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Study Committee A3

Transmission and Distribution Equipment

Paper 10805_2022

Short circuit analysis of a Doubly Fed Induction Generator and their Impact on Generator Circuit Breakers

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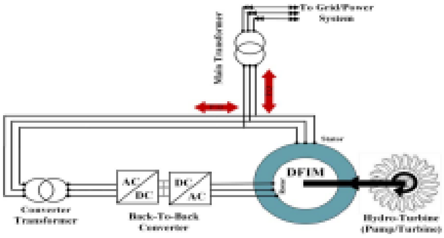
I. Motivation

- Pumped storage power plants are considered as the optimal solution for addressing the grid stability issues created by renewable energies connected to the grid
- Variable-speed generators like doubly-fed induction generators (DFIG) are more preferred for PSPPs due to their higher efficiency and flexibility to operate at different speeds.
- Understanding the short circuit behavior of such machines important while designing the protection of such power plants.
- A detailed analysis of short circuit behavior and how a generator circuit breaker with vacuum switching technology are suitable for the protection of such machines is described in this paper.

II. Short Circuit Behavior of a DFIG

- A DFIG is directly coupled to the grid but it has a power electronic converter connected between the rotor windings of the induction machine and the grid
- During Short circuit, due to magnetic coupling between stator and rotor, high currents will flow in the rotor circuit and through the converter system. crowbar resistors are used to limit these short circuit currents and avoid thermal failure of these converters.



PSPP using DFIG fed by a back-to-back power electronics converter

One of the most important criteria of selecting the crowbar resistance value is to find an optimum balance between limiting the short circuit current below the thermal break down level of the converter system and at the same time not leading to very high voltage drop across the converter terminals which could also lead to converter damage.

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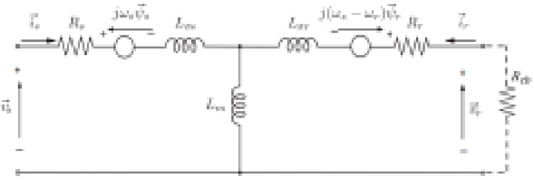


Equivalent circuit of a DFIG machine

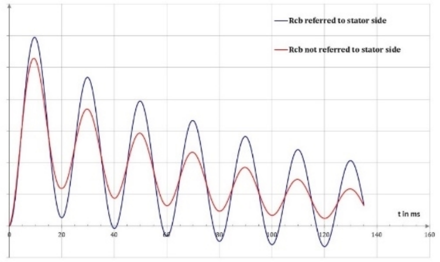
When a three-phase short circuit occurs at stator terminals, it is important to mention that the dc component of the fault current decays with the stator time constant T'S while the decaying of the ac amplitude is influenced by the rotor time constant T'R as shown below.

$$L'_S = L_{\sigma S} + \frac{L_{\sigma R} \cdot L_m}{L_{\sigma R} + L_m} \qquad T'_S = \frac{L'_S}{R_S}$$

$$L'_R = L_{\sigma R} + \frac{L_{\sigma S} \cdot L_m}{L_{\sigma S} + L_m} \qquad T'_R = \frac{L'_R}{R_R}$$

Similar to the transformer principle, the crowbar resistance value used on rotor side, needs to be calculated to the stator reference while calculating rotor time constant and its contribution in decay of AC component on stator contribution to short circuit current

$$R_{cbS} = R_{cb} \times \left(\frac{U_S}{U_R}\right)^2 \qquad T'_R = \frac{L'_R}{R_R + R_{cbS}}$$



Short circuit currents when crowbar resistance is referred to the correct side

II. Vacuum generator circuit breaker (VGCB)

- VCBs are used for these application since 90's and today they are available up to 100kA of short circuit current and 14000A of rated current with further ratings under development.
- Modern VGCBs use Axial magnetic field contacts to interrupt such high short circuit currents since a diffused arc leads to long life time and more electrical switching operations
- The arc voltage across the AMF contacts are typically in the range of 80-120 V and show a noticeable effect on the DC decaying behavior of short-circuit current in generator circuits, especially in case of generator-source current.

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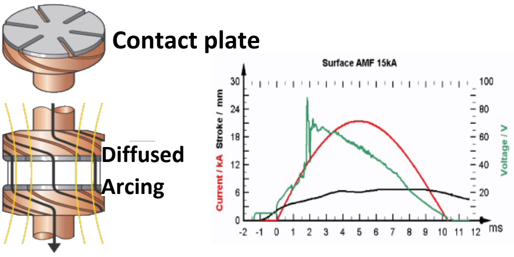


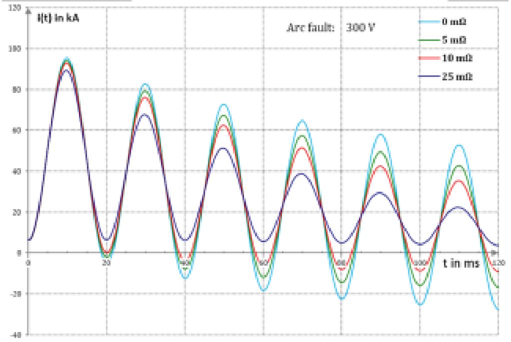
Typical arc voltage of AMF contacts

III. Case study

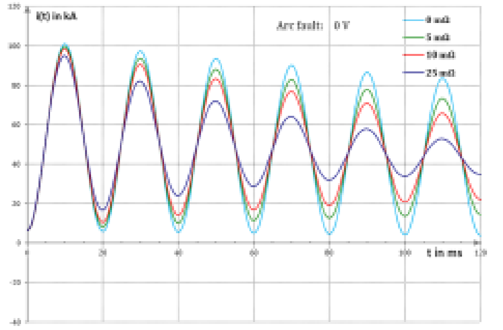
- The typical parameters of a DFIG used in a PSPP is simulated using the Electromagnetic Transients Method. Simulations are primarily focused to show the influence of different crowbar resistance value and different available crowbar implementation philosophies
- Further the machine is always under service conditions when the fault occur, it is also considered during the simulations, as stated in the dual logo standard IEC / IEEE 62271-37-013 an external arc fault voltage of 300 V in the calculations

Cases	R_{cb1}	R_{cb2}	I_{sym}	DC%	i_p	t_{arc}
1	0 mΩ	0 mΩ	30,9 kA	61 %	95 kA	8 ms
2	5 mΩ	0 mΩ	26,7 kA	71 %	94 kA	8 ms
3	10 mΩ	0 mΩ	23,1 kA	82 %	93 kA	7 ms
4	25 mΩ	0 mΩ	14,9 kA	128 %	89 kA	45 ms
5	25 mΩ	10 mΩ	19,6 kA	96 %	89 kA	6 ms
6	25 mΩ	5 mΩ	21,6 kA	88 %	89 kA	7 ms

Effect of crowbar resistance on fault currents



Effect of crowbar resistance with external arc voltage



Effect of crowbar resistance without external arc voltage

IV. Conclusion

- Correct usage of crowbar resistance values having a significant influence on the short circuit calculations of a DFIG.
- VGCBs with their inherent arc voltage along with external arc voltage showed can avoid delayed current zeros and thus are suitable for DFIG protection.

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