ELECTRICAL SAFETY IN LVDC DISTRIBUTION SYSTEM

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ABSTRACT

An LVDC (low voltage DC) distribution system is a new concept in a field of distribution systems. One of the key issues in new system development is electrical safety of the customers.

This paper presents LVDC distribution system safety analysis concentrating to contact voltages and currents affecting customers during indirect fault situations. The main questions to be studied in the paper are: contact voltage and touch current values during insulation faults, contact voltage and touch current values during double insulation faults, and defining limits for system values to ensure human safety. The analysis is based simulations in PSCAD environment.

INTRODUCTION

The studied LVDC distribution system is a neutral isolated ± 750 VDC bipolar system, which customer connections are made with unipolar connections to separate DC poles. The customer's 230 VAC operating voltage is created with its own 1-phase customer-end inverters. Example of an LVDC distribution system is shown in figure 1.

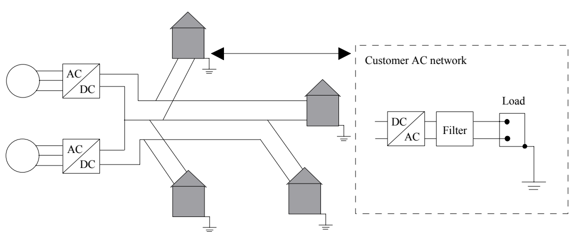

Fig.1. Example of an LVDC distribution system.

Because the power electronic converters don't create galvanic isolation by itself, the whole LVDC system creates a one galvanic circuit from the LV transformer to the customer-end AC network. The galvanic connection through the system introduces a requirement that customer AC network needs also to be neutral isolated system. [6]

For safety reasons, the customer equipotential bonding needs still to be used [4] in neutral isolated system. All the galvanic parts of the customer installation as sinks, water pipes, installations PE-conductors are connected to the main grounding of the system.

The contact voltage values are depending on the used grounding arrangement and system characteristics. Earlier studies have shown that LVDC distribution systems [6] can introduce contact voltages of dangerous level during DC earth faults, when grounded TN grounding arrangement is used. The IT system was found to provide best choice of grounding arrangements for human safety [1].

The DC system used in earlier studies [1] is different compared to the LVDC distribution system; the used system voltage is smaller and the used converters are different. Due to these differences the other systems results can not be assumed to be applied to presented ± 750 VDC bipolar LVDC distribution system.

The main questions to be studied in the paper are: contact voltage and touch current values during insulation faults, contact voltage and touch current values during double insulation faults, and defining limits for system values to ensure human safety.

HUMAN SAFETY

Electric currents are dangerous to the human body. The current flow thought the body can create muscular paralysis and ventricular fibrillation. The affect of current flow depends on many factors such as current path, duration of the current flow, surface are of contact, moisture on the skin and electrical system frequency. All these factors affect the human equivalent impedance which is seen during fault situations. [2]

The impedance of the human body can be analysed with equivalent circuit shown in figure 2.

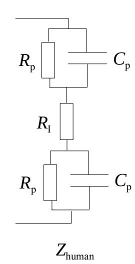

Fig.2. Equivalent human impedance [2].

The parameters of human impedance are:

Z_{human} = Human total impedance,
R_P = Human skin resistance,
C_P = Human skin impedance,
R_I = Human internal impedance.

The parameters of the impedance vary depending on the many factors. The recommendation for total impedance is 1000 Ω for normal conditions and 250 Ω for harder conditions [2]. The normal case parameters of the human impedance are chosen to be R_P = 500 Ω, C_P = 1.5 µF and R_I = 600 Ω. The selection is based on the previous studies [1] to enable comparisons between the systems.

As the current frequency depends on the affects of the fault current to the human body, the DC current is less dangerous than AC because of the lack of the let-go threshold and the higher fibrillation threshold. The frequencies 50/60 Hz are especially dangerous to human, but as the frequency is higher the affects are less dangerous. The fibrillation above 10 kHz frequencies are usually not to be expected. [2]

The risk of ventricular paralysis depends on time of current flow though the body. The 5 % risk is 40 mA in AC current and 150 mA in DC current when current flow duration is 1000 ms. During shorter time of current flow duration the risk decreases or the same 5 % risk is exists with the higher current flow. [2][5]

The LV standardization [4] defines only the maximum allowed contact voltage levels to DC and AC systems. To ensure human safety the allowed value limits are [2][4]:

- AC contact voltage: 50 VAC
- DC contact voltage: 120 VDC

Because of the used system construction, the LVDC distribution system contact voltage and current includes both of the components, AC and DC. As the fault current during the fault situation is AC the safety analysis should be based on defined AC limits.

Equivalent Circuit

An equivalent circuit for indirect fault situations in neutral isolated system is shown in figure 3.

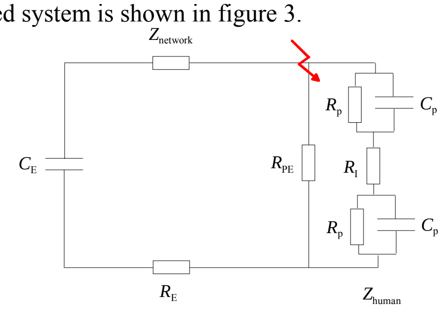

Fig.3. Neutral isolated IT network equivalent fault circuit.

The parameters of circuit are:

C_E = Earth capacitance,
$Z_{network}$ = Network total impedance,
R_E = Earth resistance,
R_{PE} = PE-conductor resistance.

SIMULATION MODEL

PSCAD simulations are based on actual model of bipolar LVDC distribution system shown in figure 1. The simulation model construction and used parameters are chosen to be as close as possible to a real LVDC distribution system.

The used PSCAD simulation model contains two customers, one on the each pole of the system. The AC/DC rectification is made with two 6-pulse thyristor bridges. The voltage supply is made with 35 kVA transformer with two secondary outputs which secondary outputs are delta/star which creates 30º phase shift between the outputs. The DC branch is created with 4x35 mm^2 AXMK cable which length is 200 m. The PEM-conductor of the DC system is created with two parallel connected conductors. The capacitance against the ground is modelled with 0.04 µF capacitances, which are connected to the ground from each conductor.

The customer AC network and customer 230 VAC operating voltage is created with 1-phase customer-end inverter. The load of the customer during the fault on the other customer is 10 kW and on the other customer 0 kW. The fault situations are simulated to be in the customer's device. The supply is made with 2.5 mm^2 installation cable which length is 25 m.

SIMULATION RESULTS

Single Fault

At the single fault situation there occurs indirect fault in customer AC network. The human impedance parameters are R_P = 500 Ω, C_P = 1.5 µF and R_I = 600 Ω. The earth resistance is 5 Ω. The indirect customer AC network earth fault is shown in figure 4.

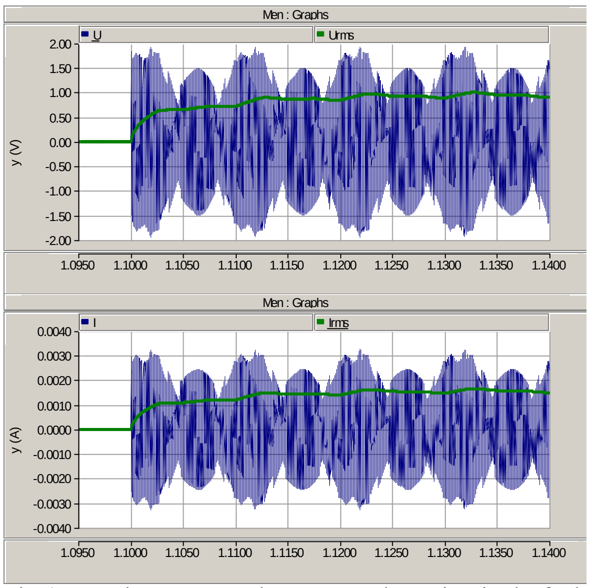

Fig.4. Touch current and contact voltage in single fault situation when earth resistance is 5 Ω. The peak and RMS

values are drawn in the figure.

The figure 4 shows that introduced touch current and contact voltage values are not at dangerous level. The touch current value during fault is 1.9 mA and contact voltage value is 1.2 V. The values indicate that the fault is not dangerous to human. The RMS current through the fault circuit is 6.2 A.

When the earth resistance is 1 Ω the touch current value during fault is 2.6 mA and contact voltage value is 1.6 V. The values indicate that the fault is not dangerous to human. The RMS current through the fault circuit is 8.3 A.

As the human impedance varies due to many factors the impedance is not always as high as previous fault case. During harder conditions the human impedance can be 250 Ω. The fault situation is shown in figure 5 when human body is concerned as a 250 Ω resistance and earth resistance is 1 Ω.

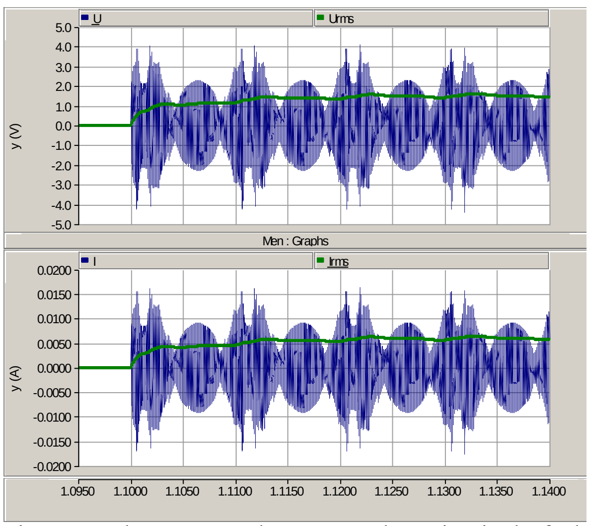

Fig.5. Touch current and contact voltage in single fault situation when human body resistance is 250 Ω and earth resistance is 1 Ω. The peak and RMS values are drawn in the figure.

The figure 5 shows that in hard conditions the contact voltage is 1.6 V and touch current is 6.0 mA. The values indicate that the fault is not dangerous to human. The RMS current through the fault circuit is 8.4 A.

The results show that single faults are not dangerous to the human body in LVDC distribution system. In all fault cases the contact voltage and touch current are below dangerous levels. The fault current though the fault circuit is less than 10 A due to current flow through the cable leakage capacitances.

Double Fault

At this case there happens two simultaneous insulation faults, one in the DC pole and one in the customer AC network. The faults exist in separate DC poles which introduce higher voltage across fault circuit compared to single fault situation.

The double fault situation is shown in figure 7. The earth resistance is 5 Ω. The human impedance parameters are R_P = 500 Ω, C_P = 1.5 µF and R_I = 600 Ω.

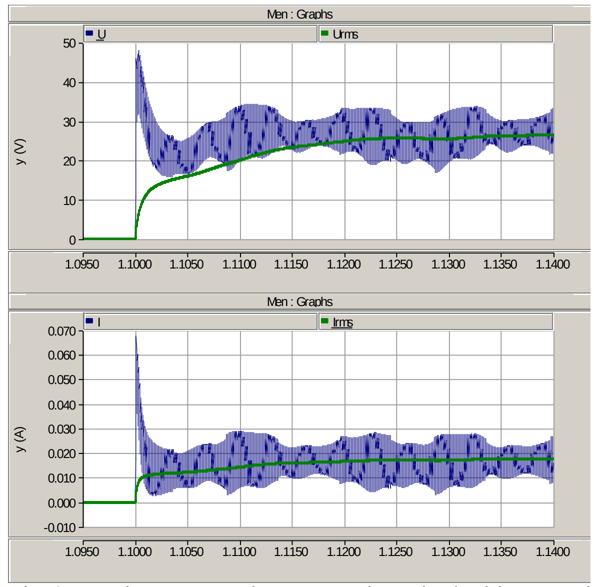

Fig.6. Touch current and contact voltage in double ground fault situation when earth resistance is 5 Ω. The peak and RMS values are drawn in the figure.

The figure 6 shows that during double fault the touch current and contact voltage values are not at dangerous level. The touch current value during fault is 18 mA and contact voltage value is 27 V. The values indicate that the fault is not dangerous to human. The RMS current through the fault circuit is 146 A.

At the start of the fault there exists transient in current and voltage compared to single fault situation. The transient occurs due to high DC offset against the ground. The steady state values are achieved during few milliseconds, as capacitances of the circuit are charged. Due to transient small duration it doesn't introduce danger to human body.

When the earth resistance is 1 Ω the touch current value during fault is 37 mA and contact voltage value is 54 V. At this fault situation the contact voltage exceeds LV standardization defined contact voltage limit and contact current is near dangerous limit value. The RMS current through the fault circuit is 293 A.

During harder conditions the human impedance can be 250 Ω. The fault situation is shown in figure 7 when human body is concerned as a 250 Ω resistance and earth resistance is 1 Ω.

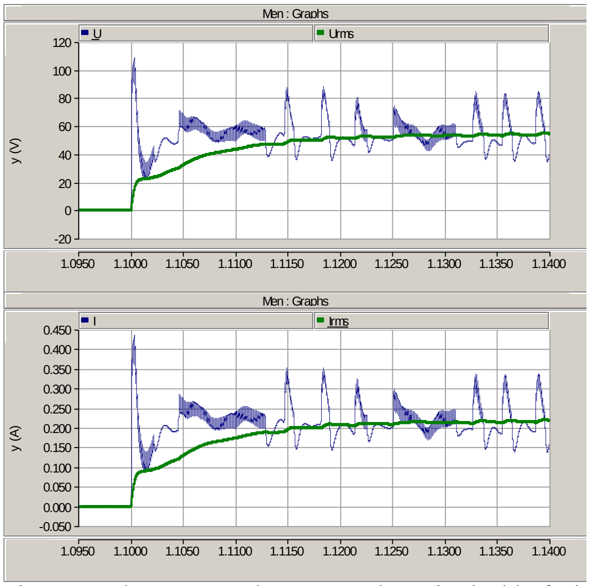

Fig.7. Touch current and contact voltage in double fault situation when human body resistance is 250 Ω and earth resistance is 1 Ω. The peak and RMS values are drawn in the figure.

When the earth resistance is 1 Ω the touch current value during fault is 220 mA and contact voltage value is 54 V. At this fault situation both contact voltage and touch current exceeds LV standardization defined contact limits. The RMS current through the fault circuit is 293 A.

The results show that the double fault situation can introduce dangerous contact voltages and touch currents to the human body. The fault currents through the circuit are depends highly on the earth resistance. The high contact voltage and touch current values are introduced with the low earth resistance value. With the high value of earth resistance the contact voltage and touch current are below dangerous limits.

The usage of power electronic converters allows possibilities to use active control of customer operating voltage and current. With fault current limiting in the customer-end inverter can restrict contact voltage and touch current below dangerous levels at low earth resistance values. The current limiter value to ensure human safety depends on length of longest PE-conductor and parameters of human impedance. At these fault cases the current limitation to 140 A restricts contact value and touch current below dangerous values.

CONCLUSIONS

The paper presents analysis of indirect faults for bipolar LVDC distribution system. The analysis is made in PSCAD simulation environment. The simulation model is constructed to as close as possible of a real LVDC distribution system construction.

The results show that the single indirect fault doesn't introduce dangerous contact voltages and currents to the human body when earth resistance is above 1 Ω. The double faults can introduce dangerous contact voltages and currents to the human body. At normal state for human impedance and when earth resistance is above 5 Ω the contact voltage and current is within allowed limits. Below the 5 Ω earth resistance or smaller human impedance parameters the fault current arises to the dangerous zone.

At the double fault situations the total fault current is high compared to the single fault situation which introduces high contact voltage and touch current values. The power electronic converter usability to limit output current can be used to reduce values. Inverter current limiting circuit usage restricts contact voltage and touch current values to below dangerous limits depending on the used current limitation value.

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