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GROUND CURRENTS IN VOLTAGE FREQUENCY DRIVES FED FROM THE NON-GROUNDED POWER NETWORK

Abstract

The voltage inverter is a common mode voltage generator which provokes high frequency ground currents. Ground currents cause electric shocks and upset the correct work of power protection device. They also provoke damage of voltage inverters. Negative consequences of ground current in non-grounded power networks must be solved in a different way than in grounded power networks. The usage of a double screened power cable to reduce ground currents in an external grounded screen of the motor cable is presented as a possible solution.

INTRODUCTION

Problems of minimizing the high frequency ground current of the voltage frequency inverters in high power drives in non-grounded - IT (Isolated Terra) or high-resistance grounded power networks are highly relevant because of the increasing number and power of VFDs (Voltage Frequency Drive) in mining applications. In surface mining, for example in brown coal mining, typical industrial VFIs (Voltage Frequency Inverter) are used which are prepared to work in grounded power - TN (Terra Neutral). Their documentation and technical manuals explain only installation procedures for power supply from TN networks. Technical recommendations for TN networks, when applied to non-grounded power networks, lead to the inverter's damage - especially in the case of big power inverters. In industrial applications, substantially more damage is observed in the case of big power inverters supplied from IT networks than in the case of those supplied from TN networks. In IT networks, because of their much larger ground parasitic capacitances for FC (Frequency Converter) power outputs in comparison to the power inputs, high frequency voltage distortions occur on transformer output phase voltages. Since the main reason for this damage is an inverter's common mode voltage which deforms the transformer's phase voltage, it is necessary to use special techniques to reduce the said transformer's voltage distortions. It is important to avoid a big power inverter damage because the repairing process is very costly for its end users.

1. VOLTAGE FREQUENCY DRIVES IN NON-GROUNDED POWER NETWORKS

Figure 1 shows a typical VFD which is powered from a widely used power network of TN type. In accordance with this Figure, equations of common mode voltage - u_{CM} can be described by equations (1a and1b) for short motor cables (below 10m) and equations (2a and 2b) - for long motor cables (above 10m) [1]. The common mode voltage which is produced by an input rectifier $u_{O'O}$ may be omitted because its value is relatively low in comparison to an inverter's common mode voltage u_{CM-INV}. Typically, maximum lengths of motor cables are [2]:

- 300m for unscreened motor cables,
- 150m for screened motor cables.

The high frequency current flows from the motor to a grounded neutral point of the transformer via a protection cable (PE). In TN networks, the neutral point of the transformer *O* is firmly fixed to the ground. In this case the transformer's output phase voltage distortions depend only on the transformer output inductances L_s. For a long motor cable the amplitude of the common mode voltage for motor terminals is doubled. It is a well-known result of the reflected wave effect between a cable impedance and a motor impedance [3].

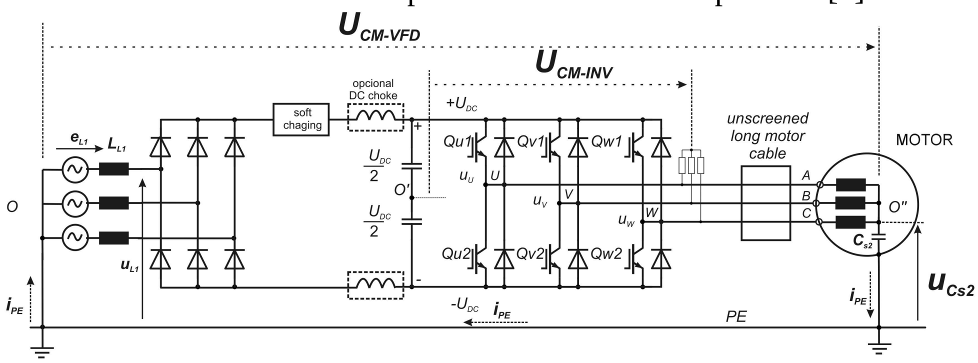

Fig.1. Two-level VFD connected to an induction motor supplied from a grounded TN power network.

$$\textit{for motor cable below } 10m$$

$$(1a)\quad u_{CM-VFDs} = \frac{u_{U0'} + u_{V0'} + u_{W0'}}{3} + u_{0'0} = u_{CM-INV} + u_{0'0} \tag{1}$$

$$(1b)\quad u_{CM-VFDs} = \left\{ \pm\frac{U_{DC}}{2} + u_{0'0} \quad \text{lub} \quad \pm\frac{U_{DC}}{6} + u_{0'0} \right\}$$

$$\textit{for motor cable above } 10m$$

$$(2a)\quad u_{CM-VFDl} = \frac{u_{A0'} + u_{B0'} + u_{C0'}}{3} + u_{0'0} = 2u_{CM-INV} + u_{0'0} \tag{2}$$

$$(2b)\quad u_{CM-VFDl} = 2\left\{ \pm\frac{U_{DC}}{2} + u_{0'0} \quad \text{lub} \quad \pm\frac{U_{DC}}{6} + u_{0'0} \right\}$$

The VFD supplied from a non-grounded power network is shown in Figure 2. Typically, long motor cables are used in mining applications. In this example, equation (2a) describes a common mode voltage u_{CM} for a motor's terminals. The voltage u_{CM} can also be described as a sum of voltages which drops on the ground capacitances C_{s1} and C_{s2}, which is presented in equation (4). Finally, equation (7) shows a transformer's phase voltage modulated by u_{CM}

voltage when an inverter output (ground) stray capacitance C_{s2} is much bigger than a supply input stray capacitance C_{s1}.

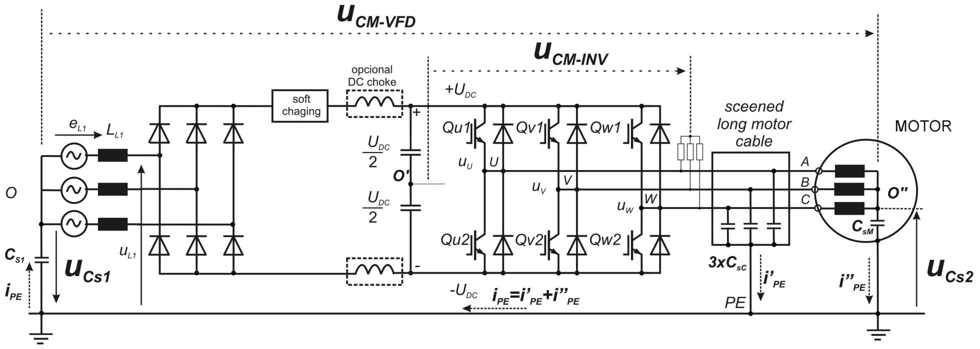

Fig.2. Two-level VFD connected to an induction motor supplied from a non-grounded IT power network

$$C_{s2} = 3 \cdot (C_{sC} + C_{sM}) \tag{3}$$

$$u_{CM-VFD} = u_{Cs1} + u_{Cs2} \tag{4}$$

$$u_{L1} = -u_{Cs1} + e_{L1} - L\frac{di_{PE}}{dt} \quad dla \quad L\frac{di_{PE}}{dt} \approx 0 \tag{5}$$

$$for \quad network \quad type \quad TN: \quad u_{Cs1} \approx 0 \quad u_{L1} = e_{L1} \tag{6}$$

$$for \quad netwok \quad type \quad IT: \quad u_{Cs2} \approx 0 \quad u_{L1} = e_{L1} - u_{CM-VFD} \tag{7}$$

The main conclusions drawn from the above analysis are as follows:

1. A transformer’s phase voltage amplitude can be increased by adding an inverter’s full DC voltage. The transformer’s phase voltage is modulated by the common mode voltage u_{CM-VFD} (7).
2. The voltage between a grounded inverter radiator and its active semiconductor power terminals can increase more in the IT (7) network than in the TN network (6).
3. To reduce the transformer’s output phase voltage distortion caused by a common mode voltage u_{CM-VFD}, the total (ground) inverter output capacitance C_{s2} must be much lower than a supply network total capacitance $C_{s1.}$

It seems to be a good technical practice to use in non-grounded IT networks, a nominal voltage of the inverter that is one level higher than the nominal voltage value of the power network.

2. METHOD OF HIGH FREQUENCY GROUND CURRENTS MINIMIZATION

In view of the above theoretical conclusions for a non-grounded power network it can be possible to prepare an AFD structure with much bigger stray capacitances C_{s1} than stray capacitance C_{s2}. Additionally, by using double screened power cables, it is possible to create a circuit for high frequency grounding currents outside a PE protection wire. Figure 3 depicts an installation without a ground stray current in the protection wire PE [4]. However, it is a good solution only for a small power AFD because of a big cost and a big weight of the motor LC (4) filters for the big power drives.

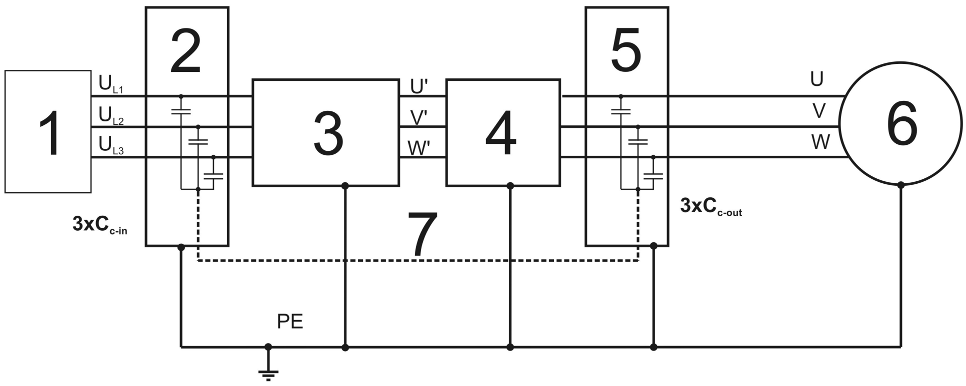

Fig.3. PWM inverter-fed induction motor supplied from the non-grounded IT network, without high frequency currents in a PE wire: 1- non grounded transformer, 2- (ground) stray capacitances ($3xC_{c-in}$) of a screened input power cable, 3- VFD, 4- motor LC filter [2], 5- ground stray capacitances ($3xC_{c-out}$) of a screened motor power cable, 6- squirrel cage motor, 7- additional wire for ground currents – e.g. an internal screen of a double screened power cable

Typically, for a big power drive the motor LC filter is not used and in this situation motor ground stray current occurs in a PE wire. A ground motor stray capacitance is usually much smaller than a ground stray capacitance of a screened motor cable [5] and as a result the current in a PE wire will also be small. An example of the connection with two double screened power cables, where one cable is used to supply a VFI from the transformer and the other is used to feed a motor from VFI is shown in Figure 4.

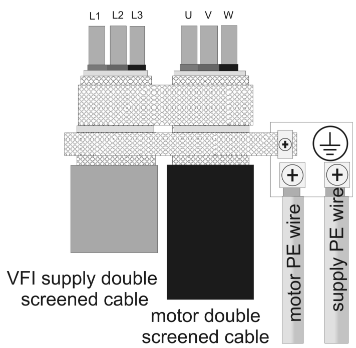

Fig.4. Power cable screen connections at a VFI power terminals:
-internal screens are connected together but not connected to the ground,
-external screens are connected together and also connected to the ground like PE protection wires.

To achieve a bigger ground stray capacitance at VFI input terminals in relation to the motor cable (ground) stray capacitance - at the same cable lengths, different types of these cables must be used. For example:

- as a cable feeding a VFI from the transformer, 4x50mm - a cable type TOPFLEX® EMC–UV-2YSLCYK (producer HELUCABEL) with **320nF/km** stray capacitances between each wire and the screen,
- as a motor cable (means cable between a VFI and motor), 3x50mm+3G10, a cable TOPFLEX® EMC–UV-3PLU 2YSLCY-J (producer HELUCABEL) with **40nF/km** stray capacitances between each wire and the screen.

Thanks to the application of such power cables in a VFD, a ground stray capacitance on the VFI inputs C_{s1} will be **8 times** bigger than a ground stray capacitance on the motor terminals C_{s2}.

CONCLUSIONS

The use of ground current filtering techniques which are dedicated to grounded TN (power) networks in non-grounded IT (power) networks can lead to a VFI damage. In non-grounded power networks with big power drives, the ground capacitance of a screened motor cable leads to the distortions of the transformer's phase voltage [5]. The use of double screened cables in VFD may significantly decrease a high frequency parasitic current in a PE protection wire. It may also significantly reduce distortions of a transformer's phase voltage.

PRĄDY DOZIEMNE W INSTALACJI NAPĘDOWEJ Z NAPIĘCIOWYM PRZEMIENNIKIEM CZĘSTOTLIWOŚCI ZASILANYM Z SIECI NIEUZIEMIONEJ

Abstrakt

Falownik napięciowy jest generatorem wysokoczęstotliwościowego napięcia zaburzeń wspólnych, które wywołuje prądy doziemne. Prądy doziemne stanowią zagrożenie porażeniowe i zakłócają prace elektroenergetycznej automatyki zabezpieczeniowej, powodują też uszkodzenia falowników. Odgraniczenie skutków występowania prądów doziemnych trzeba realizować w sieciach o nieuziemionym punkcie neutralnym inaczej niż w sieciach uziemionych. Jako finalne rozwiązanie problemu przedstawiono możliwość zastosowania kabla z podwójnym ekranowaniem do ograniczenia występowania prądów doziemnych w zewnętrznym uziemionym ekranie kabla silnika.

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