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# Future Power Distribution Grids: Integration of Renewable Energy, Energy Storage, Electric Vehicles, Superconductor, and Magnetic Bus

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### Abstract

This paper focuses on a review of the state of the art of future power grids, where new and modern technologies will be integrated into the power distribution grid, and will become the future key players for electricity generation, transmission, and distribution. The current power grids are undergoing an unprecedented transformation from the original design, changing the way how energy has been produced, delivered, and consumed over the past century. This new energy era includes the integration of renewable sources such as wind and solar, supported by the distributed or community energy storage, to power distribution grids through innovative high-frequency magnetic links and power-electronic converters. The use of emission free transportation, such as electric vehicles, and energy efficient technologies, such as superconducting generators and storage systems, are also rapidly emerging and will be integrated into the power grids in the foreseeable future. However, it is necessary to reconsider the current paradigms of system analysis and plan with a focus on how to achieve the most flexible, efficient, and reliable power grid for the future - the one that enables operation in a domain which is very different than the current one to deliver the services to consumers at an affordable cost.

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# Future Power Distribution Grids: Integration of Renewable Energy, Energy Storage, Electric Vehicles, Superconductor and Magnetic Bus

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***Abstract*—This paper focuses on a review of the state of the art of future power grids, where new and modern technologies will be integrated into the power distribution grid, and will become the future key players for electricity generation, transmission and distribution. The current power grids are undergoing an unprecedented transformation from the original design, changing the way how energy has been produced, delivered, and consumed over the past century. This new energy era includes the integration of renewable sources such as wind and solar, supported by distributed or community energy storage, to power distribution grids through innovative high frequency magnetic links and power electronic converters. The use of emission free transportation, such as electric vehicles, and energy efficient technologies, such as superconducting generators and storage systems, are also rapidly emerging and will be integrated into the power grids in the foreseeable future. However, it is necessary to reconsider the current paradigms of system analysis and planning with a focus on how to achieve the most flexible, efficient, and reliable power grid for the future – the one that enables operation in a domain which is very different than the current one to deliver the services to consumers at an affordable cost.**

***Index Terms*—Future power grids, renewable energy, energy storage, electric vehicle, superconductor, and magnetic bus.**

## I. Introduction

There is a clear need to introduce technologies that will assist in reducing greenhouse gas emissions and global warming. The fossil fuel generation of electricity is a large contributor to greenhouse gases, but the current infrastructure cannot be easily changed, as it is the product of the investment and intellectual effort of the last hundred years. In spite of the availability of renewable energy resources, it is by no means clear how the technological barriers to their more widespread adoption can be overcome, as these may require a radically different infrastructure, human behavior and attitudes. What is required is a transitional path that supports development of renewable energy resources, while cooperating with the existing infrastructure. The most promising approach for remote electrification and/or reduction in dependency on fossil-fuel based grid power is the concept of renewable energy based hybrid electric energy system [1].

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Grid Smart micro-grids with renewable energy based distributed generation (DG) and electric vehicles (EVs) are becoming popular to solve energy crisis and environmental degradation problems [2]. EVs help to keep the environment green and serve as distributed energy storage, which can help to minimize load shading as well. It will mitigate the intermittency and uncertainty effects of renewables and provide certainty in reliable power output. However, the battery system has low energy density, self-discharge, and leakage; it alone is not good for long-term energy storage. Therefore, a self-reliant remote power system must contain both short-term and long-term energy storage systems [3].

A superconducting magnetic energy storage (SMES) serves as short-term energy storage due to its high round-trip efficiency, suitability for charging/discharging, and also to support the instantaneous load spikes and variation, and renewable energy peak and load fluctuation. It is expected that the combination of an SMES with the long-term energy storage consisting of hydrogen fuel cell and battery bank can radically improve the performance of the distribution grid with a high penetration of renewable energy resources. The operation of a hybrid 500 W commercial fuel cell and energy storage system with a full bridge dc/dc boost converter to supply a fast changing load has been investigated in [4]. Authors in [5] have discussed the operation of SMES in an electric energy system using hybrid hydrogen connected to the power grids.

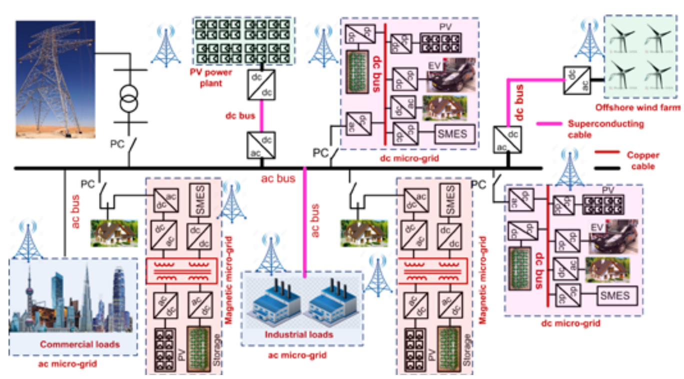


Fig. 1. Block diagram of a future distribution grid.

In general, a step-up transformer and line filter are commonly used for the medium voltage grid integration of renewable power plants [6]. In order to reduce the size and weight of the energy conversion system, a step-up transformer-less direct grid integration technology has been proposed in recent years [7]. A high-frequency magnetic linked medium voltage converter was proposed for direct grid integration of renewable sources [8]. With the current research and developmental trends, it is obvious that future distribution will have different types of micro grids including various distributed sources. Fig. 1 shows a basic block diagram of a future distribution grid.

It is now obvious that superconducting cables may reduce the power transmission losses effectively as the electrical resistance of the dc superconducting cable is more than 100 times lower than from the traditional dc cable resulting in almost zero electrical losses [9]. However, the refrigeration technology is the critical issue especially in the long length cable systems. Several attempts can be found in the literature to develop high temperature superconducting (HTS) cables [10]. The magnesium diboride ($MgB_2$) HTS cable is a promising alternative, which can operate with a temperature between 15–25 K (liquid hydrogen or gaseous helium can be used as the cooling medium for $MgB_2$ wires) [11]. Compared with the liquid helium, the gaseous helium is cheaper which may significantly reduce the running cost of a long length HTS cable. A liquid nitrogen cooling medium in the range 70 to 80 K is used for the thermal shield insulation. The sub-cooled liquid nitrogen has been used to cool the 10 kA HTS dc cable in Henan province, China [12]. The cost of $MgB_2$ cable is much lower than that of any other HTS cables as the magnesium and boron are abundant in nature. The $MgB_2$ cables were designed with multiple $MgB_2$ strands, which are helically wound around a flexible multi-strand copper core [11].

The recent development of the superconducting wind generator has significantly reduced the size and weight of the wind turbine nacelle and also reduced the installation cost of offshore wind farms. A 12 MW superconducting generator for the wind turbine was developed with NbTi/Cu cable-based LTS coils cooled with the forced flow supercritical helium at 4 K [13]. Currently, the $MgB_2$ HTS wires are commercially available, which lead to a new direction to develop low cost, compact and lightweight large rating generator having both rotor and stator windings with HTS materials [14]. A cryogenic vessel structure has been proposed for cooling HTS field coils [15]. In recent years, extensive research has been carried out toward the performance improvement of the HTS generator both (i) in the electrical and mechanical design [16], (ii) in increasing the operating temperature [17], (iii) in developing totally or partially superconducting generator [18]. The analysis of the technical performance and the life cycle assessment have also been analyzed and explored in [19].

In this paper, a review has been conducted on the current trends and recent development in renewable energy, energy storage, electric vehicles, superconductor and magnetic bus that will be employed in the future power grids. Also new research and development in these areas have been discussed.

## II. A New Concept to Utilize the Energy Storage in a Future Electricity Grid

Usually, a limited amount of energy is available in a storage system, and therefore the value of the storage should increase exponentially as the energy is dissipated or when the state of charge (SoC) is getting smaller and smaller. This is to ensure that there will be a sufficient energy available at the later period when the demand may become higher. Fig. 2(a) shows the state of charge and the value of storage during one discharge-cycle, where the value of storage increases rapidly once the state of charge decreases. Fig. 2(b) shows the corresponding active and reactive power injection from the storage unit which depend on the value of storage. When the value of storage is low, more active power and less reactive power can be supplied from the storage, whereas when it is high, less active power can be injected and therefore more reactive power should be injected from the storage to mitigate the PV impacts. This is because reactive power can act as an indirect source of support to mitigate the renewable energy (RE) impacts when active power is not available to fully meet the requirements. In such a case, the storage can be operated as a source to supply active or reactive power or both. If the storage is full, it is preferable to supply active power as much as possible, however when it is approaching towards an empty state, it is preferable to reduce the supply of active power and increase the supply of the reactive power. In a similar way, Fig. 3(a) shows the state of charge and the value of storage during one charge-cycle, where the value of the storage decreases quickly once the state of charge increases. Fig. 3(b) shows the corresponding active and reactive power absorption by the storage system which depend on the value of storage.

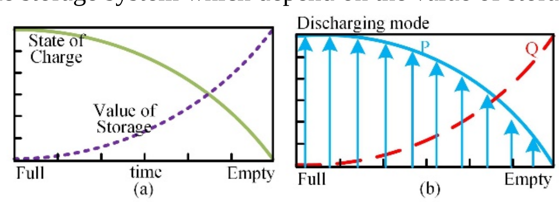


Fig. 2. Discharging mode: (a) SoC and value of storage, (b) P and Q injection.

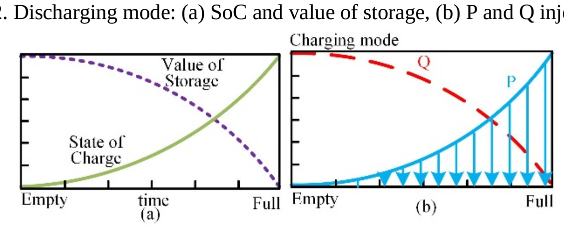


Fig. 3. Charging mode: (a) SoC and value of storage (b) P and Q absorption.

When the value of storage is high, more active power and less reactive power should be absorbed by the storage, whereas when it is low, less active power can be absorbed, and therefore more reactive power should be absorbed by the storage to mitigate the photovoltaic (PV) impacts. For example, if PV generation is more than the demand, the storage can be operated as a load drawing active or reactive power or both. If the storage is empty, it is preferable to absorb active power as much as possible, however when it is approaching towards a full state, it is preferable to reduce the absorption of active power and increase the absorption of the reactive power.

## III. Recent Development in Power Conditioning Systems with SMES for Renewable Energy Application

SMES has the ability to go from full charge to full discharge very quickly, which would make it extremely useful for integration with renewables to mitigate its adverse impacts. A suitable core needs to be designed to allow SMES to have high stored energy [21]. A suitable application of this new technology is to mitigate the renewable energy impacts. In the past, it was not possible because of the high-cost of superconducting coil for SMES [21]; however the cost is now reducing due to new development of HTS technology.

Since the solar energy resource is intermittent in nature and continually fluctuates, sometimes with high ramp-rate, it is necessary to have energy storage with fast response capacity. However, it is well known that some energy storage systems which are based on chemical reaction are relatively slow to respond to fast fluctuations, in particular fuel cells with electrolyzers and battery energy storage systems. On the contrary, the SMES is well known for its rapid response. The SMES can be used as a fast acting buffer storage due to its fast response capability, which can smooth the fluctuations in solar power output.

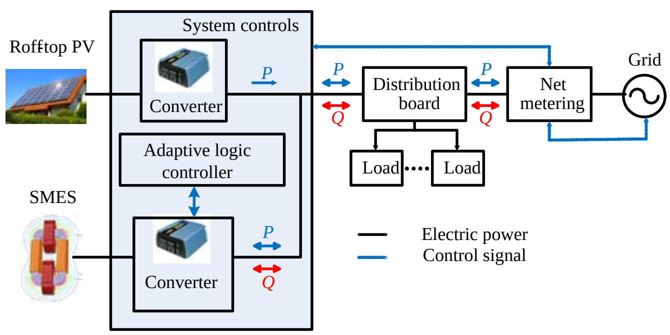


Fig. 4. Arrangement of an integrated PV-SMES.

A power conditioning strategy can be designed using an SMES as discussed in [20] for application to PV power smoothening. To control the charging and discharging of the SMES, an advanced control loop for power conditioning system needs to be carefully designed and implemented to achieve this. Fig. 4 shows the proposed configuration of a distributed SMES integrated with the PV system where SMES can be used as a source or sink or both to provide active and/or reactive power to overcome the PV impacts. The integrated SMES-PV unit can be acting as a constant generator operating at its optimum operating point during normal conditions. With this configuration, the capacity of the rooftop PV installations in the feeder can be increased without detrimental effects on the low voltage distribution. The above system can be upgraded with two-way communication to communicate with smart meters and system controllers. It is expected that the combination of an SMES with the long-term energy storage such as battery banks can radically improve the performance of the distribution grid with a high penetration of renewable energy resources.

## IV. Recent Development in Electric Vehicles

Electric vehicles (EVs) are becoming increasingly popular day-by-day. With the variability of load demand at the network connection point, the net power available for EV charging may also vary throughout the day. The power consumed in the charging operation depends on the charging rate, the battery voltage, and the present SoC of the battery and the battery capacity. Due to the dependency on these storage parameters and the available charging power, the amount of power consumed for charging operation requires a detailed study for assessing the viability of EV technology to replace the existing engine based vehicles. A detailed modeling of EV battery storage is necessary to capture the realistic EV battery behavior. A suitable strategy needs to be developed for control of charging and discharging operations of EV storage units. The EV storage devices are usually charged directly from the low voltage electricity networks.

By having this ability, a real-time EV management algorithm can be developed to determine accurately the range available to the drivers to the nearest charging stations. This can be achieved by calculating and predicting the time-dependent geographical distribution of the charging stations. A real-time warning system can be developed to warn the drivers if the distance is less than a certain safety margin, with the capability of updating the warning based on traffic conditions in the roads. Once the EVs are connected to the charging stations, a real-time EV charging strategy based on the SoC can be used to ensure fast charging time and the ability to estimate the duration of charging. The information such as SoC, location of the charging stations, the time and place of connection to the grid and charging pattern can be stored for use by the distributors in the future to infer the potential impacts of EVs on their networks.

Based on the storage model developed, the closest locations of vehicles for charging before the energy is exhausted can be determined and the amount of charging required can be estimated in advance to help the distributors to know the demand that can be expected. A real-time pricing model can be developed based on the information gathered to ensure the power demand from the EVs will not be detrimental to the network capacity. Using the information collected at different charging locations, the distributors can plan the expansion of the networks to ensure that enough capacity is available to meet the EV rising demand. Also, a load forecasting model can be developed using a suitable model available in literature [22]–[24] to predict the patterns of future load and source distribution for EV purposes.

## V. Recent Development in Superconducting Wind Generators

Using superconductors for the field and/or armature winding is the only available technology that could satisfy the technical requirements for some megawatt range wind turbines. The generators with both field and armature superconductor windings are known as fully superconductor (FSC) generator. Fully superconducting direct drive (FSDD) generators are very promising option for wind turbines with high output power to weight ratio. The absence of gearbox decreases overall wind turbine cost and weight and facilitates maintenance and increases reliable operation of wind turbine. The output power to weight ratio of an 8 MW FSDD is about 2 times of a conventional geared with double fed induction generator (DFIG) wind turbine. Presently, there are several companies which are exploring large superconducting (SC) generators for offshore wind systems [25]. These include American Superconductor (AMSC-10 MW), Converteam (8 MW) now owned by GE, China-TECO Westinghouse (5 MW), China Sinovel (5 MW), Advanced Magnet Lab (AML-10 MW), and GE (10–15 MW) [26]–[28].

A survey of recent research in the field of FSC wind turbines shows that the most of the research investigation are on designing or performance analyzing the SC generator as a *rotating machine*. While according to the American National Renewable Energy Laboratory, the wind turbines larger than 10 MW, SC generators are superior to the permanent magnet generators; their suitable topology is under study. Almost all of the design aspects of the MW class wind turbines including the comparison between fully versus partially superconducting concept, direct drive versus gearbox drive, rotating armature versus rotating field, radical versus axial flux, air core versus iron core concept in addition to superconducting support system, cryogenic cooling system, excitation system and superconductor wire types are under study and can be considered to be still very new areas for research. One of the most important ongoing researches for the MW class FSC wind turbines is their performance during fault conditions. This is a critical problem which should be analyzed and have to be addressed by the SC generator designers before their practical applications.

The operation of FSC wind turbine during fault conditions from the electrical machine point of view has to be thoroughly investigated. Also, some important issues in the application of fault ride- through (FRT) in FSDD wind turbines, such as permissible voltage rise of the dc link voltage, the maximum tolerable current of full-scale back-to-back converter and the limiting values for mechanical stresses on the shaft need to be understood for its full utilization.

## VI. Recent Development in Magnetic Bus for Applications to Future Grids

Fossil fuels based electricity generation causes nearly 41% of the world $CO_2$ gas emission. The internal combustion engine based vehicles causes about 23% of the global $CO_2$ gas emission [29]. Renewable energy based DG and EVs are becoming popular to solve these enormous challenges. EVs help to keep the environment green and serve as distributed energy storage, which minimizes load shading and excits the growth of renewable generation. Therefore, the smart micro-grid technology is now ready to integrate multiple renewable energy sources, EVs, and energy storage with intelligent energy management system [30]. In general, a common dc bus or link is used to integrate multiple sources.

There are a number of key challenges with the traditional dc bus based grid integration technology such as galvanic isolation and common mode. In literature, the high-frequency transformer based isolated dc-dc converters are proposed to solve these problems. Moreover, the use of low voltage two-level grid connected converter requires additional heavy and bulky devices, such as step-up transformer and line filter [31]. These additional devices not only increase the system loss and cost but also increase the volume and weight. To solve these enormous challenges a common magnetic bus is proposed in [32] to replace the common dc bus. In the proposed topology, a high-frequency common magnetic bus interconnects multiple renewable sources, storage units, EVs, loads and grid directly without using any step-up transformer and line filter circuit.

A number of literature reported the advantages of advanced soft magnetic material such as amorphous and nanocrystalline to replace the commonly used materials such as ferrite, silicon steel and permalloy for the development of high-frequency transformer [33]. Amorphous magnetic material has very high magnetic saturation, high permeability, high electrical resistivity, low specific core loss and good stability, which makes it suitable for use to design a high-power density and efficient high-frequency magnetic bus [34]. Recently a few vendors have been developing the amorphous core material, e.g. Metglas and WENERGY and deliver as ribbon of thickness between 15–35μm. However, core development technology with the amorphous ribbon is not mature yet, and it requires special process due to its thinner flexible structure. A fundamental idea for the development of amorphous core was presented in [35]. However, extensive research is needed for further design optimization of high-frequency magnetic bus as the design of the high-frequency magnetic bus highly affects the performance of the whole system.

## VII. Conclusion

This paper has reviewed the state of the art of future power distribution grids containing renewables, energy storage, electric vehicles, superconducting devices and magnetic bus. A new concept of charging and discharging energy storage based on its current SoC has been described. A power conditioning system based on an SMES has been demonstrated to be capable of smoothing out the power output of renewable energy. The use and the benefit of the electric vehicles have been discussed. Recent developments of superconducting wind generators have been reviewed. Finally, the application of a magnetic bus in future grids has been presented. The application of magnetic bus made of advanced soft magnetic materials to replace the existing dc bus or ac bus, especially for the grid integration of renewable sources, has been found to be a promising technology for future power grids. Beside the comprehensive review on state of the art of the technologies towards future grids, future research directions are also presented in this paper, which may give a possible route for the further development of the technologies.

## References


[1] B. Zhou *et al.*, "Optimal scheduling of biogas–solar–wind renewable portfolio for multicarrier energy supplies," *IEEE Trans. Power Systems*, vol. 33, no. 6, pp. 6229–6239, Nov. 2018.

[2] M. R. Islam, Y. G. Guo, J. G. Zhu, H. Lu, and J. X. Jin, "Medium frequency-link power conversion for high power density renewable energy systems," in: Proc. *IEEE 2013 Int. Conf. Appl. Supercond. Electromag. Devices (ASEMD 2013)*, 25–27 Oct. 2013, Beijing, China, pp. 102–106.

[3] K. Agbossou, M. Kolhe, J. Hamelin, and T K Bose, "Performance of a stand-alone renewable energy system based on energy storage as hydrogen", *IEEE Trans. Energy Conver*., vol. 19, no. 3, 2004, pp. 633–640.

[4] D. Sutanto and K. Ding, "Hybrid fuel cell and energy storage systems using superconducting coil or batteries for clean electricity generation," in *Proc. of 2009 IEEE Int. Conf. Appli. Supercond. Electro. Devices,* 25-27 Sep. 2009, pp. 365–368.

[5] H. Louie and K. Strunz, "Superconducting magnetic energy storage (SMES) for energy cache control in modular distributed hydrogen-electric energy systems," *IEEE Trans. Appl. Supercond.*, vol. 17, no. 2, pp. 2361–2364, Jun. 2007.

[6] H. Choi, M. Ciobotaru, M. Jang, and V. G. Agelidis, "Performance of medium-voltage dc-bus PV system architecture utilizing high-gain dc–dc converter," *IEEE Trans. Sustain. Energy*, vol. 6, no. 2, pp. 464–473, Apr. 2015.

[7] M. R. Islam, Y. G. Guo, M. Jafari, Z. Malekjamshidi, and J. G. Zhu, "A 43-level 33 kV 3-phase modular multilevel cascaded converter for direct grid integration of renewable generation systems," in: Proc. *IEEE Innovative Smart Grid Technologies Conference (ISGT) Asia*, 20–23 May 2014, Kuala Lumpur, Malaysia, pp. 594–599.

[8] M. R. Islam, Y. G. Guo, and J. G. Zhu, "An amorphous alloy core medium frequency magnetic-link for medium voltage photovoltaic inverters," *J. Appl. Physics*, vol. 115, no. 17, p. 17E710, May 2014.

[9] A. B. Abrahamsen *et al*., "Comparison of levelized cost of energy of superconducting direct drive generators for a 10-MW offshore wind turbine," *IEEE Trans. Appl. Supercond.*, vol. 28, no. 4, p. 5208205, Jun. 2018.

[10] T. Ishigohka, "A feasibility study on a world-wide-scale superconducting power transmission system," *IEEE Trans. Appl. Supercond.*, vol. 5, no. 2, pp. 949–952, Jun. 1995.

[11] Y. Xu, N. Maki, and M. Izumi, "Performance comparison of 10-MW wind turbine generators with HTS, copper, and PM excitation," *IEEE Trans. Appl. Supercond.*, vol. 25, no. 6, p. 5204006, Dec. 2015.

[12] Z. H. Chen, J. X. Jin, L. H. Zheng, and Z. H. Wu, "Advanced HTS dc transmission with self-protection function," *IEEE Trans. Appl. Supercond.*, vol. 26, no. 7, p. 5403105, Oct. 2016.

[13] J. Wang et al., "Design of a superconducting synchronous generator with LTS field windings for 12 MW offshore direct-drive wind turbines," *IEEE Trans. Ind. Electron*., vol. 63, no. 3, pp. 1618–1628, Mar. 2016.

[14] S. S. Kalsi, "Superconducting wind turbine generator employing $MgB_2$ windings both on rotor and stator," *IEEE Trans. Appl. Supercond.*, vol. 24, no. 1, p. 5201907, Feb. 2014.

[15] Y. Xu, N. Maki, and M. Izumi, "Study of key parameters and cryogenic vessel structure of 10-MW salient-pole wind turbine HTS generators," *IEEE Trans. Appl. Supercond.*, vol. 25, no. 2, p. 5200406, Apri. 2015.

[16] Y. Xu, N. Maki, and M. Izumi, "Overview study on electrical design of large-scale wind turbine HTS generators," *IEEE Trans. Appl. Supercond.*, vol. 28, no. 5, p. 5206905, Aug. 2018.

[17] J. S. Jeong, D. k. An, J. P. Hong, H. J. Kim, and Y. S. Jo, "Design of a 10-MW-class HTS homopolar generator for wind turbines," *IEEE Trans. Appl. Supercond*., vol. 27, no. 4, p. 5202804, Jun. 2017.

[18] Y. Xu, N. Maki, and M. Izumi, "Operating temperature influence on performance of 10 MW wind turbine HTS generators," *IEEE Trans. Appl. Supercond*., vol. 25, no. 3, p. 5200605, Jun. 2015.

[19] M. Saruwatari *et al*., "Design study of 15-MW fully superconducting generators for offshore wind turbine," *IEEE Trans. Appl. Supercond.*, vol. 26, no. 4, p. 5206805, Jun. 2016.

[20] M. V. Aware and D. Sutanto, "Improved controller for power conditioner using high-temperature superconducting magnetic energy storage (HTS-SMES)," *IEEE Trans. Appl. Supercond*., vol. 13, no. 1, pp. 38–47, 2003.

[21] G. Lei, C. Liu, M. Jafari, J. G. Zhu, and Y. G. Guo, "Multilevel robust design optimization of a superconducting magnetic energy storage based on a benchmark study," *IEEE Trans. Appl. Supercond*., vol. 26, no. 7, p. 5701405, Oct. 2016.

[22] D. H. Vu, K. M. Muttaqi, A. P. Agalgaonkar, A. Bouzerdoum, "Short-term electricity demand forecasting using autoregressive based time varying model incorporating representative data adjustment", *Appl. Energy*, vol. 205, pp. 790–801, 2017.

[23] M. J. E. Alam, K. M. Muttaqi, and D. Sutanto, "Effective utilization of available PEV battery capacity for mitigation of solar PV impact and grid support with integrated V2G functionality", *IEEE Trans. Smart Grid*, vol. 7, no. 3, 2016, pp.1562–1571, 2016.

[24] D. H. Vu, K. M. Muttaqi, A. P. Agalgaonkar, and A. Bouzerdoum, "A variance inflation factor and backward elimination based robust regression model for forecasting monthly electricity demand using climatic variables", *J. Appl. Energy*, vol. 140, pp. 385–394, 2015.

[25] J. X. Jin *et al.*, "HTS power devices and systems: principles, characteristics, performance, and efficiency," *IEEE Trans. Appl. Supercond*., vol. 26, no. 7, p. 3800526, Oct. 2016.

[26] R. Qu, Y. Liu, J. Wang, "Review of superconducting generator topologies for direct-drive wind turbines," *IEEE Trans. Appl. Supercond*., vol. 23, no. 3, p. 5201108, Jun. 2013.

[27] S.-J. Jung, *et. al*., "Stator winding fault influence on the field coil of a 10 MW superconducting synchronous generator," *IEEE Trans. Appl. Supercond*., vol. 23, no. 3, p. 5200104, Jun. 2013.

[28] American National Standard Requirements for Synchronous Machines, ANSI C50.

[29] M. H. K. Tushar, *Intelligent Energy Management for Microgrids with Re-newable Energy, Storage Systems, and Electric Vehicles*, Doctoral thesis, Concordia University, Montr´eal, Qu´ebec, Canada, Apri. 2017.

[30] H. Choi, M. Ciobotaru, M. Jang and V. G. Agelidis, "Performance of medium-voltage dc-bus PV system architecture utilizing high-gain dc–dc converter," *IEEE Trans. Sustain. Energy*, vol. 6, no. 2, pp. 464–473, Apr. 2015.

[31] H. A. Hamed, A. A. F. Abdou, S. S. Acharya, M. S. El Moursi and E. E. El-Kholy, "A novel dynamic switching table based direct power control strategy for grid connected converters," *IEEE Trans. Energy Conv*., vol. 33, no. 3, pp. 1086–1097, Jan. 2018.

[32] M. R. Islam, K. M. Muttaqi, D. Sutanto, and J. G. Zhu, "Design and implementation of amorphous magnetic material common magnetic bus for the replacement of common dc bus," *IEEE Trans. Magn*., vol. 54, no. 11, p. 2002004, 2 Jun. 2018.

[33] M. R. Islam, Y. G. Guo, and J. G. Zhu, "A medium-frequency transformer with multiple secondary windings for medium-voltage converter based wind turbine generating systems," *J. Appl. Physics*, vol. 113, no. 17, p. 17A324, May 2013.

[34] M. R. Islam, Y. G. Guo, and J. G. Zhu, "*Power Converters for Medium Voltage Networks*," Green Energy and Technology Series, Springer-Verlag GmbH, Heidelberg, Germany, Sept. 2014.

[35] M. R. Islam, A. M. M. Rahman, M. M. Islam, Y. G. Guo, and J. G. Zhu, "A modular medium voltage grid connected converter with improved switching techniques for solar photovoltaic systems," *IEEE Trans. Ind. Electron.*, vol. 64, no. 11, pp. 8887–8896, Nov. 2017.