Pressure Effect Due to Arcing Faults of Shipboard MV Switchboard

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Abstract. In this paper, the pressure effects of arcing faults in the shipboard MV switchboard are analyzed. First the estimated method of arcing fault energy is discussed. Then the pressure model of the MV switchboard due to arcing fault is put forward. And based on Simulink platform, simulations are processed according to a shipboard switchboard example. The results of this paper are helpful to the design on new switchboard products and can supply scientific basis to the research of equipment possibly having arcing faults.

Introduction

Current marine electric capacity is increased significantly. Many large ships and ocean engineering structures have already adopted MV power systems. Many situations will lead to the deterioration of insulation, such as the abnormal bad working environment or staff error operation. And this may cause the cabinet internal arc fault, rapid changes in pressure and temperature in the compartment, even the cabinet body damage. [1-6, 9,10].

The effect of the switchboard internal arcing fault can be combustion pressure effects, burning effect (thermal effects), radiation and sound effects. When medium voltage switchboard in the event of an internal arc fault, the arc temperature can reach *200000* ℃. Burning arc will heat the surrounding air, causing the air to expand and generate enormous pressure inside the switchboard. In addition, the pressure will make some loose parts thrown from the switchboard. With the arcing effect, metal and non-metallic material particles will escape from the cabinet, causing injury or even a fire. In short, it is a great danger to both switching equipment and staff nearby. Especially in marine, the space is narrower, the environment temperature is higher and the electric connection is depending on cables generally. These will make easily to have a short circuit fault. So it is necessary to research arcing fault effects according to the actual structure of the shipboard switchboard.

To solve this problem, optimal design of the cabinet remains a major difficulty. In the internal arcing faults process, the pressure inside the switchboard is a very important parameter. The gas pressure tightly links the energy released and stress changes on switchboard structure. Therefore, it is necessary to make simulation on the rising pressure and make test analysis, so as to provide reference to the strength of the door, the cabinet structure design, and to optimize the design of pressure relief cover plate finally.

Developing process of the arcing faults

The development of the pressure of an internal short circuit arc in switchboard is shown as Fig.1.[1-4,8]:

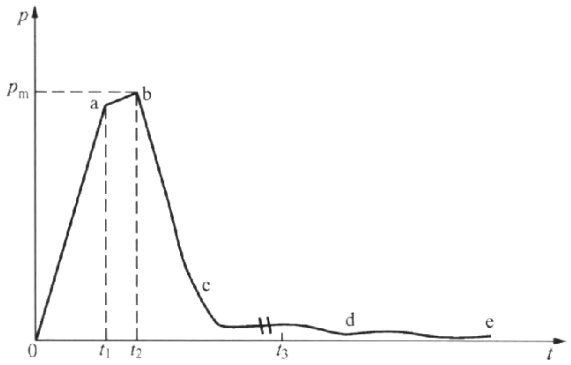

Fig.1.The three stages of the pressure

The first stage is pressure building stage, from the moment of arc producing to the opening moment of the relief cover plate, also from *0* to t_1. The bigger the fault current, the higher the arc voltage, the smaller the compartment size, the faster the pressure rise. This period of time is about *5~10ms.*

The second stage is expansion stage. When the pressure in the cabinet rises to a certain value, the cover plate of the cabinet is opened at t_1. The air in the cabinet is rapidly released through the exhaust port. Although the velocity of the pressure rising will decrease, but the pressure reaches the highest peak at the moment of t_2. This stage lasts about *5~10ms*.

The third stage is thermal effect stage(t_2 –t_3). Arc energy mostly concentrates on the fixed components, resulting in the destroy of metal parts or insulation. After the extinction of arc (>t_3), it is remaining on the heating stage.

In this paper, we mostly concern about the first and the second stage. Theoretical analysis and numerical simulation is made. The maximum pressure and the open moment of the cover plate can be obtained.

The energy estimation of the arcing faults

The energy of arc is the source of the pressure calculation and analysis. Accurate equation of the arc energy is easily shown as Eq.1.

$$P = \int_{t_1}^{t_2} u_{arc}(t) i(t) dt \quad . \tag{1}$$

In the formula, t_1 is the separation time of the breaker contact components, t_2 is the current zero crossing time, the U_{arc} is the arc voltage, and the I is the breaking current.

Pressure effects analysis of switchboard internal arcing fault

In this section, the pressure effect of internal short circuit arc will be discussed. The estimation of the pressure effect can be based on the law of energy conservation and the law of ideal gas pressure effects. Before the relief cover plate is opened, the internal cabinet gas can be seen as the ideal gas and constant volume expansion. Gas state change model is the ideal gas state equation. After the arc relief cover plate has been opened, the gas flow must be considered. And the flow of gas will meet the isentropic gas mass equation, assuming the speed of the fluid through the exhaust port is uniform.

The gas mass transfer *dm* in time *dt* is shown as Eq.2.[1,8]:

$$dm = \begin{cases} 0 \\ Ap_i \left\{ \dfrac{2Y}{Y-1} \dfrac{1}{RT_i} \left[\left(\dfrac{p_0}{p_i}\right)^{\frac{2}{Y}} - \left(\dfrac{p_0}{p_i}\right)^{\frac{Y+1}{Y}} \right] \right\}^{\frac{1}{2}} dt \end{cases} \quad . \tag{2}$$

In the above formula, p_i is the gas pressure of last moment, Y is the multi coefficient, the heat flow is equal to 1.3, R is the air gas constant 287*J/(kg • K)*, T_i is the gas temperature for the last

moment，A is arc vent port area.

The calculation method of the critical pressure is shown as Eq.3.

$$P = \frac{(G + P_0 S)}{B(L_e^{\ 2} - L_b^{\ 2})}. \tag{3}$$

Where G is the gravity of the arc relief cover plate, S is the area of the cover plate. The width of the exhaust port is B, the nearest distance to the turning axis is L_b, the furthest distance is L_e.

To follow the law of thermodynamics, as shown in Eq.4. and Eq.5.

$$\frac{dQ}{dt} - \frac{dE}{dt} = \frac{d}{dt}(c_v mT). \tag{4}$$

$$\frac{dT}{dt} = \frac{1}{c_v m + mT\frac{dc_v}{dt}}(\frac{dQ}{dt} - \frac{dE}{dt} - \frac{dm}{dt}c_v T) \approx \frac{1}{c_v m}(P_{arc} - \frac{dE}{dt} - \frac{dm}{dt}c_v T). \tag{5}$$

Where dQ/dt is the arc energy injected to the gas, dE/dt is the energy loss in every moment of the system which is shown as Eq.6. c_v is constant volume specific heat capacity. For situation of STP, c_v =720$J/(kg \cdot K)$, m is gas quality, P_{arc} is average arc heating power.

$$\frac{dE}{dt} = c_v T\frac{dm}{dt} + \frac{1}{2}v_a^{\ 2}\frac{dm}{dt} + c_{v\,steel}m_{steel}\frac{dT}{dt}. \tag{6}$$

The gas temperature at every moment can be calculated as Eq.7.

$$T_{i+1} = T_i + \Delta T_{i+1}. \tag{7}$$

Thereafter, according to the ideal gas state equation at every moment, the pressure of the gas can be obtained as Eq.8.

$$p_{i+1} = \frac{m_{i+1}}{V}RT_{i+1}. \tag{8}$$

Simulation test results

Based on the calculation method above, the numerical simulation is processed on the pressure effect of MV switchboard internal short circuit arcing faults. The structure of the switchboard example is shown in Fig.2. Because the cable compartments are most easily to endure an arc fault, so the analysis focuses on the case of the cable compartment.

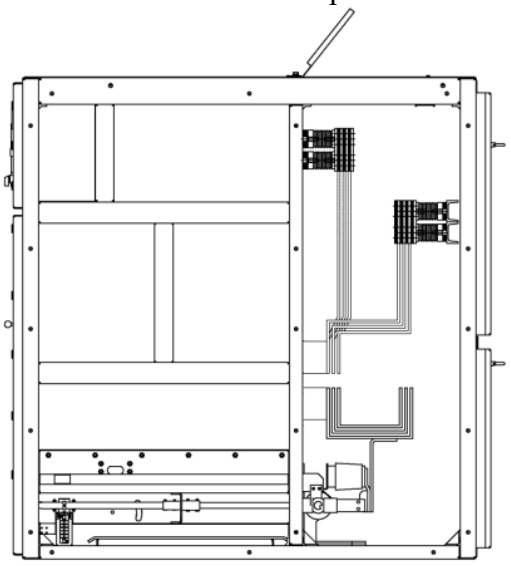

Fig.2. The structure of MV switchboard example

According to the parameters shown in Table 1, differential equations of the standard calculation method are established on a Simulink platform which is shown in Fig.3. Via the numerical simulation, the inside pressure and temperature changes with time are obtained. Arc energy are

supposed to *10MVA* and *20MVA* two cases. The internal parameters of the simulation model are based on the actual situation of the shipboard switchboard cable cabin.

Table 1. Cable cabin parameters

Arc relief port area[m^2]	0.08
Arc relief port equivalent hydraulic area[m^2]	0.06
Weight of arc relief cover plate[kg]	0.686
Critical pressure[Pa]	1.09×10^5
Total capacity[m^3]	0.418
Total weight of the air in the cabin[kg]	0.5434

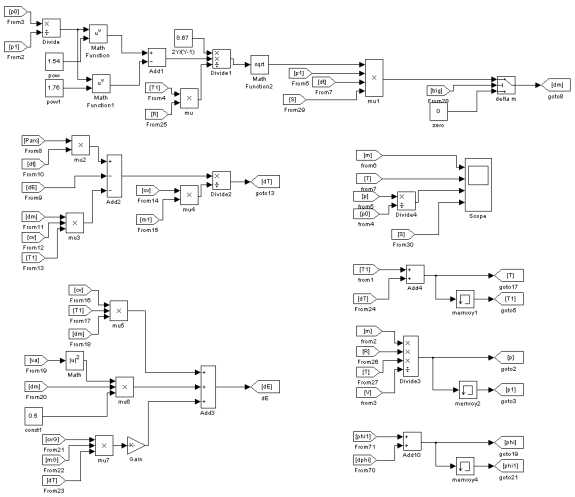

Fig.3.Internal arcing fault simulation model

The simulation results are shown in Fig.4.

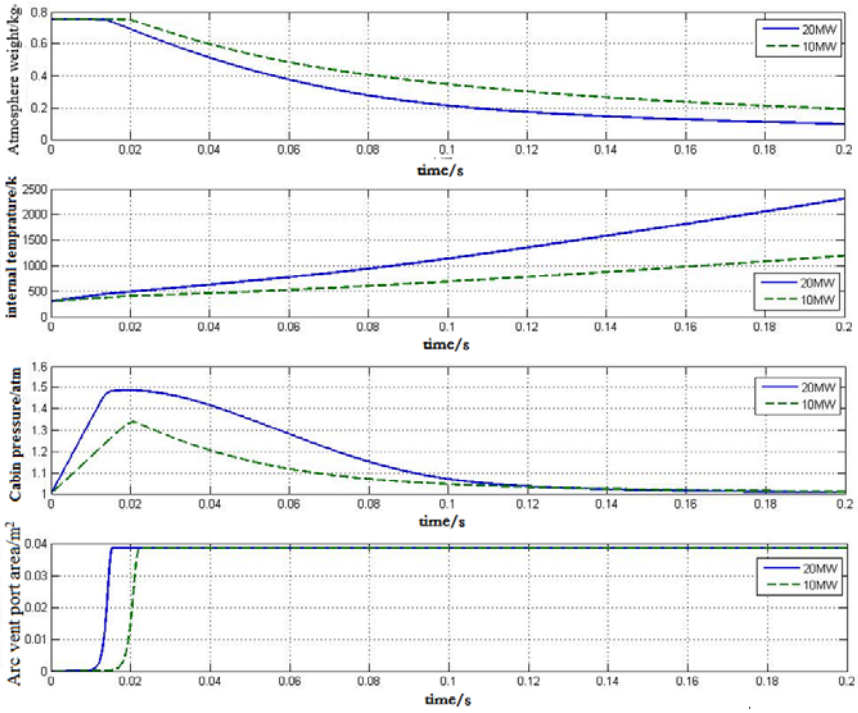

Fig.4.Pressure and temperature versus time graph

The simulation results reflect that when the internal arc fault energy is about *10MVA*, the arc relief cover will fully open in *22ms*, the cabinet maximum pressure is *1.35atm*. When the internal arc fault energy is about *20MVA*, the arc relief cover will fully open in *15ms*, the cabinet maximum pressure is *1.48atm*.

Based on the above results, the design of switchboard door and cabinet body can be optimized. Assuming that the minimum tensile strength of each bolt and screw are substantially equal, then the number of hinges and bolts needed can be calculated to ensure the door close tied. Taking into the consideration of the instability load to the different bolts or screws when the internal fault occurs, as well as the situation of overload, the final result has to be multiplied by a certain factor of safety.

Conclusion

Based on the analysis of the arc developing process and the energy estimation, the pressure of switchboard during the arcing fault is researched and the differential equation models are established. According to the shipboard actual switchboard structure parameters, the numerical calculation and simulation of the pressure various according to time are processed. The results reflect the maximum pressure in certain energy input, the opening time of the arc relief cover plate on its certain weight. So these results are helpful to optimize the switchboard structure so as to make insurance of the human safe and equipment safe.

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