Super conductivity and super conductor engineering essay

Engineering

The conventional AC power system is Voltage Sourced Voltage Intensive power system. The equivalent dual for such a system is a Current Sourced Current Intensive power system. The complete dual relationship between the two systems is summarized in Table 1. The key enabling technology for the Current Sourced Current Intensive power systems is the existence of the superconductors. The superconductors transmit the high (i. e. intense) current with zero resistance which means an ideal power transmission process. Table 1

Conventional system

New system

(Superconductor based)

Voltage IntensiveCurrent IntensiveVoltage SourceCurrent SourceBased on near ideal voltage insulatorBased on near ideal current conductorLoads in parallelLoads in seriesLow impedance fault conditionHigh impedance fault conditionHigh fault currentsHigh fault voltagesFault removal by opening(breaking)Fault removal by shorting(making or crowbarring)Voltage tolerances small(voltage regulation) but current tolerances large(breaker current setting)Current tolerances small(Current regulation) but voltage tolerances large(crowbar voltage setting)Catastrophic faults fuse out the conductor(evaporate) the conductor into open circuitCatastrophic faults short out the insulator(arc over the insulator to maintain current continuity)This report presented a summary for superconductivity concepts, super conductors' wires and superconductor cables, High temperature super conductors and superconducting magnetic energy storage as presented in [1]. The report is outlined as shown below. Figure . Conventional Power

System(Voltage Sourced Voltage Intensive)Figure . New Power System(Current sourced Current Intensive)Table of Contents

Superconductivity

Superconductivity is a phenomenon of exactly zero electrical resistance and expulsion of magnetic fields which takes place in certain materials when it is cooled below a characteristic critical temperature. It was discovered by Dutch physicist Heike Kamerlingh Onnes on April 8, 1911 in Leiden[2].

Reason for superconductivity

The electrical resistivity of a metallic conductor decreases as temperature decreased. In ordinary conductors, such as copper or silver, this decrease is limited by the conductor impurities and other defects. Even near absolute zero, a real sample of a normal conductor shows some resistance. In a superconductor, the resistance drops abruptly to zero when the material is cooled below its critical temperature. An electric current flowing in a loop of superconducting wire can persist indefinitely with no power source.

Meissner effect

The Meissner effect was discovered in 1933 by German physicists Walther Meissner and Robert Ochsenfeld. The Meissner effect is a phenomenon in quantum physics in which a superconductor negates all magnetic fields inside of the superconducting material. It does this by creating small currents along the surface of the superconductor, which has the effect of cancelling out all magnetic fields that would come in contact with the material. One of the most intriguing aspects of the Meissner effect is that it allows for a process that has come to be called quantum levitation[3].

Figure . A magnet levitating above a superconductor cooled by liquid nitrogen

Classification for superconductors

The super conductor can be classified by their critical temperature

High temperature super conductors

Generally considered if they reach the superconducting state by just cooling them with liquid nitrogen, that is, if Tc > 77 K.

Low temperature super conductors

Generally, the superconductors need other techniques to be cooled under their critical temperature.

Superconductor applications

Superconductive Generators

The super conductors can be used in building superconductive generators. The use of super inductor would increase the size of the machine since it can carry more current and reduce the operating voltage which means smaller insulators.

Superconductor in Magnetic resonance Imaging

The current state of the art technology in the Magnetic resonance imaging machines requires high main magnetic field which could be as high as 11 Tesla [4]. To produce such high magnetic field value within a large air core superconductor wires are the only suitable candidate to be used. The superconductor wires are used to form the main field coils and they have to be coiled using cryogens to maintain the zero resistance value.

Super conductor cables

The longest installed superconductor cable is about 1km long which is connecting two transformers in Ruhr city of Essen [5]. There are also a demonstration of superconducting cable technology at Brookhaven National Laboratory. The cable is rated at 138kV; 1000MVA ad was 115m long which is epically designed for AC transmission. Another DC superconductor cable is developed at Las Alamos Scientific Laboratory which is operating at 100kV to transmit 1 to 10 GW of power. The super conductor cables could be used in voltage sourced current intensive system and current sourced current intensive as following.

Super conductor cables in Voltage sourced Current Intensive system

The main challenge in such a system is to control the short circuit current. Cryo-stable cables can be used where it has two modes of operation, the normal mode where the power is delivered to the load using the super conductor. at short circuit the superconductor is quenched so the super conductor cable restore its non-super conducting state and it has a finite non-zero resistance value which limits the short circuit current.

Super conductor cables in Current Sourced Current Intensive systems

The Current sourced current intensive systems are series system. All the system elements are series connected in closed loop form. In HVDC transmission system, the converter bridges are connected in series to achieve the optimum DC transmission voltage. The basic series system which is shown in Fig. 1 is an extension for this concept. In the shown system, the current is controlled by one converter while the rest of the converters are working in voltage control mode to satisfy Kirchhoff voltage law. Due to such configuration, the converters can easily be added to or removed from the system and the power could easily be reversed. It is not necessary to have circuit breaker in this system. The power is independently controlled in each converter station. If the shown configuration is implemented using normal copper or aluminum conductors it will suffer from the following problems. Low efficiency. Isolation for the med point stationHigh reactive power requirement in the ac side. By implementing super conductor wires/cables, the above mentioned limitation could be avoided. The efficiency is reaching 100% since the losses is almost zero in the super conductors. The med point station isolation is no longer a big challenge as the voltage level is no higher than 5-10 kV. Reactive power could be independently controlled due to recent development in high power switching devices. Figure . Current Sourced Current Intensive power system architecture

Superconductors in Magnetic Energy Storage (SMES)

Superconductors are used in the utility power system as magnetic energy storage which can be used to store electric energy and use it during peak demand. The injection of brief bursts of power plays a crucial role in maintaining grid reliability especially with today's increasingly congested power lines and the high penetration of renewable energy sources, such as wind and solar. There are several reasons for using superconducting magnetic energy storage instead of other energy storage methods.

Advantages of SMES in CSCI systems

Very small time constant

The most important advantage of SMES is that the time delay during charge and discharge is quite short. Power is available almost instantaneously and very high power output can be provided for a brief period of time. Other energy storage methods, such as pumped hydro or compressed air have a substantial time delay associated with the energy conversion of stored mechanical energy back into electricity. Thus if a customer's demand is immediate, SMES is a viable option. When SMES is used in a current sourced current intensive power system grid as shown in Fig. 1 its current is controlled by one of the converters. Each converter can be either a rectifier or an inverter. In the presented circuit configuration, each converter or the SMES can easily be added or removed by shorting them and the converter power could be reversed. The power is controlled independently without the need for a high load dispatch control. Circuit makers are used for fault removal while circuit breakers are no longer needed. SMES high inductance value is used to stabilize the system at sudden load variation. When the load power changes, SMRS is compensating for this power change using its stored magnetic energy. Due to this fast dynamic power compensation, the grid current is considered constant over a short period of time (minutes).

Load leveling

Using SMES will help in reducing the size of the generating units. SMES is being able to do this maintaining a constant value for load current. SMES is being charged during low load demand and discharged during high load demand.

Power recovery of 100% efficiency

Another advantage is that the loss of power is less than other storage methods because electric currents encounter almost no resistance. Additionally the main parts in a SMES are motionless, which results in high reliability.

Limited environmental impact

Environmentally beneficial as compared to batteries; superconductivity does not rely on a chemical reaction and no toxins are produced in the process

Current sourced current intensive systems operation concerns

Safety

The safety of this system is a big concern as the superconductor could quench at moment and loses its zero resistance properties and get converted to a normal conductor with high resistance which is a problem in the current sourced power system. Superconductor shielding can be a solution for this problem as shown in Fig. 2. Another solution is by separation of the load from the CSCI system by use of distribution lines. Figure . Shielded CSCI power system

High current switching

The power electronics devices switching could be problematic is in CSCI systems. This results from the fact that the current has high values. One solution for this problem is to use superconductive switches. The control signal for the superconductor switch could take two formsHeat injection techniqueA small amount of heat in applied on the superconductor to cause some resistance. This resistance will result in an ohmic losses in the superconductor therefor a positive feedback cycle starts and the superconductor turns to be a conductor with a high resistance finally, the current path is opened. To close the current path again, the superconductor is cooled back to restore its superconductor state. Magnetic quenching methodsA magnetic field greater than the critical magnetic field of the superconductor is applied the super conductor goes into normal regime and the current path is opened.

High Magnetic Field

High magnetic field due to high currents may be hazardous to personal and instruments around. However, using superconductive shielding techniques most of the magnetic effect can be eliminated. When a magnetic field exists on the surface of superconductor, surface currents are created. These currents impose an equivalent opposite field. Therefore, the outside field cannot cross through the superconductor. Shielding the superconductor can be accomplished in a coaxial structure as shown in Fig. 2.

Superconducting switches

Switching of high currents for power transfer to and from the CSCI loop is problematic. Semiconductor switch loses become significant due to conduction voltage drops. One solution to this problem may be to use superconductive switches which were described previously.

Maglev and CSCI

CSCI technology can be combined with other developing superconductor technologies. One of these is the Maglev(Magnetic Levitation Train). Maglev network for transportation which may replace heavily traveled short air routes, has been proposed by the U. S Department of Energy. The system will use superconductors for magnetic levitation. The corridor of this system may also be used for a CSCI power system. Therefore, Maglev network and CSCI system would share the same superconducting power transmission technology that may result in added economic advantage[6]. As an example the Dallas-Austin corridor which is indicated in a Department of Energy’s Argonne National Laboratory report, is well suited for such a system combination. Figure . JR-Maglev EDS suspension is due to the magnetic fields induced either side of the vehicle by the passage of the vehicle's superconducting magnets[6]Figure . EDS Maglev propulsion via propulsion coils[6]