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Study Committee A3

Transmission & Distribution Equipment

Paper 11068_2022

Switching Behaviour, Voltage Distribution and Post-Arc Current of series-connected Vacuum Interrupter Units ≥ 420 kV

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Motivation

- Companies and countries commit themselves to reduce CO_2 emissions
  → Aim: bringing them down to zero
- Legislative proposal of European regulation on F-gases proposes a phase-out of SF_6 and other F-gases with GWP ≥ 10 starting from 2026
- Reliable equipment for highest voltages without GHG emissions needed

Approach

Vacuum switching technology:

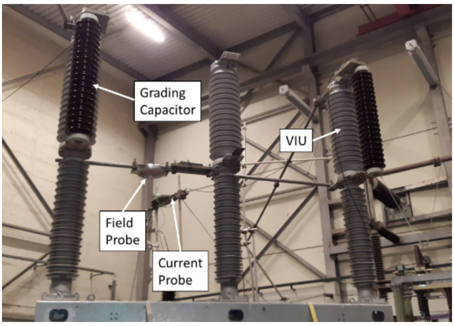
- Well known and in service for many decades in MV-applications
- Combined with Clean Air insulation: GWP = 0
- Single-break vacuum interrupter units available for voltages up to 170 kV, under development for 245 kV
- Dielectric strength of vacuum does not increase linearly
  → Switchgear with series connection of two VIUs under development for 420 kV, 550 kV and beyond

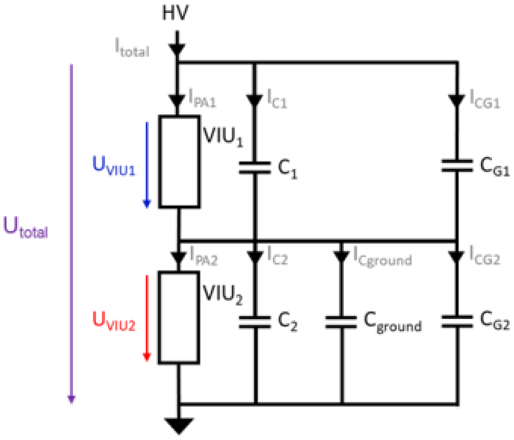
Theory

- Parasitic capacitances
  → Voltage does not equally distribute over both VIUs after current interruption
- Grading capacitors connected in parallel used to equalize voltage distribution
- Assumption: $C_{G1} >> C_1$ and $C_{G2} >> C_2 + C_{ground}$
- For $C_{G1} = C_{G2} = C_G$ voltage distribution can be equalized so that $\Delta U = U_{VIU1} - U_{VIU2} \approx 0$
- Post-arc currents i_{PA1} and i_{PA2} can also influence voltage distribution
- $$\Delta U = \frac{q_{C_1+C_{G1}}(t)}{C_1+C_{G1}} - \frac{q_{C_2+C_{G2}+C_{ground}}(t)}{C_2+C_{G2}+C_{ground}} = \frac{\int_{t_0}^{t} i_{C_1+C_{G1}}(t)dt}{C_1+C_{G1}} - \frac{\int_{t_0}^{t} i_{C_2+C_{G2}+C_{ground}}(t)dt}{C_2+C_{G2}+C_{ground}} = \frac{\int_{t_0}^{t}(i_{PA2}(t) - i_{PA1}(t))dt}{C_G}$$
- Difference between i_{PA1} and i_{PA2} results in different charging of the grading capacitors and directly affects ΔU
- If i_{PA1} and i_{PA2} are significantly different
  → Uneven voltage distribution

Experimental setup

- Two poles of a live-tank VCB equipped with grading capacitors and connected serially
- Short-circuit breaking tests according to IEC 62271-101 performed
- Post-arc current influenced by different factors
- Artificially forced delayed opening of one VIU (by modification of operating mechanism)
  → Different arcing times in VIUs
- Different post-arc currents expected to have influence on voltage distribution





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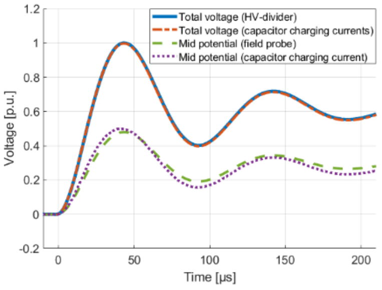
continued

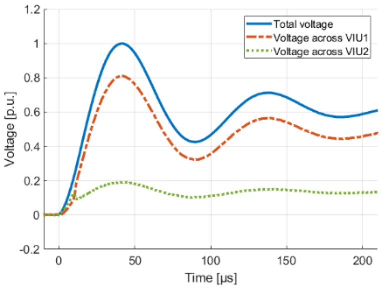
Voltage distribution with C_G

- Mid potential measured non-invasively with field probe
- Additionally calculated using capacitor charging currents to verify results of field probe
- Good degree of consistency
  → Field probe successfully applied
- Voltage distribution: 51% : 49%



Voltage distribution without C_G

- Voltage distribution only measured with field probe
- No grading capacitors connected
  → Distribution mainly caused by parasitic elements
- Voltage distribution: 81% : 19%

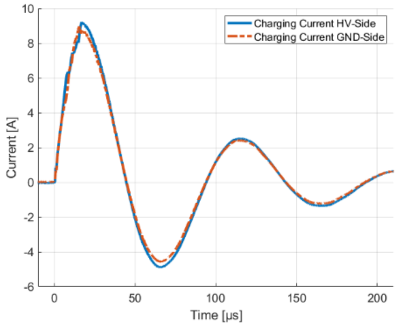


Example 1 - No influence of PAC

Charging currents of C_{G1} and C_{G2}

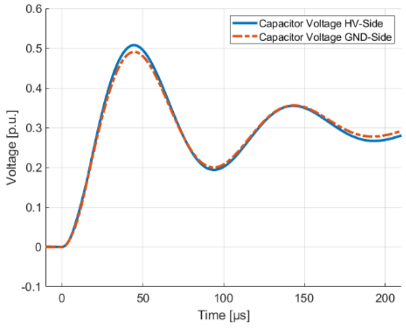
- Similar capacitor charging currents result from similar post-arc currents

  → No influence of post-arc current



Voltages U_{VIU1} and U_{VIU2}

- Post-arc currents do not influence the voltage distribution
- Voltage distribution: 51% : 49%



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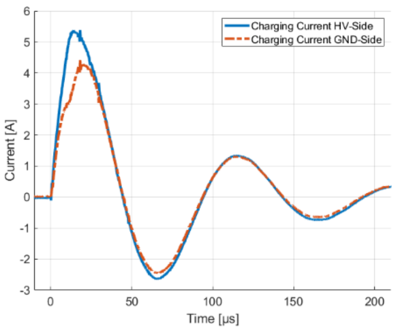
continued

Example 2 - Minor influence of PAC

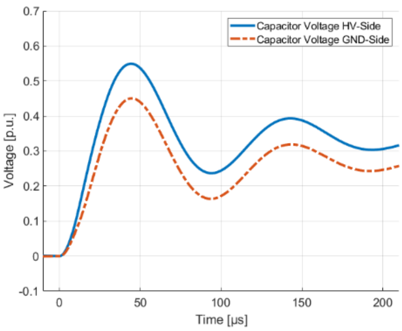
Charging currents of C_{G1} and C_{G2}

- Minor influence of post-arc current



Voltages U_{VIU1} and U_{VIU2}

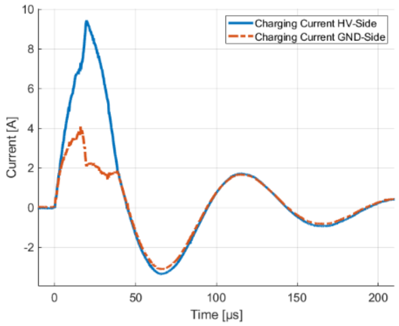
- Voltage distribution 55% : 45%



Example 3 - Major influence of PAC

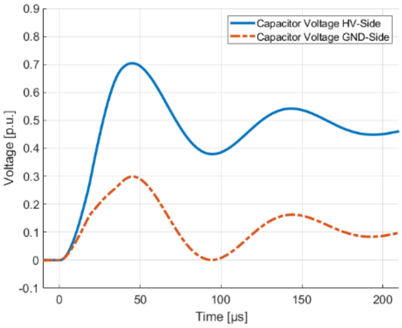
Charging currents of C_{G1} and C_{G2}

- Major influence of post-arc current due to artificially forced delayed opening of VIU_2



Voltages U_{VIU1} and U_{VIU2}

- Voltage distribution 70% : 30%
- Distribution close to setup without grading capacitors



Conclusion

- Voltage distribution in series connection of VIUs is not symmetrical due to parasitic effects
- Influenced by stray capacitances and post-arc currents
- Grading capacitors connected in parallel used to diminish influence of stray capacitances
- Charging currents of grading capacitors are in same value range as post-arc currents
- Direct link between post-arc current and voltage distribution across the interrupter units
- Especially at the limits of the short-circuit breaking capability of the vacuum interrupter units this effect needs to be accurately considered for optimizing the breaking performance

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