Enhancement of Electrical Power Transmission Capacity by Smart Materials

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Abstract: *As the electric industries moves in to a more competitive environment with the introduction of open access transmission network, the transmission companies required to enlarge their transmission capacity and maintain a stable and secure transmission system. Due to problems associated with new transmission lines, it becomes necessary to upgrade existing transmission networks to increase the transmission capability. With the advancement of new technologies smart materials is the future of power industries to increase the transmission capacity.*

Keywords: transmission lines, smart materials, transmission capacity.

1. Introduction

With the increase in demand for electric energy, it is necessity for improvement in reliability and efficiency grows the electrical power. Transmission of AC voltage at generating end and it is far away from the receiving end substation. To increase the efficiency and to reduce the losses extra high voltage and HVDC transmission is used. In HVDC transmission the equipment used for conversion is expensive. The technical aspects of the challenges that will be posed by this rapid growth include both improving existing technology through engineering and inventing new technologies requiring new materials. Some materials advances will improve present technology and some will enable emerging technology (e.g., superconducting cables, fault current limiters, and transformers), and some will anticipate technologies that are still conceptual (e.g., storage for extensive solar or wind energy generation) [1].

1.1 Electrical Power Transmission Lines

To transmit electric power over long distances so losses will increase. The major loss, which can be reduced by increasing the voltage and decreasing the current. Corona losses are reduced by using bundled conductors in long EHV transmission lines. A step-up transformer is used at the generating end substation to step up the voltage. Long-distance transmission is typically done through overhead lines with voltages of 132 to 400 KV. Now at present 750 KV transmission is also employed. The power transmission capacity of an overhead line varies with the voltage and the transmission distance.

To avoid system failures, the amount of power flowing over each transmission line must remain below the line's capacity. The principal limitation on the capacity of a line is its temperature. As a line gets warmer, it sags, and in the worst cases, it can touch trees or the ground. Another factor is the mechanical strength of the support structure. Conductors with higher Strength-to-weight ratios for a given current-carrying capacity can increase the overall capacity of the right-of-way. Typically, the right-of-way for a 230 kV transmission line is 75–150 feet (23–46 m). Because of skin effect the standard material for overhead conductors in transmission systems is aluminum conductor steel reinforced (ACSR), which consists of fibers of aluminum twisted around a core of steel fibers. The steel core provides the mechanical strength, and the aluminum provides the electrical conductivity. A number of alternative composite cable materials have been developed over the past several years. The basic composite materials for the substitution of core support members include 1350 H19 aluminum, stainless steel, S-2 glass fibers, E glass fibers, epoxy, T-300 carbon fibers, and Kevlar 49 fibers. Recently, 3 M has been developed and Oak Ridge National Laboratory (ORNL) has been tested the designs of advanced overhead cables, using a composite core in place of the steel; this is an aluminum metal matrix containing Nextel fibers. The conductor wires are made of an aluminum–zirconium alloy; the zirconium precipitates, providing a dispersed strengthening to essentially pure (and thus high-conductivity) aluminum. Kirby26 points out that the improved composite conductor substituted for the traditional ACSR in an existing transmission line could carry up to three times the current without the need for tower modification or additional rights-of-way. The current objective is to develop a conductor to increase the capacity of existing corridors at five times that of ACSR. The ultimate goal is to achieve transmission corridor power densities for cables and conductors of 50 times that of ACSR by 2025. It is inevitable that an electrical grid built on such a huge scale in a patchwork manner over 100 years will have reliability issues. In addition to mechanical failures, overloading a line can create power supply instabilities such as phase or voltage fluctuations. For an ac power grid to remain stable, the frequency and phase of all power generation units must remain synchronous within narrow limits. A generator that drops 1.5 Hz below 50 Hz will rapidly build up enough heat in its bearings to destroy itself, so circuit breakers comes in role and sends a command to relay to trip the breaker. It indicates instability in the grid, a 30 mHz drop in frequency reduces power delivered by 1.4 GW. The fig. (1.0) below shows the total energy demand and requirement in Chhattisgarh grid India [10]. The table 1.1 & 1.2 shows the energy demand continuously increasing; the total installed capacity has to be increase 18.46 % in one year as compared to July 2013 to July 2014 and increase in total energy requirement for Chhattisgarh grid is 8.48%.
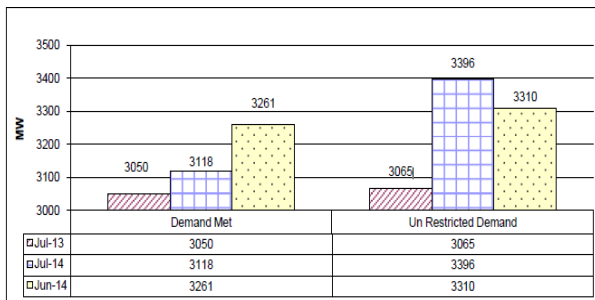
Figure 1: Energy Demand in Chhattisgarh Grid

1.2 Chhattisgarh Grid for the Month of July-2014

Table 1: Installed Capacity of SGS & Share from Central Sector

Installed Capacity (MW)	State Sector Gen. Stations (MW)	Central Sector Share (MW)	Total
July/14	2418.7	1190.92	3609.62
July/13	1918.7	1128.38	3047.08
% Increase	26.06%	5.54%	18.46%

Table 2: Energy Requirement (MUs)

Energy	Requirement (In MU)	Total Supply (upto 132 KV) (In MU)
July/14	1750.72	1706.16
July/13	1613.81	1602.08
% Increase	8.48%	6.50%

2. Smart Materials

The future of power grid is Smart materials to give it the ability to self-recover with fast response in milliseconds under any power quality events. Each component of smart material has intelligent to make self-recovery. The reconfigurable power electronic devices with a distributed controller to function as high-speed switches to redirect power flow is most variably used and they must also have an overall architecture suitable to the new control/communication paradigm. Finally, these components must possess a fault-tolerant; agent based collaborative intelligence at the lower level of the system.

Smart materials and structures (SMS) is the one class of materials having the unique capability to sense and physically respond to changes in the environment, changes in temperature, pH, or magnetic field, for example. Generally consisting of a sensor, an actuator, and a processor, SMS devices based on such materials as piezoelectric polymers, shape-memory alloys, hydro gels, and fiber optics can function autonomously in an almost biological manner. Smart materials have already appeared in a number of consumer products and are being studied extensively for aircraft, aerospace, automotive, electronics, and medical applications. SMS hold promise for real-time condition assessment of critical power plant components, allowing continuous monitoring of remaining life and timely maintenance and component replacement in the electric power field. The Control of power plant could be done rapidly and automatically with smart systems to inject chemicals that counter pollutants or chemical imbalances.

Control of NOx creation in boilers could be accomplished by adjusting the combustion process with sensor and activation devices distributed at different boiler locations. For the transmission wires used in the electric power industry, smart materials could be utilized to monitor the condition of conductors, breakers, and transformers to avoid outages. To avoid potentially catastrophic sub synchronous resonance in generating units and to adjust transmission line loads according to real-time thermal measurements Smart materials could be used. Critical capability gaps are related to integrating smart materials into sensors, actuators, and processors; embedding the SMS components into the structure to be controlled; and facilitating communication between smart structure components and the external world.

Include piezoelectric ceramics and polymers are materials, such as lead zirconate titanate ceramics and polyvinylidene fluoride polymers that react to physical pressure. They can be used as either sensors or actuators, depending on their polarity. Shape-memory alloys are metal alloys, such as nitinol, that can serve as actuators by undergoing a phase transition at a specific temperature and reverting to their original, unreformed shape [4]. Shape-memory polymers are a class of elastomeric-like polymers, such as polyurethane, that actuate by relaxing to their unreformed shape when heated above their glass transition temperatures. Conductive polymers are polymers that undergo dimensional changes upon exposure to an electric field. These versatile materials can be used as sensors and actuators, but also as conductors, insulators, and shields against electromagnetic interference. Electro rheological fluids are materials containing polarized particles in a non conducting fluid that stiffens when exposed to an electric field. As such, they can be used in advanced actuators. Magneto restrictive materials include molecular ferromagnetic materials and other metallic alloys that change dimensions when exposed to a magnetic field. Polymeric biomaterials are synthetic, muscle-like fibers, such as polypeptides, that contract and expand in response to temperature or chemical changes in their environment. Hydro gels are cross-linked polymer networks that change shape in response to changes in electric fields, light, electromagnetic radiation, temperature, or pH. Fiber optics is fine glass fibers that signal environmental change through analysis of light transmitted through them.

The most versatile sensor material, optical fibers can indicate changes in force, pressure, density, temperature, radiation, magnetic field, and electric current. These materials, when matched to an appropriate application, provide the base functionality for both simple and higher level smart structures and systems. Sensory structures, such as optical fibers embedded in concrete bridge support pillars, only furnish information about system states; with no actuator, they are able to monitor the health of the structure but cannot physically respond to improve the situation. Adaptive structures contain actuators that enable controlled alteration of system states or characteristics; electro rheological materials, for example, can damp out vibrations in rotating mechanical systems when an electric field is applied. Controlled structures provide feedback between sensors and

actuators, allowing the structure to be fine-tuned continuously and in real time. Examples of higher-level smart structures and systems that can be built from smart materials and utilized in the power grid include flexible alternating-current transmission (FACTS), high-voltage direct current transmission systems, and dynamic line rating. Flexible ac transmission (FACTS) devices are a family of solid-state power control devices that provide enhanced dynamic control of the voltage, impedance, and phase angle of high-voltage ac transmission lines. FACTS controllers act like integrated circuits. By applying FACTS devices, utilities can increase the capacity of individual transmission lines by up to 60% and improve system. There is a need to reduce the costs of FACTS technology to provide for larger use. One method for reducing the costs is to replace the silicon-based power electronics with wide-bandgap semiconductors such as silicon carbide (SiC), gallium nitride (GaN), and diamond. High-voltage direct-current (HVDC) transmission systems are based on to rectify the ac and then conversion back to ac at the other end of the transmission line[3]. Modern power systems are based on thyristor valves (solid-state power control devices) to perform the ac to dc/ac conversions. Conventional HVDC transmission systems have been built with power transfer capacities of 3000 MW and ±750 kV. A new class of HVDC converter technology, referred to as voltage source converters, introduced in the past few years. These devices are based on gate turn-off and turn on switching technology or insulated gate bipolar transistors (IGBT) and are capable of higher switching frequencies. HVDC transmission is used for long-distance bulk power over head transmission or for long submarine cable crossings [9].

Dynamic line rating could enable increased power flow over existing transmission lines. The maximum power that can be carried by a transmission line is ultimately determined by the line heats up and expands. Most thermal ratings today are static in the sense that they are not changed through the year. For such ratings to be reliable, they must be based on worst-case weather conditions, including both temperature and wind velocity. In contrast, dynamic line ratings use real-time knowledge about weather or line sag to determine power can be transmitted safely. Typically, a dynamically monitored line can increase its allowable power flow by 9 –14 % over that allowed by static ratings.

Incorporating smart materials and higher-level smart structures and systems into the grid will require the development of advanced hardware components. These include advanced meters, advanced sensors and monitors, advanced motors (including superconducting motors), advanced transformers (including the concept of a universal transformer that would be a standardized portable design, a FACTS phase- shifting transformer capable of controlling power flow, and next-generation transformers using solid-state devices and high-temperature superconductors), power electronics (including FACTS, which include DSATCOM, DVR that controls reactive power flow, solid-state breakers, switchgear, and fault current limiters), computers and networks, mobile devices, and smart equipment and appliances [8]. Advanced hardware includes both cable and

storage options. Among advanced cables are gas-insulated lines for underground cables, advanced composite conductors (which are lighter and carrying more current than the current ACSR conductors), and high-temperature superconductors [9]. It is pointed out that these could also revolutionize generators, transformers, and fault current limiters. Potential developments in electric storage include superconducting magnetic energy storage (SMES), advanced flywheels using composites and/or superconductors for higher efficiency and capacity, flow batteries that charge and discharge fluid between tanks, and liquid molten sulfur batteries built to utility scale.

3. Nanotechnology

Nanoparticals are objects with all three external dimensions at nano scales. This area relates the behavior and properties of various materials with aspects of their molecular, supramolecular or macromolecular structure and their physical and chemical characteristics at the atomic or molecular level. Imaging / characterization of nanomatrials is an essential parts of nanoscience. The development of nanotechnology in energy application is geared toward directions in to nonmaterial's for energy storage and nanotechnology for energy saving. Owing to the advantages of high reactivity, large surface area (200–2200 m^2/g), self-assembly (1 to 4-nm active catalyst), super crystal characteristics (10 to 32-nm nanostructures), and special opto-electronic effects of nonmaterial for energy saving, several countries are heavily engaged in the development of energy-related nonmaterial's. There is an expectation that nanotechnologies will enable the development of power storage systems with energy densities that are at least several times higher than those of current batteries. Because of the small dimensions (5–20 nm), high specific surface areas, and special optical properties of nonmaterial's, nanotechnology for energy saving is expected to increase with the contact area of the medium. This will shorten response time and improve thermal conductivity by a factor of two. Nanotechnology applications for energy storage include using nanoparticles and nanotubes for batteries and fuel cells. Nanotechnology is being used to better the performance of rechargeable batteries through the study of molecular electrochemical behavior. Newly patented lithium ion batteries that use nanosized lithium titanate can provide 10–100 times greater charging/discharging rates than current conventional batteries. Other new batteries that apply nanotechnology could provide added power and storage capabilities by applying a concept based on mechanical resonance using a single microelectromechanical systems (MEMS) device; such devices use the combined technology of computers and mechanical devices to improve the power density, offering significant benefits for portable equipment.

4. Future Opportunities and Challenges

The following issues must be addressed for future opportunities such as low-cost, practical electric and thermal energy storage; micro grids, ac and dc, including both self-contained, cellular, and universal energy systems and larger building- or campus-sized systems; advanced (post-silicon) power electronics devices (valves) to be embedded into flexible ac and dc transmission and distribution circuit

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breakers, short-circuit current limiters, and power electronics-based transformers; power electronic-based distribution network devices with integrated sensors and communications; safe communications that are transparent and integrated into the power system; cost-competitive fuel cell; low-cost sensors to monitor system components and to provide the basis for state estimation in real time; cost-effective integrated thermal storage (heating and cooling) devices; thermal appliances that provide "plug-and-play" capability with distributed generation devices; high-efficiency lighting, refrigerators, motors, and cooling; enhanced portability through improved storage and power conversion devices; efficient, reliable, cost-effective plug-in hybrid electric vehicles (PHEVs); technologies and systems that enable "hardened" end-use devices; conductors that enable greatly increased power flow capability; smart, green, zero-energy buildings; and thermoelectric devices that convert heat directly to electricity. However, these technologies will require sustained funding and commitment to research, development, and demonstration. Given the state of the art in electricity infrastructure security and control, creating a smart grid with self-healing capabilities is no longer a distant dream; considerable progress has been made toward this goal. Both the technical and economic paradoxes can be resolved through knowledge and technology.

5. Conclusion

Smart materials are very useful to increase the power transmission capacity and losses can be greatly reduced. With the use of FACTS devices and smart materials the power quality of power system can be improved. In future, smart materials and structures are expected to appear in applications that span the entire electric power system, from power plant to end user. Smart materials, in their versatility, could be used to monitor the integrity of overhead conductor splices, suppress noise from transformers and large power plant cooling fans, reduce cavitations erosion in pumps and hydro turbines, or allow nuclear plants to better handle structural loads during earthquakes. Nano materials are extremely important materials for a wide range of applications. These materials have experienced enormous growth in size and sophistification of both scientific base and technological and commercial developments.

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