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Analysis of switching transient overvoltages in the power system of floating production storage and offloading vessel

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ABSTRACT

Large transient overvoltages can be caused by the switching operation of vacuum circuit breakers (VCBs) during disconnection of induction motors. In this paper VCBs, cables, generators, busbars, induction motors and surge arresters are modeled by making use of ATP-EMTP. Switching transient overvoltages of four typical induction motors under the starting, the full load and the light load working conditions in the power system of the selected floating production storage and offloading (FPSO) vessel are analyzed. A suitable protection against the switching transient overvoltage is proposed and the results are presented accordingly.

1. Introduction

Floating production storage and offloading (FPSO) vessel is a floating unit used by the offshore petroleum industry for the processing of hydrocarbons and for oil storage. The 11 kV electrical power system of FPSO vessel is very compact. Thirteen induction motors ranging from 0.8 MW to 10.9 MW are working together to provide power to different machines such as compressors and pumps for supplying continued process of oil and gas production. Each motor is equipped with a vacuum circuit breaker or a fused vacuum contactor, depending on the rated motor power. During motor switching, overvoltages could take place, and when the overvoltage reaches the motor's basic insulation level (BIL), the insulation may be damaged and might fail. Consequently, the total reliability and the security of electrical power system in the FPSO vessel are decreased.

The major contribution of this work is to check the possible switching transient overvoltages that may occur for four typical induction motors, and if the overvoltage exceeds the motor's BIL, a suitable solution to mitigate the overvoltage should be proposed.

2. Description of the model

The simplified layout of 11 kV power systems is illustrated in Fig. 1. The motors are supplied with electricity from three main generators connected to the same busbar. Some induction motors and transformers, which have the rated power around 1–4 MW are not shown in Fig. 1. The 11 kV network is with the isolated neutral point. Four typical induction motors under starting, full and light load conditions are analyzed: the 10.2 MW main gas compressor A motor (T711) connected by 180 m cable to a VCB; the 10.2 MW main gas compressor B motor (T713) connected by 300 m cable to a VCB; the 5.5 MW water injection pump motor (T261) connected by a 160 m cable to a VCB; the 1.25 MW refrigerant compressor motor (T794) connected by 240 m cable to a VCB.

3. System modeling

3.1. Vacuum circuit breaker modeling

In order to perform transient analysis in power system, the correct model of vacuum circuit breaker (VCB) is very important. The VCB model takes into account the stochastic behavior and requires chopping currents, dielectric recovery strength and quenching capabilities at high frequencies. The applied method of modeling is fully described in [1–3]. In this study, a Cu/Cr (75/25) contact material is assumed, which is normally used for modern VCBs. Hence, the mean value of current chopping is 5 A [3]. The

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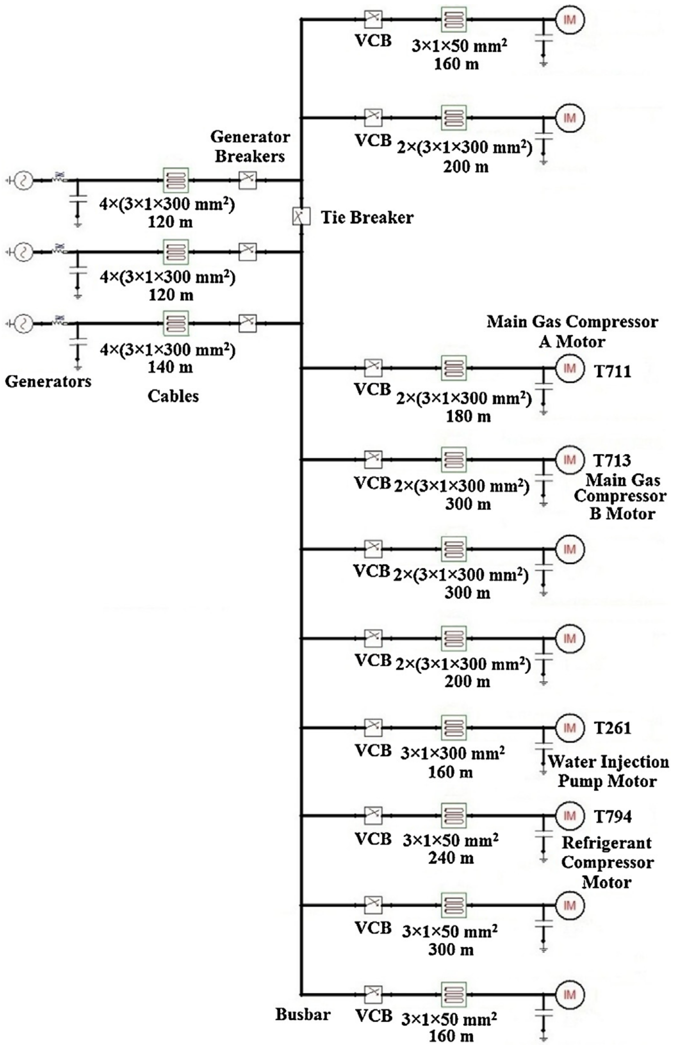

Fig. 1. Simplified layout of 11 kV power system in FPSO vessel.

Table 1
Dielectric parameters and quenching capability parameters.

A (kV/ms)	20–30
B (V)	0
C (A/μs^2)	0
D (kA/μs)	0.5–0.7

statistical characteristics of current chopping are represented by normal distribution with mean value 5 A and 15% standard deviation. The cold gap breakdown is considered in this work, the dielectric strength is according to [1] and represented by (1),

$$U = A(t - t_{\text{open}}) + B \tag{1}$$

where U is the value of the dielectric strength, A, B are constants and t_{open} is the opening time of the contacts. The mean value of dielectric strength is calculated by (1). The statistical characteristics of dielectric strength are represented by using normal distribution with the defined mean value and 15% standard deviation. When a reignition occurs, the high frequency (HF) current is superimposed on the power frequency current through the arc. The HF current has several current zero crossing points and the VCB can clear the HF current in one of those current zero points. The value is the linear relationship between the changing rate of current and the time. The typical equation is shown below [1],

$$\frac{di}{dt} = C(t - t_{\text{open}}) + D \tag{2}$$

where di/dt is the current slope, C, D are constants and t_{open} is the opening time of VCB. The mean value of quenching capability is calculated by (2) and the statistical value is calculated by using normal distribution with the defined mean value and 15% standard deviation. If the changing rate of HF current in the zero point is smaller than di/dt, the HF current will be extinguished. Here, the values of A, B, C and D for a Siemens medium voltage VCB are used and shown in Table 1.

A single phase test circuit of a VCB is shown in Fig. 2. The basic structure consists of a voltage source $U_n = 6.35$ kV, a source side inductance and a capacitance of $L_n = 5$ mH and $C_n = 100$ nF respectively. The cable is represented by a resistance and an inductance of $R_\sigma = 2\ \Omega$ and $L_\sigma = 0.04$ mH respectively. The capacitance of the load and the cable is $C_L = 10$ nF. The cable ends up with an ohmic-inductive load of $R_L = 10\ \text{k}\Omega$ and $L_L = 120$ mH. A damping resistance of $R_S = 50\ \Omega$, an inductance of $L_S = 0.5$ nH and a capacitance $C_S = 0.2$ nF represent the VCB gap. The values of different elements are taken from [2].

After the contacts of the VCB are opened, the dielectric strength of the vacuum gap will increase with the time. When the increase of the transient recovery voltage (TRV) is faster than the increase of the dielectric strength, a reignition takes place. When the rate of rise of the HF current is lower than the quenching capability of the VCB in one of its zero points, the HF current is interrupted and the TRV appears again, as shown in Fig. 3. After multiple reignitions have occurred, the TRV is built to a high level, while the dielectric strength of the vacuum gap is also increased due to the contact movement. Once the dielectric strength could withstand the TRV peak, the load current will be successfully interrupted.

During VCB restrikes 4 dominant frequency oscillations normally take place. The first one is a frequency oscillation that results from the current chopping. It depends on the cable inductance and gap capacitance ($f_1 = 1/2\pi\sqrt{L_\sigma C_s} \approx 1.7$ MHz). The

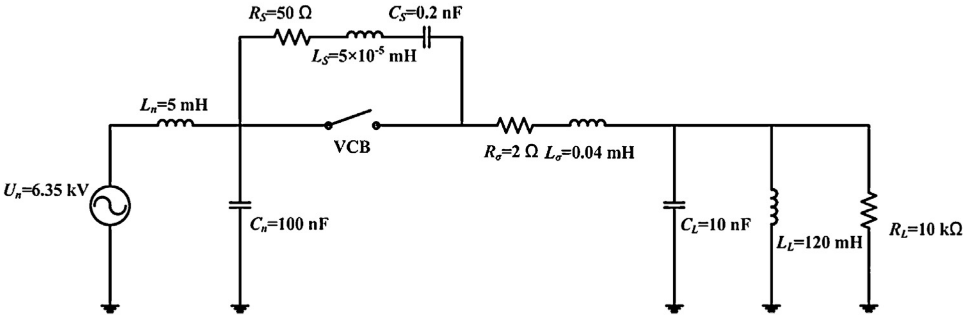

Fig. 2. Single phase test circuit of VCB.