Chapter 2

Sustainable Power Technology: A Viable Sustainable Energy Solution

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Additional information is available at the end of the chapter

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Abstract

There is no doubt that power reliability in most nations of the world has increased. Over the years, electric power has grown beyond providing utilities to being a dominant and fundamental part of civilization with smart phones, electronic vehicles, personal computers, etc. In order to meet the power demands of a growing economy, energy losses need to be minimized along transmission and distribution lines from power generation to the final load. This chapter discusses renewable energy sustainable solutions and superconducting power applications as a possible solution for energy sustainability, the environmental impacts of sustainable and superconducting technology with their future trends. It introduces smart grid and its roles in sustainability.

Keywords: superconductivity, power technology, sustainable energy

1. Introduction

Superconducting power technology offers the possibility of transmitting and distributing power with zero resistance through the adoption of a cooling method known as the cryogenics. Superconducting cables and many other applications use materials called “High Temperature Superconductors (HTS)” or Low-Temperature Superconductors (LTS). This chapter focuses more on HTS applications, which uses environmental friendly liquid nitrogen as the coolant. As shown in **Figure 1**, below the critical parameters: the critical temperature (Tc), the critical field (Hc), and the critical current, superconducting; this in turn makes the power density very high, and losses are practically zero. This region below the three constraints is known as the critical surface. Unlike conventional wires, HTS cables operate at a very high current with reduced operating voltage that produces efficient power in the grid.

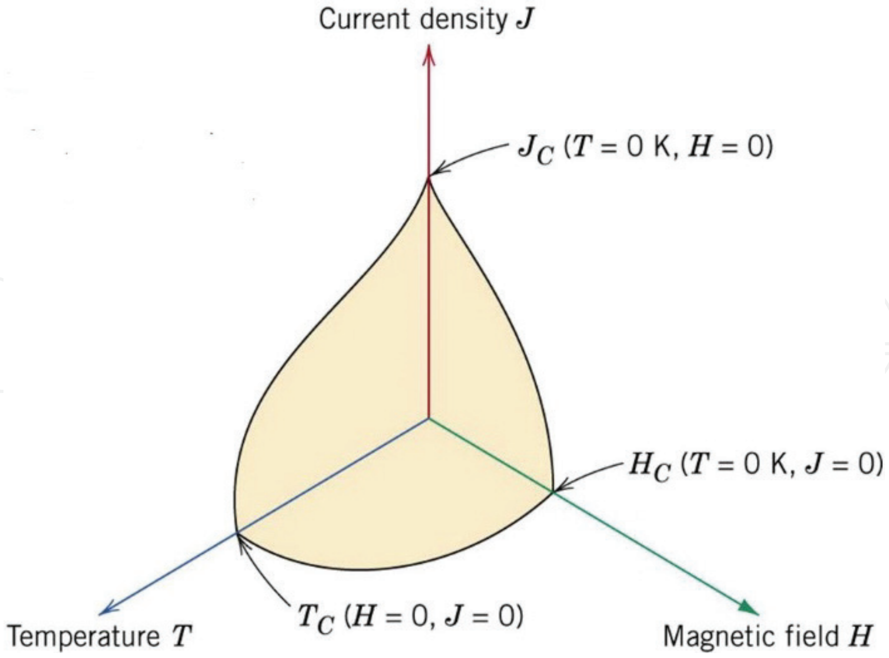


Figure 1. The critical surface of a superconductor [1].

In our society with increasing appetite for various electrical smart gadgets coupled with the high level of industrial production, the power generated has to be efficiently transmitted in order to meet the needs of consumers. The power grid serves as the intermediary network between the power generation plants and consumers. Power reaches its consumer in the following order:

1. Generation
2. High-voltage transmission substation
3. High transmission lines
4. Primary distribution substation
5. Secondary distribution substation
6. Consumers

It was estimated in the United States that power demand will grow from 3.9 billion kWh in 2010 to 4.7 billion kWh in 2035 [2]. This massive load growth poses a challenging overload to conventional aluminum or copper technology; the requirement to minimize inefficiency from overloading can be met by superconducting power technology because it can carry large amounts of power in a small cross-sectional area. **Figure 2** shows the stages of power transmission and distribution. The closed-loop cryogenic application does not support heat loss to the outside environment as compared to conventional systems that have direct

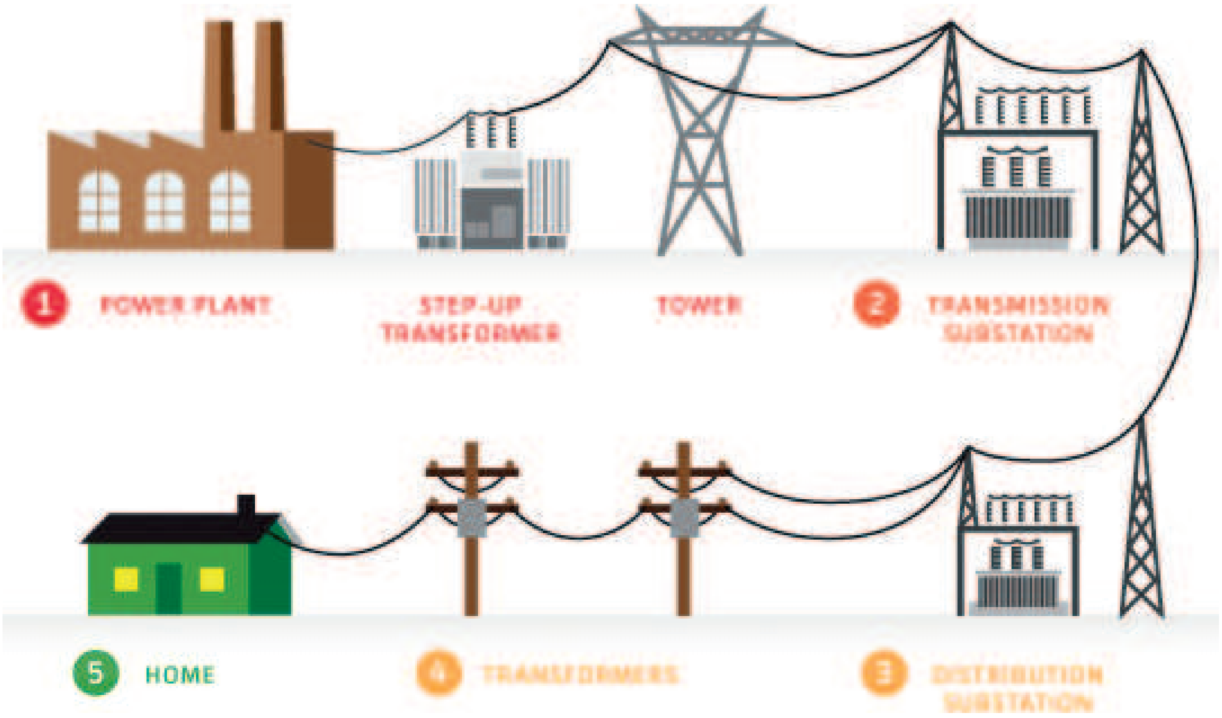


Figure 2. Typical power transmission and distribution [4].

heat loss impact on the environment. Moreover, due to its high energy per unit volume, superconducting applications are light in weight and are compact unlike the heavy conventional systems made of copper [3].

2. Energy sustainability

There are different sources of electrical power energy which are grouped as renewable (the wind, geothermal, solar, and hydropower) and nonrenewable (nuclear, coal, oil, and natural gas) energy sources. Sustainable energy has become a necessity for mankind and has a lot to do with renewable energy sources, which can provide energy for this present generation without wasting the natural resources needed for the future generations. In order to sustain power for the future, many renewable sources such as the wind, solar, hydroelectric, and biomass generation have been explored. This section discusses the various types of renewable energy as sustainable energy sources which are environmentally friendly. Presently, only 23.7% of the global electricity generation comes from renewable sources [5].

2.1. Biomass energy generation

Biomass is gotten from forest residues, wood waste, agricultural residue, and biomass feedstocks. Biomass is regarded as a clean energy because it emits lower carbon dioxide when compared to nonrenewable energy sources. Although the entire biomass power generation cycle is not totally free of CO_2, harvesting and transporting biomass involves biochemical and thermochemical processes that release the biogas and heat, respectively. As of 2010, 4% of the energy used in the United States were from biomass [6].

Biomass continues to be the largest non-hydroelectric renewable technology throughout the forecast horizon, growing from a capacity of about 6.7 GW in 2000 to about 10.4 GW by 2020. Similarly, generation from biomass will grow from 38.0 billion kWh in 2000 to 64.3 billion kWh by 2020 [7]. This means that the need for power generation from biomass alone will increase by about 69.2%.

2.2. Hydroelectric power generation

This being the first-generation renewable energy source, it is the most commercialized renewable energy source. Hydroelectric power is generated through the kinetic energy from the high-speed water made to flow through a dam. The water turbine actuates the speed control and in turn, drives the generator. From **Figure 3**, the large hydroelectric plant is projected to

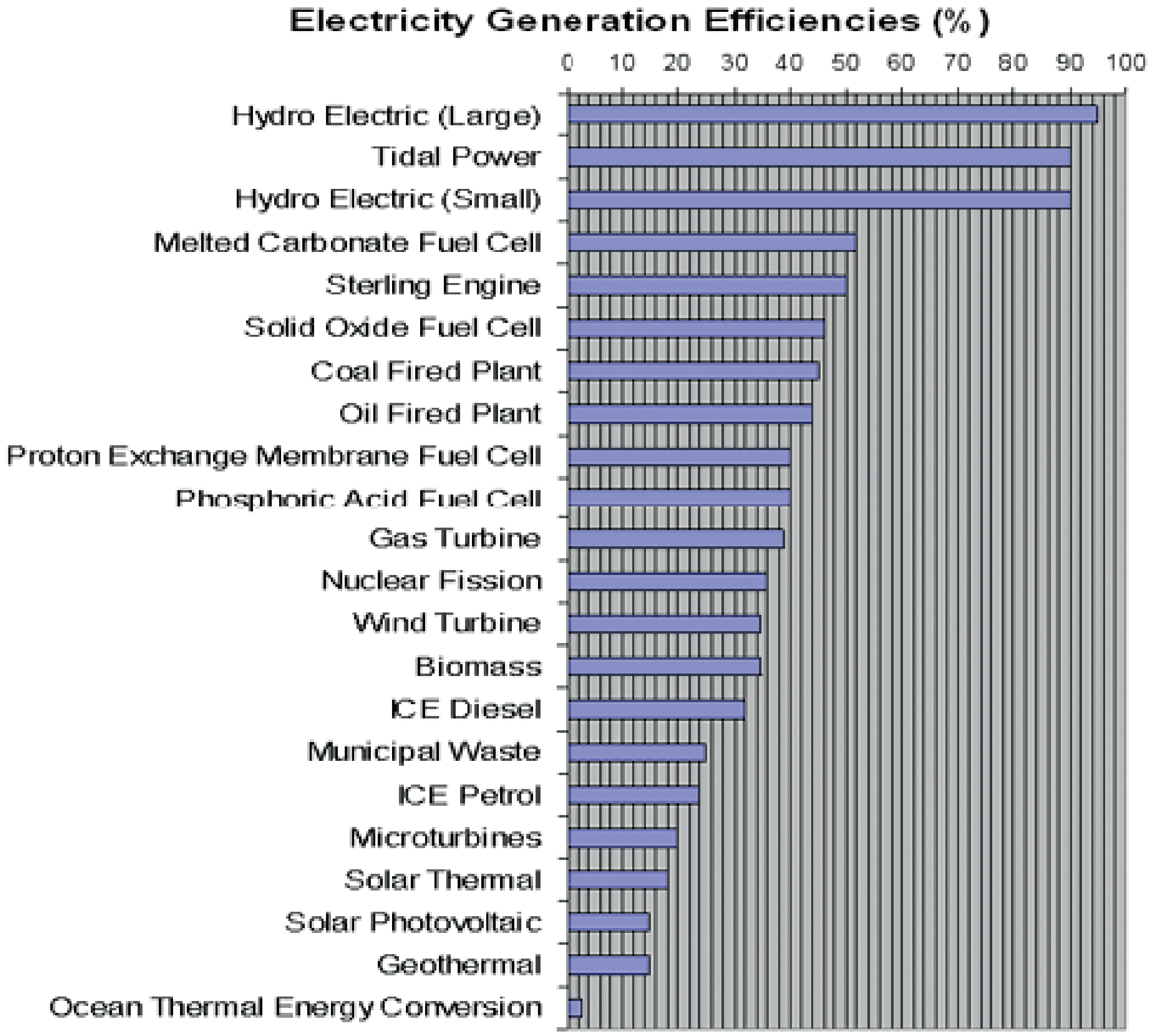


Figure 3. The efficiency of various power plants [8].

have efficiency as high as 95% in 2020; efficiency is based on the turbine design, wave power, volume of water, and other conversion system limitations.

2.3. Solar energy generation

This is the process of absorbing sunlight to be converted to electricity, and because it does not emit CO_2, it is one of the solutions to minimizing greenhouse gases. The light produced by sunlight is absorbed by solar panels and stored as direct current (DC), before it is converted to alternating current (AC) electricity by an inverter. One of its major disadvantages is that its peak period is during the day and at such, energy needs to be stored during the peak period so energy can be supplied in the off-peak period. PV cells convert solar energy into electrical energy with a conversion efficiency of around 15%.

2.4. Wind energy generation

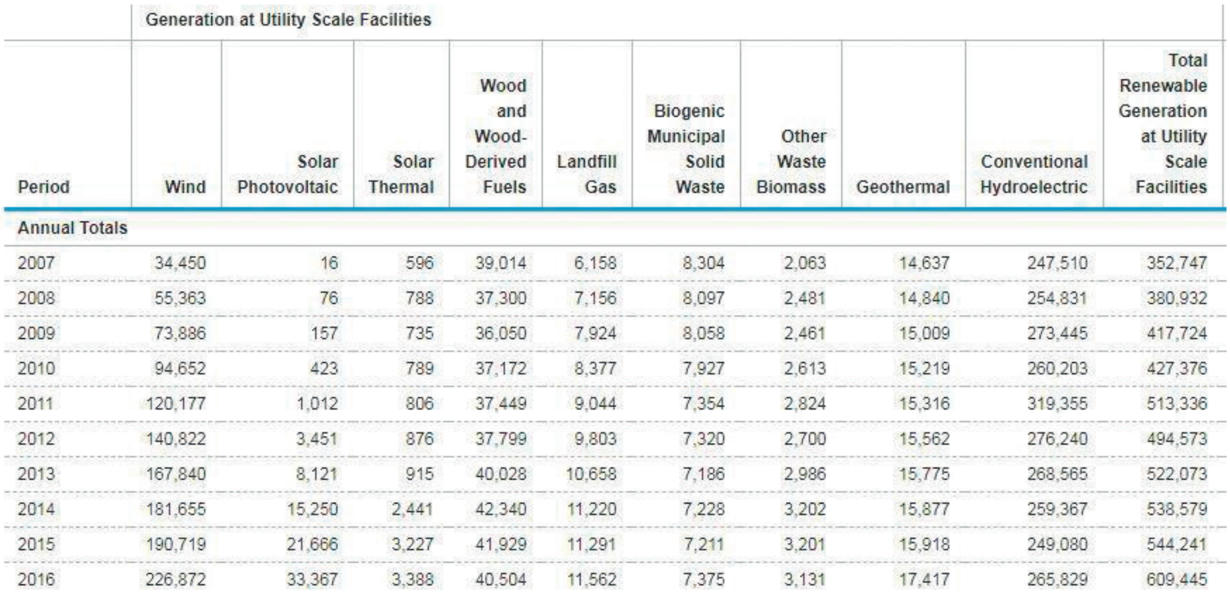
Wind generation involves the use of wind turbine to convert the movement of air into electrical energy. The movement of air increases with height. Power generated depends on the efficiency of the system, wind speed rotor blade design, capacity of storage systems, and density of air. In a century where environmental pollution has caused great impacts like global warming on our planet, there is the drive to pursue cleaner means of energy like. Considering superconductivity in the power grid, solar energy and wind energy are the most used renewable energy sources.

2.5. Geothermal energy generation

Energy generated from heat in the Earth is referred to as geothermal energy. This energy is readily available as it can be found in different corners of our environment, be it at the dump stand or at the top of the mountains. This energy is one of the clean and sustainable solutions to the dependency on fossil. As shown in **Figure 4**, the United States in 2015 produced 15,918 thousand MW with a state like California, which has 7% of the state's electricity generated exothermally. One of the major resources of geothermal energy is below the Earth's crust, where there is a constant heat layer known as the hot molten rock or magma. This layer has the highest underground temperature with seismically active regions that allow heat to pass through tectonic plate boundaries. There are about three basic designs for geothermal plant, but the simplest is the dry steam generation. This concept involves getting the steam from the hot layer into the turbine, and then a condenser turns the hot steam into water that controls the turbine. The turbine in turn drives the generator which generates power. Unlike wind and solar energy, geothermal energy is found all through the year; it is not a seasonal renewable energy source [9]. Geothermal power costs 3.6 cents/kWh as compared to 5.5 cents/kWh for coal [10].

3. Applications of superconductivity in the power grid

Based on the existing infrastructure, superconducting technology has made reasonable headway into the electrical power transmission and some part of its distribution, but the downside



	Generation at Utility Scale Facilities									
Period	Wind	Solar Photovoltaic	Solar Thermal	Wood and Wood-Derived Fuels	Landfill Gas	Biogenic Municipal Solid Waste	Other Waste Biomass	Geothermal	Conventional Hydroelectric	Total Renewable Generation at Utility Scale Facilities
Annual Totals										
2007	34,450	16	596	39,014	6,158	8,304	2,063	14,637	247,510	352,747
2008	55,363	76	788	37,300	7,156	8,097	2,481	14,840	254,831	380,932
2009	73,886	157	735	36,050	7,924	8,058	2,461	15,009	273,445	417,724
2010	94,652	423	789	37,172	8,377	7,927	2,613	15,219	260,203	427,376
2011	120,177	1,012	806	37,449	9,044	7,354	2,824	15,316	319,355	513,336
2012	140,822	3,451	876	37,799	9,803	7,320	2,700	15,562	276,240	494,573
2013	167,840	8,121	915	40,028	10,658	7,186	2,986	15,775	268,565	522,073
2014	181,655	15,250	2,441	42,340	11,220	7,228	3,202	15,877	259,367	538,579
2015	190,719	21,666	3,227	41,929	11,291	7,211	3,201	15,918	249,080	544,241
2016	226,872	33,367	3,388	40,504	11,562	7,375	3,131	17,417	265,829	609,445

Figure 4. Net generation of renewable energy sources from 2006 to 2015 in the United States [11]. Annual totals are in thousand MW.

to this technology is that its cryogenic cooling requirement makes it expensive when compared to conventional technologies. Therefore, utility companies have not adopted the technology yet.

Superconductivity applications such as superconducting generators and motors, superconducting fault current limiters, superconducting transformers, and superconducting magnetic energy storage systems all find their usefulness in the power grid. These systems are compact and energy efficient. The major drawback of superconducting technology is the cost of maintaining its cryogenic systems. **Figure 5** shows the response of electrical resistance against temperature in High Temperature Superconductors (HTS) and Low Temperature Superconductors (LTS). LTS operate at low temperature (about 4K) in liquid helium, and they require little energy to quench.

HTS are superconductors with high-temperature margin and heat capacity which is responsible for its high stability margin. Prior to 1986, the highest critical temperature of a superconductor was 23.2 K until Bednorz and Müller measured a critical temperature of about 30 K in La_2CuO_4 La_2CuO_4. Examples of high-temperature superconductors are $Bi_2Sr_2CaCu_2O_x$ (Bi-2212), $Bi_2Sr_2Ca_2Cu_3O_x$ (Bi-2223), and $YBa_2Cu_3O_x$ (Y-123). They are usually cooled with liquid Nitrogen at about 77K. They are also known for their large magnetic field >23T, high current density > 300 A/mm^2 and high allowable heat input [12].

3.1. Fault current limiters

The continuous growth in the demand for power necessitates the need for superconducting fault current limiters (SFCL). The bigger the size of the grid, the higher the chances of faults; this affects the operation of power equipment like transformers and other machines in the grid. A fault condition reduces the efficiency of the system, and this may cause a power outage if not promptly addressed. Moreover, the standardization of this technology is still immature, and due to cost issues, its marketability is very low, but this is not to underestimate its significant benefits.

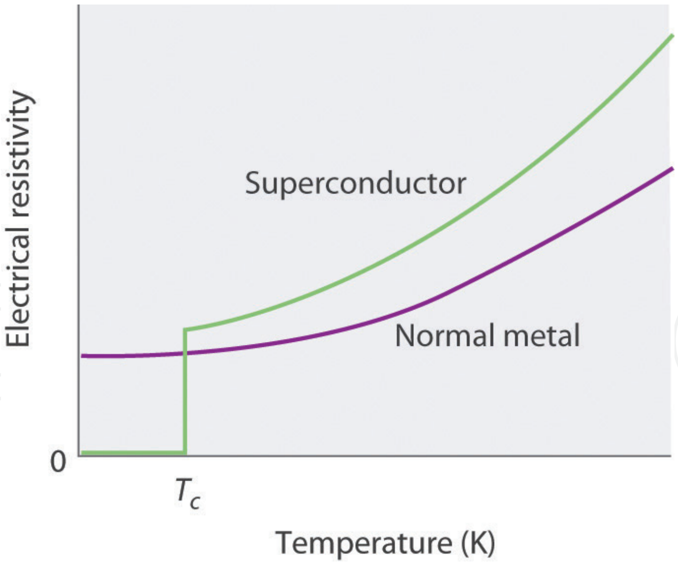


Figure 5. Plot of electrical resistance against temperature [13].

There are several types of SFCL designs, but the basic design works by applying the superconductivity principle as a means of protection. It basically has the superconducting material connected in parallel with a shunt, more resistive in the superconducting state but less resistive in the normal state. The superconductor continues its operation in liquid nitrogen based on its zero resistance until there is a fault condition; when current suddenly rises above its critical current, the excess current flows through the shunt metal after which the superconductor recovers its superconductivity back. SFCL employs its physical characteristic by handling the fault condition promptly within its first peak as shown in **Figure 6**.

One of the highlights of superconducting FCL is that they can protect upstream subnetworks, that is, they can protect both transmission and distribution network in a system. It is more suitable for these applications because nonsuperconducting FCL needs to have a predetermined position in order to protect subnetworks. This technology cuts out the cost of replacing circuit breakers, transformers, and separation of networks after a fault occurs. These mentioned components become reactive in a fault situation. SFCL increases stability in the transient system; instead of making significant changes like buying a new transformer or changing the circuit breaker when there is increased magnitude, SFCL protects the grid as subnetworks can be connected.

Furukawa Electric Cable (FEC) speculates that in the future, SFCL will be one of the power devices that permits a large number of renewable energy generators and avoids the risk of a network accident such as a ground fault and a circuit fault in a complex and huge power network [14]. Within the past decade, in Baiyin, Gansu province of China, a 10 kV/1.5 kA SFCL was integrated into the grid alongside with 630 kVA/10 kV/0.4 kV HTS transformer, 380 V/1.5 kA HTS AC cable of 75 m length and 1 MJ/0.5 MVA SMES [15]. In the future, continuous researches are ongoing on the improvement of SFCL and its application in the power grid especially its renewable energy applications, where SFCL will act as a protection for the network (**Figure 8**).

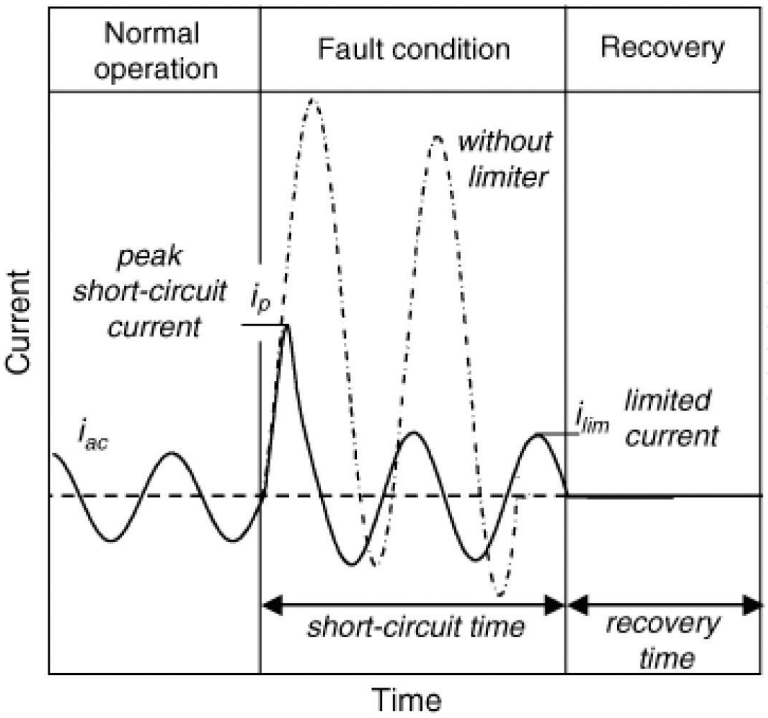


Figure 6. Plot showing how an SFCL works [16].

3.2. Superconducting magnetic storage energy systems (SMES)

Considering sustainable energy sources, there is a need to store the energy generated especially during peak periods, when most conditions at the renewable generating plant are favorable. SMES stores large energy in DC form as magnetic energy which is cycled indefinitely by the current flowing through the superconductor. SMES has power converter systems that convert DC to AC suitable for delivery to the utility bus as this makes it more reliable than other storage devices. For the purpose of superconductivity, the choice of inductors is chosen because the higher the current or the inductance, the more energy is stored. From Eq. (1), the entire volume integral is taken, because the number of turns of the inductor affects the energy:

$$E = \frac{1}{2\mu_0}\int B^2\, dv \tag{1}$$

A SMES system consists of four parts, which are the superconducting magnet (SCM), the power conditioning system (PCS), the cryogenic system (CS), and the control unit (CU) [17]. The first superconducting SMES application operating in a grid in the United States was a flexible AC transmission system [18]. The Bonneville Power Administration used a 30 MJ SMES in the 1980s. This SMES was operated for over 1200 h of energy transfers equivalent to 1 megacycle. One of the commonly adopted topologies of the SMES is the voltage source converter (VSC) shown in **Figure 7**, which is chosen based on its ability to control real and reactive power [19, 20]. This ability is a great tool used for reducing power fluctuations in renewable energy generation; hence, it is a more stable system. SMES are environmentally friendly, unlike batteries which depend on a chemical reaction and can act as a backup power supplier in case there is power loss from the main power supply (**Figure 7**).

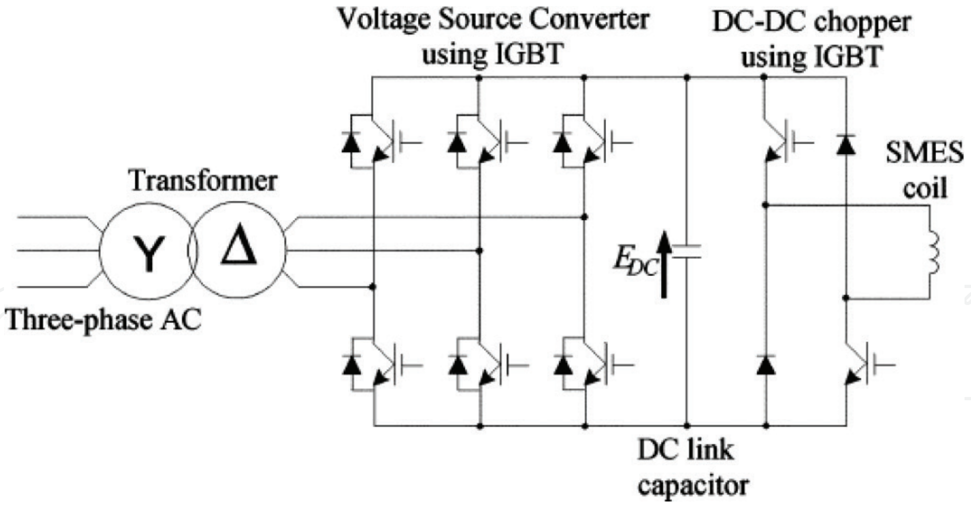


Figure 7. Schematic of a VSC SMES [21].

3.3. HTS cable

These are power cables that transmit power at lower transmission loss. There are two types of HTS cables, the direct current (DC) cable and alternating current (AC) cable. Discussing HTS Cable shown in **Figure 8**, this cable has the copper core that allows the flow of excess current in case there is a fault; the HTS tape is the superconducting layer; the high-voltage dielectric acts as an insulator, HTS shield tape, and copper shield wire; liquid nitrogen coolant flows within the inner cryostat wall and cools down the temperature below critical temperature; and the outer protective layer protects the entire assembly. Comparing HTS AC cables to conventional copper cables as discussed in [3], HTS cables can carry about 2–4 kA as Root Mean Square (RMS) voltage within the same cross section that carries 1 kA in copper. HTS cable design has current limiting capabilities. This encourages safe links between two more subnetworks in the grid in order to provide an alternative means of power supply in a power failure situation. HTS cables are light in weight and have increased capacitive charging length due to its high-line charging current.

At high frequencies AC cables are prone to AC losses generated by the power source and converters; this is the reason why superconducting DC cables improve the efficiency of electricity transmission and distribution network. Superconducting DC cables have four major parts (a) the voltage insulation, (b) the HTS superconducting tape, (c) the cryogenic envelope, and (d) the cooling fluid [22]. Other special advantages of high-voltage DC (HVDC) cables are its non-electromagnetic radiation capabilities, its compact design, and the absence of heat emission to the environment. This cable is suitable for a wind farm and photovoltaic power generation that requires the transmission of DC. In the future, DC cables can help in resolving the densely loaded power grid in urban regions.

4. Environment impact

Predominant challenges of the power sector are load growth, environmental safety, power quality, and reliability. Some of the challenges of renewable energy sources are:

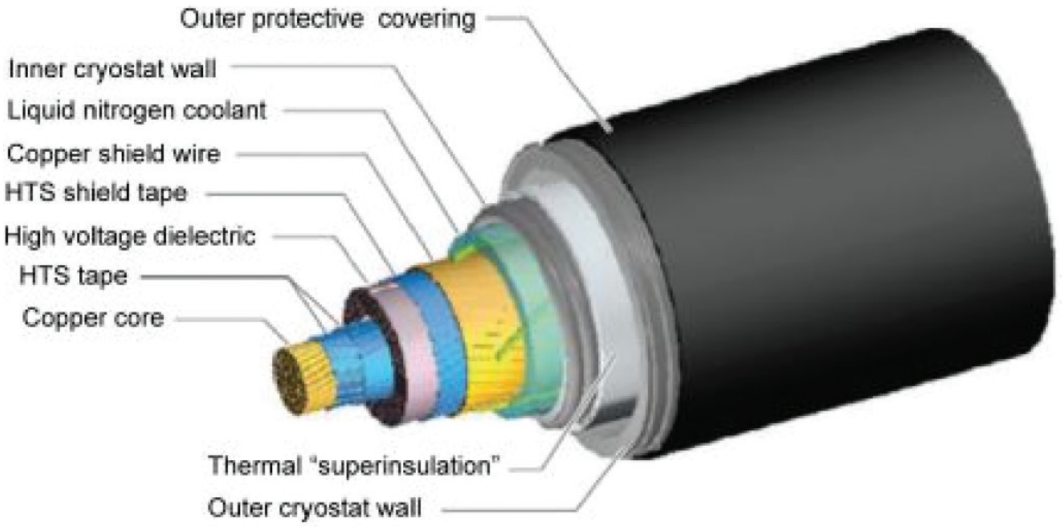


Figure 8. Cross section of an HTS AC single-core cable [23].

1. Its variance in energy production with time as renewable energy sources vary with seasons which is the reason why they have peak periods and low peak periods.
2. Its storm damage can be very destructive especially when the design is not strong enough to withstand at the level of storm.
3. The continuous availability of biomass for energy indirectly affects the richness of soil needed.
4. Most renewable energy sources produce DC which is the reason why superconducting DC cables are recommended for the future transmission. In order to use this energy in an AC grid, additional cost for SMES or inverters will be incurred.

4.1. Impact of renewable energy sources

In the United States, for aviation safety, Federal Aviation Administration (FAA) requires that wind generators should not be above 200 ft tall. In the US, the National Renewable Energy Laboratory carried out a survey of large wind facilities showing that between 30 and 141 acres/MW of power output capacity is used for large wind facilities. Moreover, less than 1 acre/MW are affected permanently, and less than 3.5 acres/MW are temporarily affected during construction [24]. The development of the wind energy generation site interrupts other biological activities in that environment. The unused part of the land at a generation site can serve other purposes like agriculture. Research has also shown that when wind speed is low, bats are more active; the change in air pressure around wind turbines has led some bat fatality. In order to reduce the fatality rate, wind turbine can be kept motionless at low speed [25].

Solar power land area requirements vary depending on the technology, the topography of the site, and the intensity of the solar resource. Land use for utility-scale PV systems ranges from

3.5 to 10 acres/MW. The unused portion of the land at a solar generation site cannot be used for other purposes due to the orientation of the photovoltaic cells. Solar energy generation in itself is a clean energy process, but the entire life cycle especially manufacturing and disposal processes contributes to global warming emission at a rate of 0.08–0.2 pounds of carbon dioxide/kWh which is still lower as compared to fossil foil power sources [26].

Hydropower generation has an extreme impact on ecology if its generation process involves flooding the land. Hydroelectric power from dams can result in the fatality of fishes if they come in contact with the turbine blades. Releasing of water periodically can also harm plants and animals downstream. The entire life cycle of hydropower generation is dependent on the region and generating plant, but it is estimated to be about 0.5 pounds of carbon dioxide/kWh [27].

4.2. Impact of superconductor applications

The following are the impact superconductivity on the environment:

1. Reduced right-of-way disruption makes it easily installed underground to avoid messing up urban cities with wires.
2. Lower voltage operation makes it less harmful to living things.
3. There is no electromagnetic radiation to the environment.
4. No heat emission to the environment.

4.3. Impact of smart grid on energy sustainability

Most existing utility grid is one way in direction; it lacks information about the system state and the load. Also, it involves the operator’s discretion to detect faults. Smart grid is the grid of the future because:

1. It is intelligent.
2. It involves two-way communication between the load (consumer) and the utility company.
3. It has sensors.
4. It is remote checked and has pervasive control.
5. It is self-healing and attacks resistance.
6. It gives consumers control.

Smart grid accommodates dynamism in the grid as it optimizes the use of its capital assets while reducing maintenance or operational cost.

5. Conclusion

In order to reduce the use of fossil fuel and reduce greenhouse gases in the future, it is proposed that renewable power sources be adopted. However, the introduction of new grid components may introduce fluctuations and instability to the grid. Superconducting power applications coupled with smart grid feature is the most promising solution for grid adjustments in the future as they are more reliable and ensure stability in the grid. Sustainable culture and skill need to be developed and maintained amidst citizens to reduce further power demand. More network installation should be carried out to review realistic situations, and more researches regarding reducing cryogenic cost are ongoing so that superconducting technology becomes marketable and less expensive.

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References

[1] SlidePlayer Inc, c18cof01 Magnetic Properties Iron single crystal photomicrographs. 2017

[2] http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf [Accessed: Febuary 12, 2017]

[3] Malozemoff AP. The Power Grid and the Impact of High-temperature Superconductor Technology: an overview. In: Superconductors in the Power Grid: Materials and Applications, Oxford, UK: Elsevier; 2015. pp. 3-28

[4] Ranjan S. How is electricity created and brought to people's home outlets?. Qph.ec.quoracdn.net, 2013. [Online]. Available: https://qph.ec.quoracdn.net/main-qimg-3bf5b97a0788435baa9f1fa37bc36d43 [Accessed: 17- Oct- 2017]

[5] Renewables 2016 global status report. http://www.ren21.net/wpcontent/uploads/2016/10/REN21_GSR2016_FullReport_en_11.pdf [Accessed: October 31, 2016]

[6] What Is Biomass. ReEnergy Holdings. N.p. 2017. Web. 27 Jan. 2017

[7] Renewable Energy Technologies: Cost Analysis Series. 2012. [Online]. Available: https://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-BIOMASS.pdf [Accessed: February 01, 2017]

[8] Energy Efficiency. 2005. [Online]. Available: http://www.mpoweruk.com/energy_efficiency.htm [Accessed: January 16, 2017]

[9] How Geothermal Energy Works. Union of Concerned Scientists. [Online]. Available: http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-geothermal-energy-works.html#.WKHoZUdf3cs [Accessed: February 13, 2017]

[10] Mims C. Can geothermal power compete with coal on price? Scientific American. 2017. [Online]. Available: https://www.scientificamerican.com/article/can-geothermal-power-compete-with-coal-on-price/ [Accessed: February 13, 2017]

[11] EIA-Electricity Data, Eia.gov, 2016. [Online]. Available: http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_1_a [Accessed: February 13, 2017]

[12] Maeda H, Yanagisawa Y. Recent development in high-temperature superconducting magnet technology (review). IEEE Transactions on Applied Superconductivity. 2014;**24**(3):1-12. DOI: 10.1109/TASC.2013.2287707

[13] Superconductors. Saylordotorg.github.io, 2012. [Online]. Available: https://saylordotorg.github.io/text_general-chemistry-principles-patterns-and-applications-v1.0/s16-07-superconductors.html. [Accessed: 17- Oct- 2017]

[14] Mukoyama S. Development of Superconducting Technologies for the Smart Grid. 2013. [Online]. Available: https://www.furukawa.co.jp/review/fr043/fr43_03.pdf [Accessed: February 05, 2017]

[15] Meerovich V, Sokolovsky V. High-temperature superconducting fault current limiters (FCLs) for power grid applications. In: Superconductors in the Power Grid: Materials and Applications. Oxford, UK: Elsevier; 2015. pp. 283-324

[16] Noe M, Steurer M. High-temperature superconductor fault current limiters: concepts, applications, and development status. Superconductor Science and Technology. 2007;**20**(3):R15-R29

[17] Sutanto D, Cheng KWE. Superconducting magnetic energy storage systems for power system applications. In: 2009 International Conference on Applied Superconductivity and Electromagnetic Devices, Chengdu. 2009. pp. 377-380. DOI: 10.1109/ASEMD. 2009. 5306614

[18] Tixador P. Superconducting magnetic energy storage: Status and perspective. IEEE/CSC& ESAS European Superconductivity News Forum. 2008;(3). Web. 8 Feb. 2017

[19] Superconducting Magnetic Energy Storage (SMES) | Superpower. Superpower-inc.com. N.p. 2017. Web. 8 Feb. 2017

[20] Ali MH, Wu B, Dougal RA. An overview of SMES applications in power and energy systems. IEEE Transactions on Sustainable Energy. April 2010;**1**(1):38-47. DOI: 10.1109/TSTE.2010.204490

[21] Sahoo A, Mohanty N, AM. Modeling and Simulation of Superconducting Magnetic Energy Storage Systems. International Journal of Power Electronics and Drive Systems (IJPEDS). 2015;**6**(3):524

[22] Bruzek CE, Allais A, Allweins K, Dickson D, Lallouet N, Marzahn E. Using superconducting DC cables to improve the efficiency of electricity transmission and distribution (T&D) networks: An overview. In: Superconductors in the Power Grid: Materials and Applications, Oxford, UK: Elsevier; 2015. pp. 189-224

[23] Malozemoff AP, Yuan J, Rey CM. High Temperature superconducting (HTS) AC cables for power grid applications. In: Superconductors in the Power Grid: Materials and Applications. Oxford, UK: Elsevier, 2015. pp. 139-140

[24] Environmental Impacts of Wind Power. Union of Concerned Scientists. 2013. [Online]. Available: http://www.ucsusa.org/clean-energy/renewable-energy/environmental-impacts-wind-power#.WJv-Nkdf3cs [Accessed: February 09, 2017]

[25] Effectiveness of changing wind turbine cut-in speed to reduce bat fatalities at wind facilities. 2009. [Online]. Available: http://www.batsandwind.org/pdf/Curtailment_2008_Final_Report.pdf [Accessed: February 09, 2017]

[26] Environmental Impacts of Solar Power. Union of Concerned Scientists. 2013. [Online]. Available: http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-solar-power.html#.WJwqIkdf3cs [Accessed: February 09, 2017]

[27] Environmental Impacts of Hydroelectric Power. 2013. [Online]. Available: http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-hydroelectric-power.html#.WJwvG0df3cs [Accessed: February 09, 2017]