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Power Systems Technical Performance

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Equivalent Impedance of Wind and Solar Power Plants for AC Harmonic Performance Assessment of VSC-HVDC Systems

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Why it is important?

- The occurrence of oscillations and harmonic currents and voltages is a common problem on HVDC transmission systems connected to converter-based networks, as wind and photovoltaic power plants.
- The accurate assessment of AC harmonic performance is of paramount importance for design and planning of HVDC systems.
- This paper details how to properly represent voltage-sourced converters on AC harmonic performance assessments.

Method/Approach

- Presentation of the most common topology and control strategy of voltage-sourced converters (VSC) based on literature review.
- Definition of impedance model of the VSCs considering the most common topology and control strategy identified.
- Comparison of impedance model results with laboratory tests provided by a manufacturer.
- Identification of the main aspects of the VSCs that are relevant for the impedance model.

Objects of investigation

- The objects of investigation are voltage-sourced converters used on wind turbines generators and PV units.
- Highlight of main aspects of VSCs which are relevant for properly represent them on AC harmonic performance analyses.
- Present an analytical expression to represent the equivalent impedance of the VSCs.

Experimental setup & test results

The most common topology and control strategy VSC, presented in Fig 1, consists of:

- Two-level three phase wire topology;
- LC filter with passive damping;
- Synchronous reference frame control (dq control);
- Synchronization by phase-locked loop (PLL);
- Proportional-integral (PI) controller and feed forward gain;
- PWM switching.

The detail VSC circuit can be represented by the simplified single-line diagram of Fig 2. Being:

- V_i the VSC output voltage defined from control;
- V_{pwm} the harmonic voltage generated on switching;
- Z_i control transfer function between V_i and PCC current (I_g);
- K_v control transfer function between V_i and PCC voltage (V_o).

- From Fig 2, the equivalent impedance of the VSCs is:

$$Z_o(\omega_h) = \frac{Z_f(\omega_h)\big(Z_{Lg}(\omega_h) - Z_i(\omega_h)\big)}{Z_{Lg}(\omega_h) + Z_f(\omega_h) - K_v(\omega_h)Z_f(\omega_h)}$$

- Being Z_f the equivalent impedance of L_f, R_f, C_f and Z_{Lg} of L_g. PLL, PWM switching and operating conditions are considered on Z_i and K_v.
- Laboratory test results of a VSC from PV units are used as benchmark to validate the model. The comparison is shown in Fig 3.
- The relevance of each part of the VSC to its equivalent impedance is assessed by disregarding individual parts from the proposed equation (see Fig 4). The cases are:
  - Complete Z_o with the VSC at nominal power operation;
  - Disregarding K_v transfer function;
  - Disregarding the delay related to sampling and PWM (K_{dl});
  - Disregarding the PLL;
  - Considering only the LC filter (Z_{Lg} parallel to Z_f);
  - Complete Z_o considering the VSC operating at zero power ($I_d = I_q = 0$);
  - Only the shunt part of the LC filter (Z_f).
- Equivalent impedance of the VSC for different active and reactive power settings presented in Fig 5.

Discussion

- As seen in Fig 3, the proposed equivalent model is similar to the results from the laboratory tests.
- From results shown in Fig 4, the main aspects of the VSC relevant to its equivalent impedance model are: output filter comprising L_f, R_f, C_f and L_g; current control transfer function Z_i; voltage control transfer function K_v; delay related to PWM switching and sampling; PLL; operating condition of the VSC.
- The impedance results depicted in Fig 5 show the active and reactive power settings impact, respectively, the phase and magnitude at low frequency range.

Conclusion

- The most common topology and control strategy of VSCs used in wind turbine generator and PV units is detailed.
- An equivalent impedance model of VSCs is presented and validated.
- The main aspects of the VSC that are relevant to properly represent them in AC harmonic performance assessment are identified.

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continued

Fig 1: Typical Voltage-sourced converter topology and control

- Two-level three-phase wire topology;
- LC filter and passive damping;
- Synchronous reference frame control (dq control);
- Synchronization by phase-locked loop (PLL);
- Proportional-integral (PI) controller and feed forward gain;
- Delays of sampling and switching PWM functions.

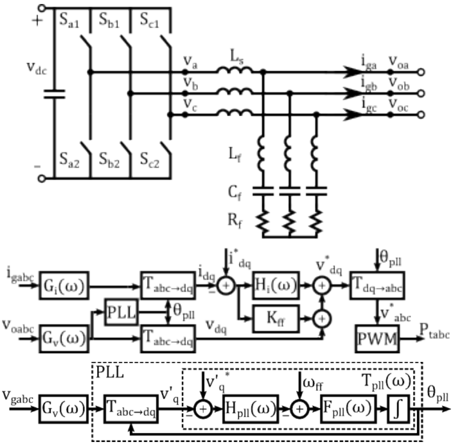


Fig 2: Simplified single-line diagram of grid-connected VSCs

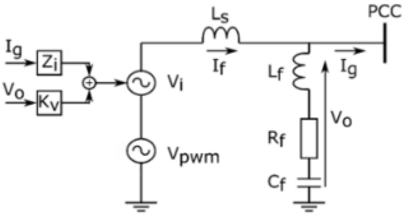


Fig 4: Network VSC impedance disregarding different parts of Zo

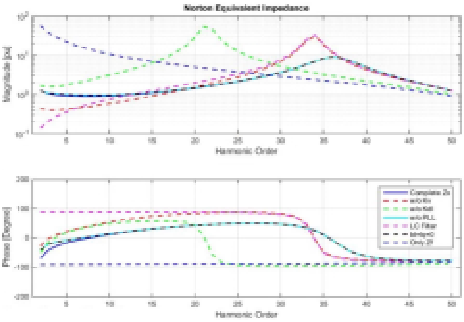


Fig 3: Comparison between VSC equivalent impedance model and manufacturer benchmark

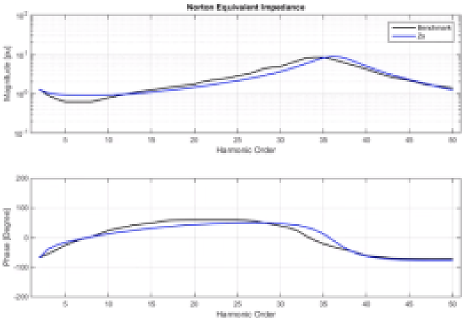
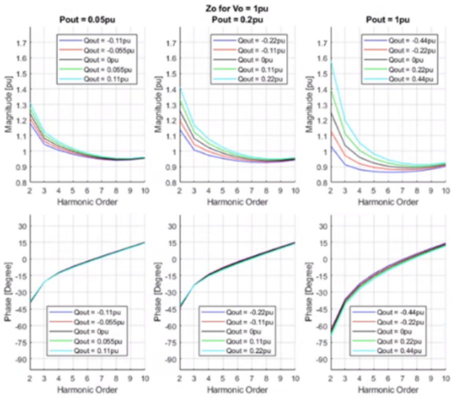


Fig 5: VSC equivalent impedance for different operating conditions



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