Study Committee B2

Overhead Lines

10775_2022

Design and protection criteria for passive loops on a 400 kV double circuit line

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Motivation

- Effective solution for reducing public exposure to magnetic fields due to Overhead Lines (OHLs) near any public or urban areas;
- Whereas the allowable ICNIRP magnetic field limit for public exposure is 100 µT, the Italian law adopts a more challenging threshold of 3 µT for new HV/EHV OHLs.

Method/Approach

- A dedicated steel tubular double circuit tower was developed by Terna allowing the installation of loop conductors. Three passive loop conductors with a diameter equal to 40.5 mm will be installed to mitigate magnetic field induction.
- In order to maximize the shielding effect, while not exceeding the loop conductors ampacity, PS will be equipped with a Series Capacitance Compensation System (SCCS), with 4 mF capacitors.

Objects of investigation

- The first issue is related to the design and sizing of the capacitor banks: as in EHV series capacitors installation, a fault in phase conductors causes significant overcurrents and overvoltages on the capacitor units.
- A proper choice of the capacitors rated voltage, protective surge arresters, and by-pass switch is thus of paramount importance for a safe and reliable installation.
- A fault on a loop conductor is unnoticeable from conventional line protection. Terna investigated the possible fault scenarios, involving both permanent and transient faults.
- The paper deals with design and protection criteria of the PCLs.

Configuration

- Two loop conductors will be installed below phase conductors, whereas the third loop conductor above phase conducotors, in lieu of a shield wire. Tower cost increases by +20-25%, if compared to a standard solution, in terms of time, there are not significant increase.

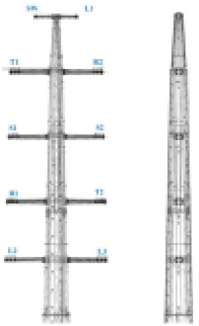

Figure 1 – Steel tubular tower with double circuit (R,S,T), shielding wire (SW) and loop conductors (L).

Discussion

- A short circuit analysis has been carried out by Terna with a software ATP-EMTP. Simulations results evidence that the worst condition is phase-phase to ground fault on the line terminal.
- Higher loop conductor must have a clearance distance equal or higher than 35 cm in order to guarantee the self extincion of secondary arc. Kizilcay's model of secondary arc has been implemented in ATP-EMTP.
- The maximum expected currents and voltages on passive loop conductors are about 1200 A and 950 V respectively.
- Fault on passive loop cannot be detected by OHL protection relay.

Conclusion

- Compensated loops can be an efficient solution to mitigate the magnetic field.
- The induced currents and voltages on compensated loop conductors are not an issue in normal operation;
- In case of external fault transient overvoltages arise on capacitor banks; therefore, surge arresters are able to guarantee a safe operation
- A possible protection relay, based on zero-sequence current measurement, has been introduced in order to discriminate internal and external faults.

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Main characteristics

- The Series Capacitance Compensation System (SCCS) identified by Terna is composed by:
- a circuit loop bay (M1) for the connection of SCCS to 400 kV OHL and protection from overvoltage and overcurrent related to internal and external faults;
- a capacitive compensation bay (M2) for the connection of 4 mF capacitors banks in series with passive loop;
- a bypass bay (M3) for the connection of a resistive-inductive load to mitigate inrush current and specific energy of surge arresters, installed in parallel to the capacitors banks.
- A dedicated protection logic system is going to be developed by Terna in order to guarantee a safe operation of surge arresters and capacitors banks: in case of overvoltage, circuit breaker of passive loop (M1) will be switched off, whereas circuit breaker of the resistive-inductive load (M3) is going to be switched on, avoiding the increasing of surge arrester specific energy.

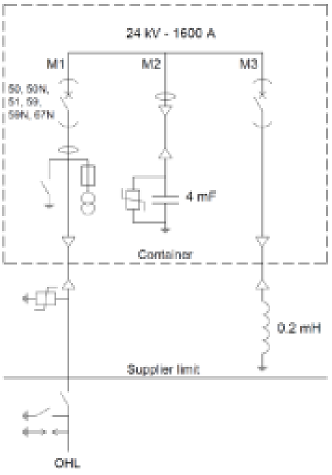

Figure 2 – Single line diagram of series capacitance compensation system for the 400 kV OHL between Colunga and Calenzano substations.

Capacitor banks	
Rated capacitance	4 mF
Rated voltage	1732 V rms
Rated current	1256 A rms
Surge arresters	
Continuous operating voltage	≥ 1.5 kV
Temporary overvolrages (TOV)	2750 Vrms / 1s
Nominal discharge current	≥ 10 kA
Residual voltage/Discharge voltage	5.4 kApeak – Ures ≤ 3.75 kV peak
Bypass load	
Rated inductance at power frequency	0.2 mH
Rated current	800 A
Short circuit current (Ikn)	20 kA
Specific energy	≥ 400 kJ

Table 1 – Main characteristics of SCCS equipment

Magnetic induction

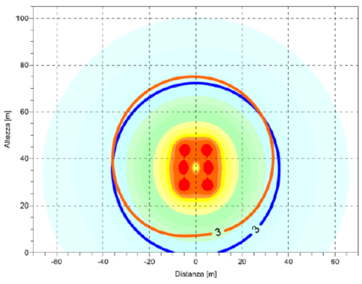

Figure 3 - Magnetic induction distribution when double circuit operates at 2310 A rated current: optimized double circuit with (orange) and without (blue) compensated loop conductors.

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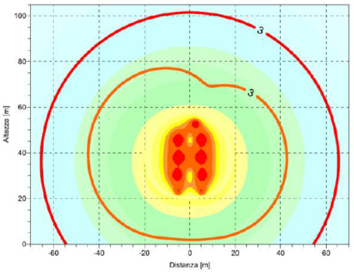

Figure 4 - Magnetic induction distribution when double circuit operates at 2310 A rated current: not optimized double circuit with (orange) and without (blue) compensated loop conductors.

Transient analysis

- The maximum short circuit impedance has been considered, corresponding to a short circuit current equal to 31.5 kA.
- Specific energy of surge arresters installed in parallel to capacitors banks attains 900 kJ. Rated specific energy of surge arresters as a function of discharge current is between 4 and 10 kJ/kV.

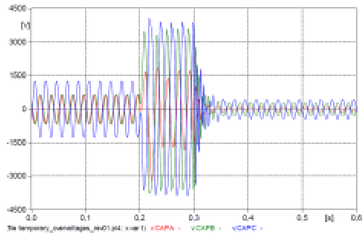

Figure 5 – Expected overvoltages on passive loop conductors due to external faluts (t=0.2 s fault time, t=0.3 s bypass switching-on).

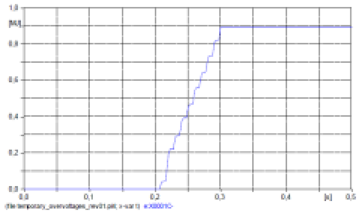

Figure 6 – Maximum specific energy of surge arrester due to transient overvoltages on passive loop conductors.

Arc extinction analysis

- Kizilcay's model of secondary arc has been implemented in software ATP-EMTP using type 94 component. Simulation results reported in Figure 7 evidence that, increasing clarence distance from 27 cm (according to IEC 60071-1) to 35 cm, the duration time of secondary arc current is reduced from about 250 ms to 30 ms.

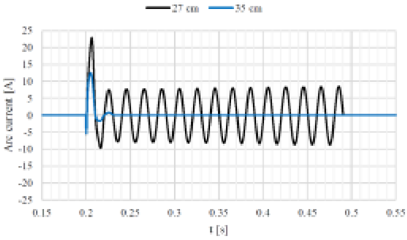

Figure 7 – Secondary arc current

Protection relay

- Zero-sequence current will be practically near to zero in case of external faults, whereas it will be on the order of thousands of amperes for internal faults.
- Neutral instantaneous overcurrent protection (50N) is needed in addition to the switches provided against faults on the overhead line (50, 51, 59, 67N). In case of a fault on the capacitor banks, only zero-sequence voltage arises and, therefore, a neutral overvoltage protection (59N) is necessary; as the OHL protection relay sees the same component, a time delay will be applied on neutral overvoltage protection of SCCS.

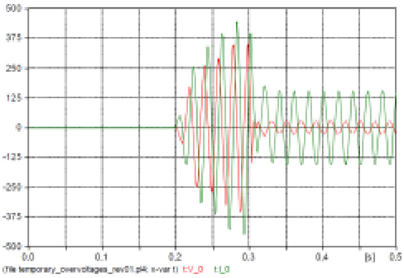

Figure 8 – Zero sequence voltage (red), and current (green).

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