# Characterization of a Large Electrical Machine Test Bench for Advanced Investigations on Wind and Hydro Generators

Amir Ebrahimi
Institute for Drive Systems and Power Electronics
Leibniz University Hannover
Hannover, Germany
ebrahimi@ial.uni-hannover.de

***Abstract*—The acceptability and also the acceleration of renewable energy technologies is tightly linked with a better understanding of dynamic behavior of drive train components and their interactions. This ultimate understanding of system characteristics can only be achieved with comprehensive experimental investigations on different phenomena of large electrical generators. This leads consequently to a better verification of numerical and analytical models of large generators. The large generator-converter lab which is discussed in this paper is a unique opportunity for deep experimental investigations on large hydro and wind generators. It is designed to deal with the current as well as future research topics in the field of wind and hydro generators and their interactions with power electronic devices and electrical grid.**

***Keywords—wind generator; hydro generator; electrical grid; power electonic converter; analytical model***

## I. INTRODUCTION

The study of megawatt generators is an ongoing important topic due to the very different phenomena and uncertainties of giant electrical machines. Despite of decades of developing of calculation methods of megawatt generators, there are still varieties of problems and aspects to be studied. There is no prototyping of big generators for investigation reasons. Considering the hydro generators of giant hydro power plants, each generator represents a unique electromechanical device which is designed and constructed for specifics requirements of a power plant. Hence, it is very common to observe unique failures or non-predictable generator behaviors after installation. Due to the large geometry and high current of the generator there are occasionally one-time unknown phenomena which have to be studied. Moreover, the increasing complexity of electrical grids and rapid emerging of frequency converter fed generators encourage a much deeper study of the converter-generator interactions. Taking a look at the recent researches in the area of large generators, one can easily observe that the most of the lately published reports are pure theoretical works which are only validated with finite element calculations. These Works include e.g. studying of circulating current or partial discharge behavior in large generators [1], [2], [3], [4]. The studies also go through the calculation of flux densities in various locations in generator under different conditions [5], [6], [7], [8], [9], [10], [11]. Also the generator grid interactions are studied in detailed [12], [13], [14], [15], [16]. However, lack of sophisticated experimental results is a critical deficit of theses woks. Particularly in the field of large generators it is barely possible to perform an isolated study on one specific phenomenon and in the reality the generator may behaves absolutely differently from the anticipated numerical and analytical calculations. Therefore, most of the available analytical calculation methods of large generators are provided with very non-explainable correcting factors. The primary goal of the large generator test bench is to develop a deeper understanding of these phenomena and to reduce the correcting factors in the available models. This paper introduces the large generator-converter lab located in Hannover, Germany which is designed to deal with current research topics of large wind and hydro generators. This paper categorized the ongoing researches on hydro and wind generators and describes the components of the large generator test bench and links them to some current research works to clarify the effectiveness of the test bench configuration. The components are numbered and colored on all figures the same and will be referred as a number in parenthesis in the text. Thus, one can follow the functionality of each component easily through different layers. At the end the necessity and the advantages of the large generator-converter test bench are briefly summarized.

## II. GENERATOR-CONVERTER TEST BENCH

### *A. Conceptual design of large generator converter lab*

The large generator-converter lab is constructed in two floors. The first floor houses the electromechanical components as it is indicated in Fig. 1. The power electronic components and transformers are placed in the second floor. Fig. 2 shows the one-line diagram of the lab. The locations of the components are also illustrated in this Figure. The test bench is realized with a pneumatic spring bed (1) whit a capacity of 40000 Kg. The load machine (2) and device under test (DUT) (3) are mounted and aligned on the pneumatically suspended mechanical bed. This facilitates the study of mechanical vibrations. These studies go through measuring and modeling

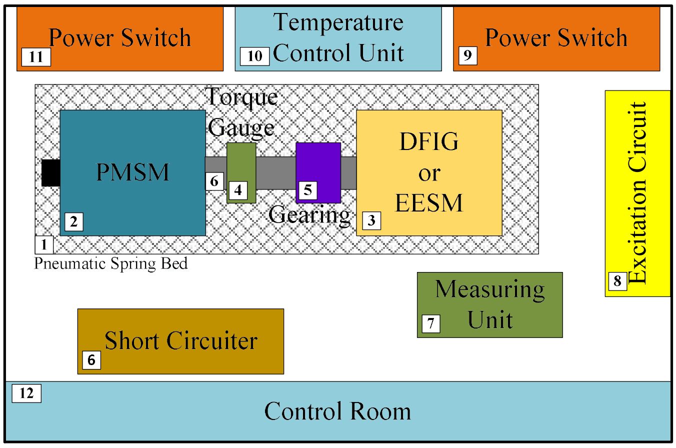


Fig. 1. Schematic of the generator test bench (first floor)

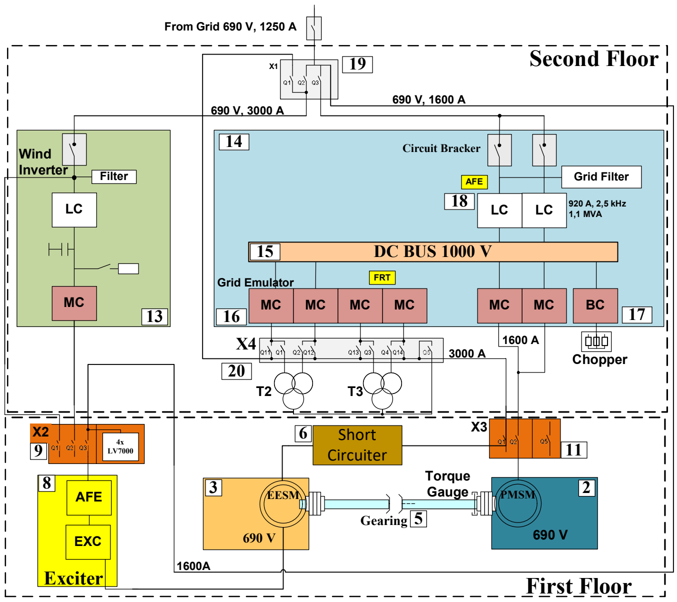


Fig. 2. Line diagram of generator-converter lab

of generator vibration to find out e.g. the vibrations effects on the stator winding and insulation [17], [18], [19]. The end winding vibration is also an important aspect which is considered in the previous works [5]. A Permanent Magnet Synchronous Machine (PMSM) (2) and A Doubly Fed Induction Machine (DFIG) (3) are coupled together on the mechanical bed. The machines are equipped with varieties of sensors and can be derived as a motor or generator as well. Both PMSM and DFIG are favorable wind generator types which are the purpose of current researches in the field of wind energy generation [20], [21]. However, it should be mentioned that the test bench can be rearranged to host any other type of generator [22]. These two machines are coupled together via a gearbox (5) for velocity matching. Thus, it is possible to test different generators in a wide range of nominal speeds. That is particularly important when one considers the emerging researches on direct drive wind generators [23], [24]. A precise torque gauge (4) is also provided on the common shaft (6). The torque gauge can measure up to 40 kNm at 6000 rpm. Study on the sideband torque in converter fed generators or investigations on the transient torques at short circuit periods can be carried out with the help of this torque sensor [6], [25]. The test bench is provided with a special excitation unit (8) for energizing the rotor of synchronous generators. Researches on the loss of excitation of synchronous generators, short circuit and no load tests can be carried out using this unit [26], [27]. The unit can supply the rotor in controlled voltage and controlled current mode with a current ramp of 1200 Ampere per milliseconds and even AC controlled current mode. This fast current ramp is used for specific eddy current measurement methods. The test bench is equipped with a fluid temperature control unit (10). The temperature of the water flowing into the generator can be set with an accuracy of 0.1 °C. The unit has a cooling power of 50 kW in the range of -10 to 100 °C. This unit plays an important role for exact efficiency calculation [9]. The efficiency of large generators are measured with measuring the temperature difference between the in- and outlet water. Detailed fluid dynamic studies on the cooling and ventilation systems of large generators can also be done with the help of this unit e.g. researches on the radial and axial ventilation methods [28], [29] or evaporative cooling systems [30], [31]. The test hall is additionally equipped with a room cooling device to stabilize the lab temperature. This is especially an important aspect for long term tests. During long term tests the test hall temperature rises and the safety systems shut down the generators and power electronic devices. Long term tests are mandatory for research topics such as control monitoring [32], [33], partial discharge [34], [2] and temperature and efficiency measurements [4]. The power switch bank (9) supplies the room cooling device. The other power switch bank (11) supplies the generators. The DUT (3) is connected to the motor converter via a short circuiter (6). The three phase short circuiter can switch 12 kA and realize symmetrical and asymmetrical short circuits. The moment of short circuit or the phase angle can be adjusted in miliseconds steps. The short circuiter facilitate investigations on the short circuit behavior of large generator [35], verification of generator models under short circuit faults [36], open circuit and short circuit characteristics [37] and transient field calculations [38]. Moreover, the test bench is additionally equipped with a mobile robot. Different types of sensor e.g. three dimensional flux sensors can be installed on the robot manipulator. This robot can be installed in the generator housing to perform an online streaming of electromagnetic fields of generator end region [39], [40], [3]. This helps to develop a better understanding of generator end region losses [8], [41]. This is especially important for pressing plate loss calculation to avoid heating of the clamping plate [42], [11]. The control room is situated in the first floor (12) and the selection of operation modes and control algorithms and the analysis of all measured parameter are carried out in the control room. The power electronic devices are situated in the second floor of the test hall as it is indicated in Fig. 2. The load machine is supplied via a full frequency converter (17). Different types of control algorithms can be realized with this IGBT based converters [43], [44]. The converter is connected to the common 1000 V DC bus (15). The AC-DC conversion is realized with the line converter (18) which is connected via a power switch bank (19) to the electrical grid. The DFIG can

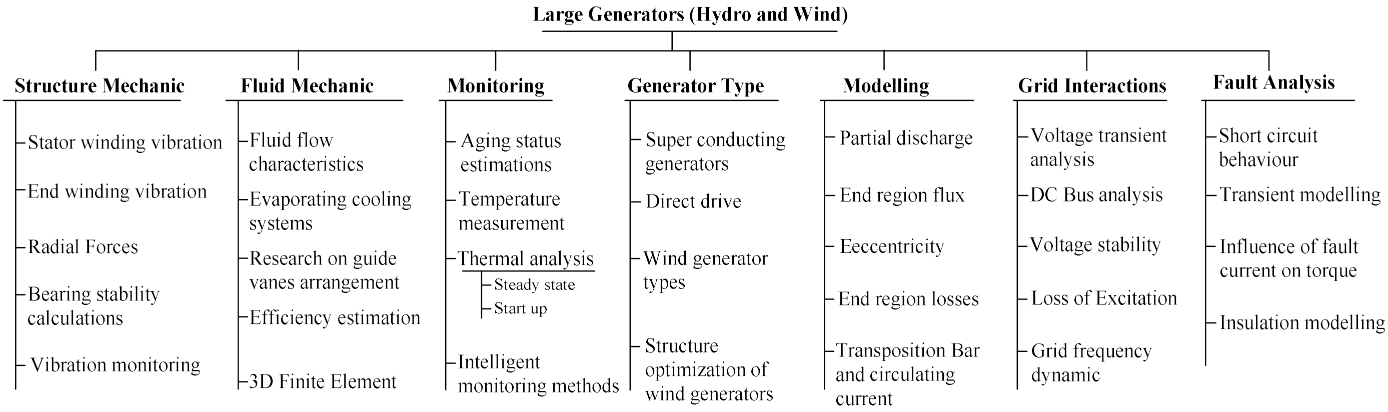


Fig. 3. Research topics in the field of large wind and hydro generators

also be supplied via the wind inverter (13). The wind converter supplies the DFIG via the power switch bank X2 (9). It is possible to test different types of wind generators and study their interactions with the grid [12]. Moreover, investigations on the generator-converter aspects such as DC bus characteristics [45], or voltage transients [46] or fault analysis [47] can sophisticatedly be carried out with this configuration. A very unique property of the large generator converter lab is the Fault-Ride-Through (FRT) grid emulator (16). This is realized with a set of frequency converters connected to the DC bus on one side and to the two transformers (20) on the other side. The wind generation influences on the electrical networks is a very relevant topic which is currently investigated worldwide. The high penetration of wind energy into the grid changes the dynamic of electrical grids of future. Large-scale wind farm integration poses challenges to the modeling and simulation of power system electromagnetic transients. Hence, the topics such as voltage regulation, frequency regulation, stability, resiliency and reliability have to be studied seriously in order to successfully integrate the large wind energy penetration. [48] and [14] study the impact of wind turbine generator type on voltage regulation in distributed feeders. [49] Develops models for simulation of large-scale induction generator wind farms. Improving the grid frequency dynamics of synchronous generator considering wind energy penetration is studied in [13]. Even the voltage stability of unbalanced systems and the impact of voltage sags and swells on wind generators are studied in detailed [15], [16]. The unique ability of large generator converter lab to prepare an experimental basis to verify all these studies and their impact on the generator has to be highlighted. The combination of wind inverter (13) and the grid emulator (16) provide the realization of very different combination of generator-converter-grid. The grid emulator can also specifically generate the 3$^{rd}$, 5$^{th}$, 7$^{th}$, 11$^{th}$ and 13$^{th}$ harmonics for detailed study of harmonic impacts on grid and generator. The transformers are also freely switchable to deal with current ripple studies in converter design. The switching frequency of the converter can be set manually with an upper limit of 5 kHz. The grid emulator can deliver an over current of 3000 A. The universal test bench is currently equipped with a double-fed asynchronous and a permanent magnetic synchronous machines each with its own 690 V inverters as well as converter-based grid emulator with 4.4 MVA.

The two generators and gearbox are indirectly water cooled. The nominal parameter of the lab are indicated in table I and a view of generator lab is indicated in Fig. 4. The selectin, arrangement and configuration of the components is a decisive criterion for measuring the large generator converter lab capabilities and productivity. Fig. 3 shows a sketch of the categorized current research topics on large hydro and wind generators. The ultimate goal of designing a large generator lab should be the creation of a technical infrastructure which could realize a deep and specific investigation on different research topics of large generators with minimum need of effort and simple reconfiguration. Another point which may not be neglected is the multi-physical behavior of large generators. Whilst a pure magnetic analysis of a small machine could restrictedly be sufficient to give a judgement about the machine performance, the thermal, mechanical, magnetic and electric interactions of large generators should be strictly be studied. Hence, it is important to observe the neighbor research areas on the generator as it is indicated in Fig. 3.

TABLE I. LARGE GENERATOR CONVERTER LAB SPECIFICATIONS

| | |
|---|---|
| Span area | 10 m x 4,3 m |
| PMSM | P= 1,2 MW , N= 375 rpm |
| DFIG | P= 2,08 MW, N= 1780 rpm |
| Grid Emulator | S= 4,4 MW |

Fig. 4. Large generator Lab; DFIG and PMSM wind generators

### B. *Measurement system*

A very unique property of the large electrical machine lab is the large number of sensors installed in the generator. In the case of synchronous machine, more than 500 sensors are placed in the generator. Vibration, temperature, magnetic flux, current, voltage, capacitive air gap length, position and speed, air flow and air pressure sensors are examples of the various sensor types properly installed in different locations in the generator for a deep investigation on the magnetic, electric, thermal and mechanical behavior of the machine. This amount number of sensors and the sophisticated measuring system (7) for preparation of measurement values cover almost all the current researches on the large generators. The excessive temperature measurements can be used for thermal analysis in steady state [50], studying the thermal stress by startup [51] and the combined study on eddy current losses and temperature rise in the generator [52]. The air gap sensor facilitates researches on the influence of the air gap on the large generators at short circuit [53]. It also facilitates the studies on the impact of eccentricity on electromagnetic forces [54] and online monitoring of eccentricity [41]. Also researches on monitoring of machine parameter with a combined measurement of different types of sensors e.g. flux and vibration or force, rotor interconnection monitoring using flux and current and partial discharge monitoring can be carried out successfully with this sensors configuration [55], [56], [57], [7], [58], [59], [60], [61], [62].

## III. Discussion

The behavior of wind generators and pumped storage hydro systems are strongly linked with power electronic converters and dynamics of electrical grid. A sophisticated test bench for investigation on different aspects of generator, converter and grid is highly appreciated. The Large generator converter lab facilitates a detailed investigation on both conventional and innovative converter and generator concepts including control and filter design methods. This includes investigations into dynamics and system stability, stationary and transient thermal loading, various methods of grid injection and control and the behavior of grid faults such as voltage dips, symmetrical and asymmetrical short circuits. It is also possible to research on the converter generator interactions and their influence on other system components such as bearing and gearbox. These could be for example the influence of current harmonics on the generator, local saturation effects as well as bearing stresses and bearing currents. Generator lab offers an optimal solution for research on the electrical drive train of wind turbines and hydro generators. However, it is worth to mention that the investigation is not limited to these two types of generator and principally any kind of generator and converter can be installed on the test bench. The machines are equipped with extensive additional measuring technologies in the stator and rotor. A modular coil circuit, adjustable eccentricity and the flux measuring in very different parts of the machine are just some examples of the machines facilities. The two- and three-pole short circuits, an unbalanced grid or harmonics in the main voltage can be generated and investigated using the Fault-Ride-Through network. A specific time dependent grid voltage fault can be individually realized for each phase. It is worth to mention that very different components can be substituted into the test bench and studied. These can be for example doubly fed asynchronous machine (DFIG), rotor converter of DFIG, synchronous Generator and the converter of synchronous generators. A quick change of components is made possible by a tensioning field and an on-site 20000 kg crane. Researches on the mentioned topics result into an improved validation of analytical modellings, diagnostic procedures and advanced simulation models for electrical and mechanical components for a better design of generators and converters.

While the research works on large generators in the past decades has mainly focused on the analytical modelling for better understanding of generator behaviors, the future is dedicated to the predictive models for complex transient analysis considering uncertainty. The upcoming topics like digital twins cannot be successfully relegalized without a comprehensive treatment of complex physical phenomena of generators. One considers e.g. the developing of life cycle prediction models of generators. A very non-straightforward topic to be deterministically described is the partial discharge of generator winding. However, this topic is directly linked with physical phenomena like insulation degradation, bearing current, vibration etc. Ones connects the same generator with a converter to the grid, all the mentioned topics should be studied again to deal with the switching nature of large converters. Not only the converter but the grid characteristics should also be taken into account. After a detailed analysis of each part, one can start with the developing of a mathematical model to predict the machine behavior and the right time to change the winding insulation. These types of models cannot be achieved without a large generator test bench like the one explained in this paper. The pure analytical modeling of generators which has been done in the past decades cannot alone solve the complex problems of future research topics in this area. For developing a comprehensive model of generator considering its past functional history and mathematical models to predict the future of generator behavior namely the digital twin of the generator, it is crucially necessary to carry out specific precise purposeful experimental studies. The described large generator converter lab facilitates these types of researches.

## IV. Conclusion

The characterization of a large generator converter test bench is discussed in this paper. The purpose behind this is providing the future research areas in the field of large generators with a sophisticated infrastructure which can deal with the future requirements of investigation on large generators. The future of large generators researches is linked with multi-physical study of generator behavior, considering the uncertainty, power electronics influences and grid interactions. The large generator test bench is designed to deal with all these topics. This helps to increase the reliability and consequently the acceptability of wind and hydro generators on the way of a future with renewable energy sources.

## REFERENCES


[1] X. Bian and Y. Liang, "Circuit Network Model of Stator Transposition Bar in Large Generators and Calculation of Circulating Current," IEEE Transactions on Industrial Electronics, vol. 62, pp. 1392 - 1399, Aug. 2014.

[2] J. Xu and B. Gao, "Research of Aging Status Assessment of Large Generator Winding Insulation by Polarization and Depolarization Current," IEEE International Conference on High Voltage Engineering and Application (ICHVE), Chengdu, China, pp. 1-4, Sep. 2016.

[3] R. Moser and B. Mark, "Automated robotic inspection of large generator stators," IEEE/ASME international conference on advanced intelligent mechatronics, Zurich, Switzerland, pp. 1-5, 4-7 September 2007.

[4] L. Weili, S. Ying, W. Purui, L. Dong, W. Yinghong and Z. Xiaochen, "Stator Temperature Field of Large-Scale Air-cooled Turbine Generator Considering Main Insulation Shelling," IEEE Conference on Electromagnetic Field Computation (CEFC), Miami, FL, USA, pp. 1-1, Nov. 2016.

[5] J. Li, Y. Yang and W. Kong, "Research on the stator end vibration characteristics of large generator sets," China International Conference on Electricity Distribution (CICED), Shenzhen, China, pp. 461 - 464, Sep. 2014.

[6] Y. Liu, R. Qu, J. Wang, H. Fang, X. Zhang and H. Chen, "Influences of Generator Parameters on Fault Current and Torque in a Large-Scale Superconducting Wind Generator," IEEE Transactions on Applied Superconductivity, vol.25, Oct. 2015.

[7] L. Wang, W. Chen, D. Tao, W. Li and B. Ge, "Research on the Impact of Screen Properties on Eddy Current and Flux in End Region of a Large Air-Cooled Turbo-Generator," IEEE Transactions on Energy Conversion, pp. 218 - 227, Oct. 2015.

[8] K. Motoyoshi, H. Kometani, N. Sora and S. Maeda, "Large-Scale 3D Electromagnetic Field Analysis for Estimation of Stator End Region Loss in Turbine Generators," 19th International Conference on Electrical Machines and Systems (ICEMS), Chiba, Japan, pp. 1-6, Nov. 2016.

[9] L. Vandenbossche, S. Jacobs, T. Lugand and A. Schwery, "Improved Calculation of Iron Losses in Large Salient Pole Synchronous Hydro-Generators," 6th International Electric Drives Production Conference (EDPC), Nuremberg, Germany, pp. 253-260, Dec. 2016.

[10] S. Li, N. A. Gallandat, J. Mayor, T. Habetler and R. Harley, "Calculating the Electromagnetic Field and Losses in the End Region of Large Synchronous Generators under Different Operating Conditions with Three-Dimensional Transient Finite Element Analysis," IEEE Transactions on Industry Applications, pp.1-1, Apr. 2018.

[11] S. Li, N. A. Gallandat, J. R. Mayor, T. Habetler and R. Harley, "Calculating the Electromagnetic Field and Losses in the End Region of a Large Synchronous Generator under Different Operating Conditions with Three-Dimensional Transient Finite Element Analysis," IEEE Transactions on Industry Applications, pp.1-1, 04 April 2018.

[12] R. M. Mathe and K. A. Folly, "Impact of Large Scale Grid-connected Wind Generators on the Power System Network," IEEE PES PowerAfrica, Accra, Ghana, pp.328-333, Jun. 2017.

[13] K. E. Okedu," Improving Grid Frequency Dynamics of Synchronous Generators Considering Wind Energy Penetration," IEEE International Electric Machines and Drives Conference (IEMDC), Miami, FL, USA, pp 1 - 6, 21-24 May 2017.

[14] B. Li, Y. Tian, D. Cheng, Y. Ke, J. Ding, H. Zhao, W. Yang and S. Zhu ,"Study on the stability of large wind power grid connected system including different types of wind generators," IEEE Conference on Energy Internet and Energy System Integration (EI2), Beijing, China, pp. 1-6, Nov. 2017.

[15] T. K. Das and J. Zhang, "Mitigating the Impact of Voltage Sags and Swells on Type IV Wind Generator Systems," Australasian Universities Power Engineering Conference (AUPEC), Melbourne, VIC, Australia, pp. 1-5, Nov. 2017.

[16] T. Datta, A. K. Sinha and P. Bajpai," Assessment of Voltage Stability of an Unbalanced Distribution System with Type-3 Wind Generator," 26th International Conference on Computer Applications In Electrical Engineering-Recent Advances (CERA), Roorkee, India , pp 359 - 364, Oct. 2017.

[17] T. Fortin and F. Duffeau, "Large generator vibration monitoring," Eighth International Conference on Electrical Machines and Drives, Cambridge, UK, pp. 155 - 159, Sep. 1997.

[18] X. Peng, Z. Jia, S. Gao, Z. Guan, L. Wang and T. Wang, "A new method for stator slot wedge testing of large generators," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 15, pp. 933 - 940, Aug. 2008.

[19] C. Staubach, T. Hildinger and A. Staubach, "Comprehensive Electrical and Thermal Analysis of the Stress Grading System of a Large Hydro Generator," IEEE Electrical Insulation Magazine, vol. 34, pp. 37-39, Jan. 2018.

[20] Z. Y. Wu, R. H. Qu, J. Li, H. Y. Fang and Z. S. Fu, "Structure Optimization of Rotor Supporting of Permanent Magnet Direct Drive Synchronous Generators for Large Wind Turbine Based on Genetic Algorithm and Finite Element Method," IEEE International Electric Machines & Drives Conference (IEMDC), Coeur d'Alene, ID, USA, pp.1755-1760, May 2015.

[21] L. A. Naugher, N. J. Baker and G. Atkinson, "Large air gap squirrel cage induction generator for a tidal turbine," 8th International Conference on Power Electronics, Machines and Drives (PEMD 2016), Glasgow, UK, pp.1-6, Apr. 2016.

[22] Y. Cheng, D. Li, W. Kong, R. Qu and F. Lin, "Electromagnetic Design of a Large-Scale Double-Stator Direct Driving HTS Wind Generator," IEEE Transactions on Applied Superconductivity, vol.28, Feb. 2018.

[23] D. Liu, H. Polinder, A. B. Abrahamsen and Jan A. Ferreira, "Potential of Partially Superconducting Generators for Large Direct-Drive Wind Turbines," IEEE Transactions on Applied Superconductivity, vol. 27, May 2017.

[24] Y. Xu, N. Maki and M. Izumi, "Overview Study on Electrical Design of Large-Scale Wind Turbine HTS Generators," IEEE Transactions on Applied Superconductivity, vol.28, Mar. 2018.

[25] B. S. Go, H. J. Sung, J. Choi, M. Park and I. K. Yu, "Modularization of the HTS Field Coils for a Large-Scale Superconducting Generator," IEEE Transactions on Applied Superconductivity, vol.26, Feb. 2016.

[26] Y. Liu, Z. Wang, Y. Su and L. Tu, "Research on loss-of-excitation protection of large generator directly connected to UHV grid," International Conference on Advanced Power System Automation and Protection, Beijing, China, pp. 1149 - 1152, Oct. 2011.

[27] G. Q. Lu, M. Long, J. H. Li, X. F. Tang, J. Zou, X. G. Yin and Z. Zhang, "Application analysis of large hydro-generator loss of excitation protection and its improvement," International Conference on Power System Technology, Chengdu, China, pp. 733 - 739, Oct. 2014.

[28] Y. Zeng-Ming and Z. Ting-Ting, "Research of guide vane proposals for the single-stage axial-flow fans used in the large generator," International Conference on Sustainable Power Generation and Supply, Nanjing, China, pp. 1-4, Apr. 2009.

[29] S. Ding, H. Liu, Z. Sun and Y. Ge, "Notice of Retraction Research of Fluid Flow Characteristic inside Radial Ventilation Duct for Large Generator," Asia-Pacific Power and Energy Engineering Conference, Chengdu, China, pp.1-4, Mar. 2010.

[30] J. Chen, H. Dong and L. Ruan, "3D steady-state thermal load analysis of the bus-bar in large-scale generator with evaporative cooling system," 17th International Conference on Electrical Machines and Systems(ICEMS), Hangzhou, China, pp. 2365 - 2368, 22-25 Oct. 2014.

[31] H. Chen, S. Yu, G. Zhu and W. Xu, "Research on evaporative cooling medium for large generator," 17th International Conference on Electrical Machines and Systems (ICEMS), Hangzhou, China, pp. 2369 - 2371, Oct. 2014.

[32] L. Nian and T. Fusheng, "The new intelligent monitoring methods for operating states of large generator units," IEEE Transactions on Magnetics, vol. 1, pp. 223 - 227, May 1995.

[33] Y. Bo, Z. Baihua, C. Xiaolin, C. Xuping and H. Xie, "Development of the online monitoring instruments technology, "Proceedings of the 7th International Conference on Properties and Applications of Dielectric Materials, vol.1, pp. 226 – 269, Jun. 2003.

[34] B. Yue, X. Chen, Y. Cheng, J. Song and H. Xie, "Diagnosis of stator winding insulation of large generator based on partial discharge measurement," IEEE Transactions on Energy Conversion, vol. 21, pp. 387 - 395, Jun. 2006.

[35] H. Jiawu, "Analysis of and reflection on the short-circuit fault of a large hydraulic generator, " IET Generation Transmission & Distribution, vol.8, pp. 661-669, Apr. 2014.

[36] A. Bermejo, C. A. Platero, F. Blázquez, F. Blánquez. and E. Rebollo, "Verification of a Synchronous Machine Model for Stator Ground Fault Simulation Through Measurements in a Large Generator," 2nd International Conference on Artificial Intelligence, Modelling and Simulation, Madrid, Spain, pp. 240-245, Nov. 2014.

[37] A.B. M. Aguiar, A. Merkhouf, K. Al-Haddad, "Open-circuit and short-circuit core losses computation in a large hydro generator," IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society, Vienna, Austria ,pp. 1 – 5, Nov. 2013.

[38] L. V. Strezoski and M. D. Prica, "Short-circuit Analysis in Large-scale Distribution Systems With High Penetration of Distributed Generators," IEEE/CAA Journal of Automatica Sinica, vol.4, pp. 243-251, Apr. 2017.

[39] L. Shufang, Y. Ruoping and G. Yougang, "Study on electromagnetic field in the end region of large generator by FEM," International Symposium on Electromagnetic compatibility, Tokyo, Japan, pp. 456 - 459, May 1999.

[40] L. Shufang, Y. Ruoping and G. Yougang, "A new method to determine the 3D field and transposition way of large generator," International Symposium on Electromagnetic compatibility, Tokyo, Japan, pp. 460 - 463, May 1999.

[41] H. Ehya, I. Sadeghi and J. Faiz, "Online Condition Monitoring of Large Synchronous Generator under Eccentricity Fault," 12th IEEE Conference on Industrial Electronics and Applications (ICIEA), Siem Reap, Cambodia, pp. 19-24, Jun. 2017.

[42] S. Li, C. Gong, N. A. Gallandat, J. R. Mayor and R. G. Harley, "Analyzing the Impact of Press Plate Structure on the Flux and Loss Distributions in the End Region of Large Generators by Transient 3-Dimensional Finite Element Method with an Improved Core Loss Model," IEEE International Electric Machines and Drives Conference (IEMDC), Miami, FL, USA,pp.1-8, May 2016.

[43] S. Rosen, P. Arunagirinathan, I. Jayawardene and G. K. Venayagamoorthy, "Optimal Tuning of Governors on Synchronous Generators in a Multi-Area Power System with a Large Photovoltaic Plant," IEEE PES Power Africa, Livingstone, Zambia, pp. 246-250, Jul. 2016.

[44] Q. Huo, Y. Shao and S Zhao, "Field Flashing Control for Large Synchronous Generator," IEEE 11th Conference on Industrial Electronics and Applications (ICIEA), Hefei, China, pp. 658 - 662, Jun. 2016.

[45] S. M. Roy, T. S. Bhatti and A. Verma, " Effect of DC link discharge resistor on transient stability of DFIG wind generator," 1st IEEE International Conference on Power Electronics. Intelligent Control and Energy Systems, Delhi, India, pp 1 - 4, Jul. 2016.

[46] M. Yagami, Y. Ichinohe, Y. kojima, K. Misawa and J. Tamura, "Enhancement of transient stability of synchronous generators using kinetic energy of variable speed wind generator", 20th International conference on electrical machines and systems, Sydney, Australia,pp. 1-6, Aug. 2017.

[47] E. Hossain, "Performance of new solid-State fault current limiter for transient stability enhancement of DFIG based wind generator," North American Power Symposium, Morgantown, USA, pp. 1-6, Sep. 2017.

[48] A. Sajadi, R. M. Kolacinski and K. A. Loparo , "Impact of wind turbine generator type in large-scale offshore wind farms on voltage regulation in distribution feeders," IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Washington, DC, USA, pp. 1 - 5, Feb. 2015.

[49] P. Li, X. Fu, C. Wang, H. Yu, D. Lin and F. Xing , "Matrix Exponential Based Algorithm for Electromagnetic Transient Modeling and Simulation of Large-scale Induction Generator Wind Farms," IEEE Power & Energy Society General Meeting, Denver, CO, USA, pp. 1-5, Jul. 2015.

[50] P. Wang, J. Liu, F. Song and H. Zhao, "Quasi-distributed temperature measurement for stator bars in large generator via use of Fiber Bragg Gratings," Proceedings of 6th International Forum on Strategic Technology, Harbin, Heilongjiang, pp. 810 - 813, Aug. 2011.

[51] S. Schmuelling and S. Exnowski, "start-up performance of very large synchronous generators," 4th International Conference on Power Engineering, Energy and Electrical Drives, Istanbul, Turkey, pp. 305-308, 13-17 May 2013.

[52] H. Wang, R. Zong, L. Liu and S. Yang, "Full 3D eddy current and temperature field analysis of large hydro-generators in different operating conditions," 17th International Conference on Electrical Machines and Systems (ICEMS), Hangzhou, China, pp. 3599 - 3603, Oct. 2014.

[53] O. Kokoko, A. Merkhouf, A. Tounzi, K. Al-Haddad and E. Guillot, "Analysis of Air-Gap Influence on a Large Hydro Generator's Parameters Using Sudden Symmetrical Short-Circuit Test," IEEE International Electric Machines & Drives Conference (IEMDC), Coeur d'Alene, ID, USA, pp. 102-107, May 2015.

[54] H. C. Dirani, A. Merkhouf, A. M. Giroux, B. Kedjar and K. A. Haddad, "Impact of Real Air Gap Non Uniformity on the Electromagnetic Forces of a Large Hydro Generator," IEEE Transactions on Industrial Electronics, pp. 1-1, Mar. 2018.

[55] P. Kung, L. Wang, S. Pan, M. L. Comanici, "Adapting the FBG cavity sensor structure to monitor and diagnose PD and vibration sparking in large generator," IEEE Electrical Insulation Conference (EIC), Ottawa, ON, Canada, pp. 11 - 15, Jun. 2013.

[56] Y. He, Y. Wang, W. Chen, L. Du, M. Chen and Y. Liu, "A multi-parameter evaluation method of large generator fault probability," International Conference on High Voltage Engineering and Application, New Orleans, LA, USA, pp.665-668, 11-14 Oct. 2010.

[57] W. Minzhen , "The fault monitoring and simulation research of large generator," IEEE Symposium on Electrical & Electronics Engineering (EEESYM), Kuala Lumpur, Malaysia, pp 48 - 51, Jun. 2012.

[58] H. C. Dirani, S. Cupillard, A. Merkhouf, S. Bélanger, A. Tounzi, A. M. Giroux and K. Al-Haddad, " Free Vibration Analysis of a Large Hydroelectric Generator and Computation of Radial Electromagnetic Exciting Forces," 2015 IEEE International Electric Machines & Drives Conference (IEMDC), Coeur d'Alene, ID, USA, pp. 328-334, May 2015.

[59] L. Zhao, J. Su, B. Zeng, J. Cheng, L. Zheng, Y. Zhang, B. Yu and P. C. Gao, "Development of a New Type of Large-Size Self-Integrating Rogowski Coils Applied in TPG-Series Generators," IEEE Transactions on Dielectrics and Electrical Insulation, vol.24, pp. 2864 - 2872, Nov. 2017.

[60] H. C. Dirani, A. Merkhouf, A. M. Giroux, B. Kedjar and K. A. Haddad, "Rotor Inter-Turn Short Circuit Impact on Large Hydro Generator Magnetic Quantities," IEEE Transactions on Industry Applications, pp.1-1, Mar. 2018.

[61] J. Redlich, J. Juergens, K. Brune, B. Ponick, „Synchronous Machines with Very High Torque Density for Automotive Traction Applications," IEEE International Electric Machines and Drives Conference (IEMDC), USA, pp. 1-8, May, 2017.

[62] S. Müller, M. Keller, M. Maier, N. Parspour, „Comparison of iron loss calculation methods for soft magnetic composite," Brazilian Power Electronics Conference (COBEP), Brazil, pp. 1-6, Nov. 2017.