending on the system configuration. Figure.6 and Figure.7 show two typical configurations for subsea ESP systems.

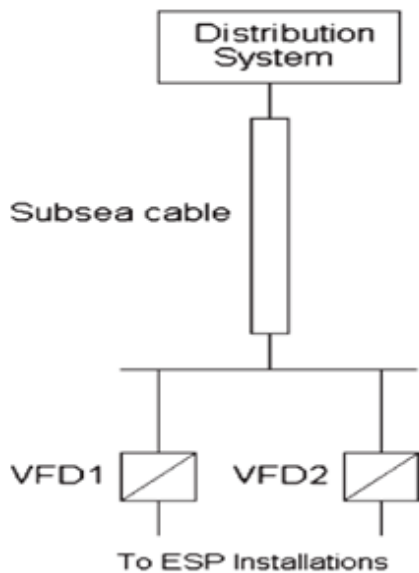


Fig 6. Configuration 1 [2]

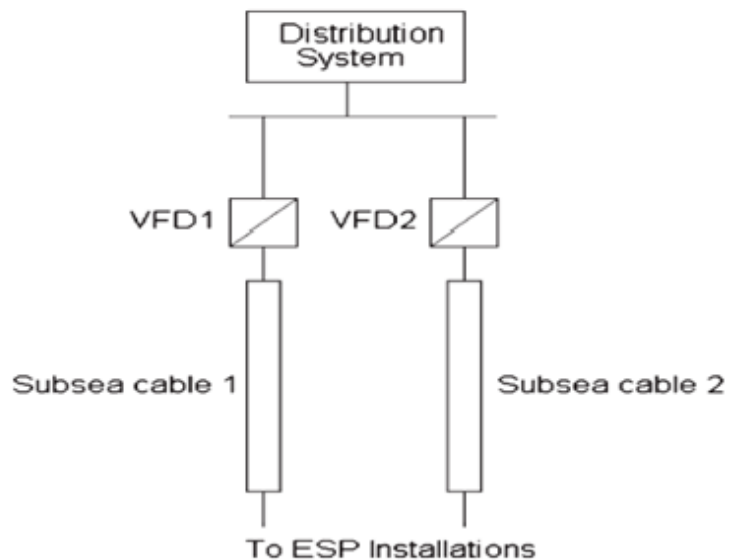


Fig 6. Configuration 2 [2]

ESP systems similar to configuration 1, shown in Figure 6, have an advantage of supporting numerous VFD-ESP wells. Another advantage of configuration 1 over configuration 2 is that the cables between VFDs and ESP motors are considerably shorter downhole cables enabling easier motor starting. However, the main problem with configuration 1 is the parallel resonance issues. Length of the subsea cable, cable parameters, and VFD type are the factors which affect the parallel resonance their harmonic current spectrums at the drive input are determined based on [2,13] and [2,15]. The parameters of the three types of subsea cables are provided in reference .Certain types of VFDs draw certain dominant harmonic currents; for example 5th harmonic dominates for 6-pulse VFDs, 12-pulse VFD draws 11th harmonic mostly, and etc. When those harmonics coincide with the resonance frequencies of the cables (resonance frequency of cables depend on the cable parameters), the magnitude of those harmonics are amplified, and total harmonic distortion of the line current on the distribution-side of the cable becomes worse than VFD-side of the cable. If the system has 6-pulse VFDs, the 5th harmonic is dominant in the waveforms and it is about 9.6% on the load side and about 88.3% on the distribution side of the subsea cable. The cable creates a resonant circuit for the 5th harmonic, thus the 5th harmonic magnitude is amplified and caused a bigger distortion on the distribution side of the cable if the system is not analyzed carefully, severe effects of parallel resonance in system

ESP systems similar to configuration 2, shown in Figure 7, could only support a single ESP well with a subsea cable. The subsea cable could be so long between the VFD and the ESP motor that severe voltage drops may occur,

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causing difficulty in starting the motor. Another problem with this configuration is that, Series resonance on the load side of the VFD for a subsea ESP installation does exist but can be successfully attenuated using a properly designed load side harmonic filter. This type of resonance was studied extensively for the drive inverter with a long cable motor drive system, also known as voltage reflection [2, 17], [2,18]. Such types of resonance or voltage reflection can be effectively attenuated by using *C* filter [2, 19], *RC* filter [18], *RLC* filter [2,18], [20], and *LC* filter [2,21], [22]. *LC* filters appear to be a commonly used method for the motor drive system harmonic mitigation through long cabling.

IV. LOAD HARMONICS ANALYSIS AND MITIGATION

The load harmonic spectrum at the output of the NPC inverter were in[12] and[27].For a three-level NPC inverter, characteristic harmonic bands of the line-to-line voltage are located around the multiple of its carrier frequency f_c . The first harmonic band appears around the carrier frequency. The harmonic spectra of the line-to-line voltage for a three-level NPC inverter with carrier frequencies equal to 750 and 1900 Hz are provided[18] and shown in fig.

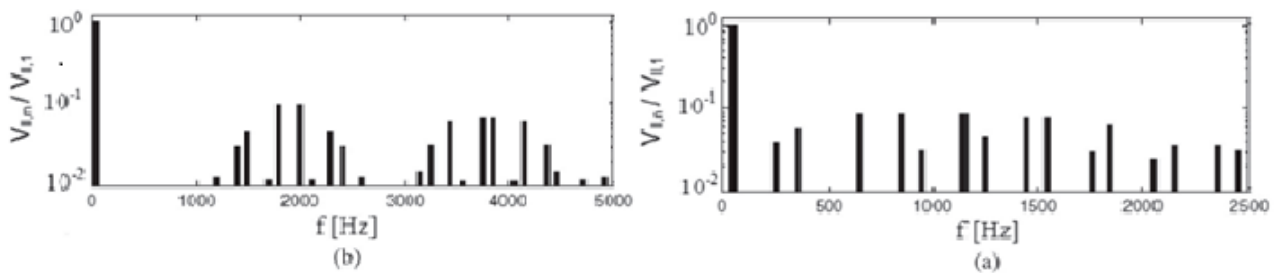


Fig.8. Harmonic spectra of the voltage at the output of a three level NPC inverter with two carrier frequencies (750 and 1900 Hz) and the fundamental frequency equal to 50 Hz [18]. (a) Carrier frequency $f_c = 750$ Hz. (b) Carrier frequency $f_c = 1900$ Hz

fig.8(a,b),using a 1900-Hz carrier frequency, the first harmonic band almost spreads to 1000 Hz .To avoid the series resonance excited by load harmonics of the voltage at the inverter output, the overall system peak resonance point should be located at a frequency away from characteristic harmonic frequencies. Therefore the method to design an effective load filter is that the resonance frequency of the load filter itself should be in the range between 750 and 1000 Hz

The resonance frequency of *LC* load filter can be calculated as follows.

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Where,

L and C are the inductance and capacitance of the circuit respectively

The method for design the filter for ESP system with MVD applications is as follows.

- 1) Find ,the resonant frequency of the load filter using the chosen *L* and *C* values .
- 2) Compare the resonant frequency value from step 1) with the criteria of [750 Hz, 1000 Hz] range.
- 3) If the value is within range, it is acceptable; otherwise, choose new *L* and *C* values, and repeat steps 1) and 2).
- 4) Simulate the frequency response characteristic of a sample ESP system with and without the load filter connected to verify the design.
- 5) The various system configurations can be checked to validate the effectiveness of the load filter.

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V. CONCLUSION

Since each VFD shows different Harmonic spectrum and frequency response and for each length of cable analysis should be conducted and best solution for the specified length should be selected. Harmonic filter should be designed to avoid series resonance which causes possible voltage spikes on motor terminal voltages.

So the load harmonic analysis always be conducted during the design stage of an ESP system to evaluate the effectiveness of the load filter. By choosing proper inductance and capacitance values of the load filter to make the system resonance frequency shift away from load harmonics The load harmonic characteristics of medium voltage drives are different as compare to low voltage drive and depend on the control methods of the drives.

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