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Protection of Solid State Transformers in Charging of Electric Vehicles

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Abstract:

Due to the increasing integration of renewable energies into the distribution grid, a deterioration of the grid power quality is expected. One of the constraints to further DC distribution system development is the lack of practical fast DC circuit breaker. One of the major contributions of industrial technology is the invention of automobiles with heat engines. Automobiles in vast numbers are posing severe problems for society and humanity. The adverse consequences include a reduction in petroleum supplies, a reduction in air quality, and a significant increase in global warming. Electric, hybrid electric, and fuel cell-based drive train systems have long been regarded as the most exciting possible alternatives to the issue of land transportation. The development of solid state transformers (SST's) is based on Silicon carbide devices that are able to block higher voltages, switch faster than silicon (si) power devices. The Grid is stressed by electric vehicle charging systems and renewable generation causing voltage variations and SST's are the solution. In this paper, DC breaker protection is discussed for various types of solid state transformer based charging of electric vehicles.

Keywords *solid state transformer(SST),Low frequency transformer(LFT), Battery energy storage system (BESS), DC circuit breaker.*

I. INTRODUCTION

The DC grid has a lot of advantages, one main problem of has hindered its development, that is the difficulty of the fault current interrupting.Compared with AC grid, there is no natural current-zerocrossing in the DC grid, so most of AC breakers are not feasible. In Fig. 1, the equivalent circuit for DC grid during the occurrence of short circuit fault is shown Fig.1. AC grid has large generators and transformers that both offer ahigh inductance thereby limiting the short current. In contract to AC system, there is no such high inductance in a DC grid.So the

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short circuit current will increase faster and higher. . In fact the real DC shortcurrent will be limited by the DC source converter .The paper proposes a novel dc breaker that is adding the poles in series and increase the resistance and there by decreasing the arc resistance and qunching the arc is the best way to mitigate the arc.Normal traditional methods using power converters were not able to handle high power ratings at that point using the ABB DC breakers were the solution .

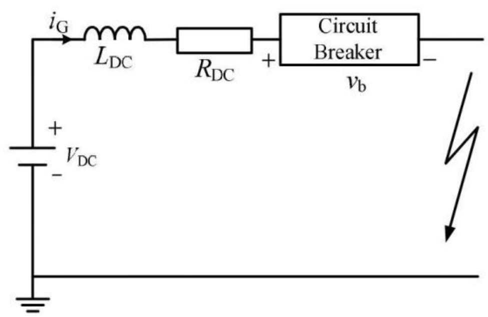

Fig.1. DC Breaker equivalent circuit [1]

Solid state transformers have rapidly advanced over the last two decades, and they are now being used in traction applications for replacement of low frequency transformer that leads to weight and volume reduction and significant reliability gains can be achieved.[2].The SST can be used to charge the electric bus by replacing the conventional transformer. The **Figure 2** below shows the solid state transformer's block diagram.

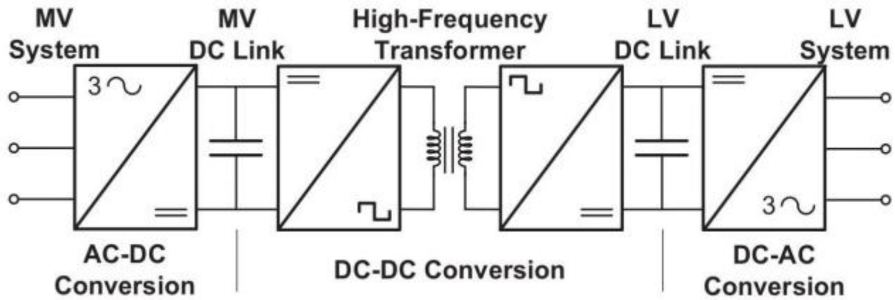

Fig. 2. The solid state transformer's block diagram [3]

The SST architecture has provision for supplying power to DC loads . The SST arrangement includes AC-DC,DC-DC and DC-AC stages of conversion an efficiency of .ηSST = η2AC-DC · ηDC-DC =94% is predicted [4]

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II. Solid State Transformer Concept

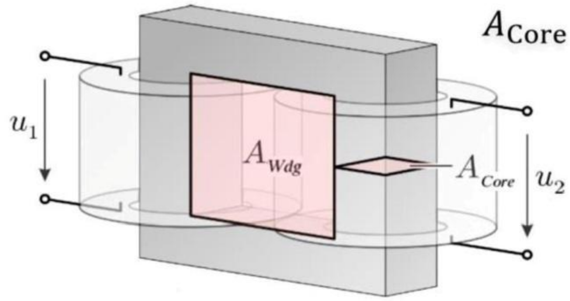


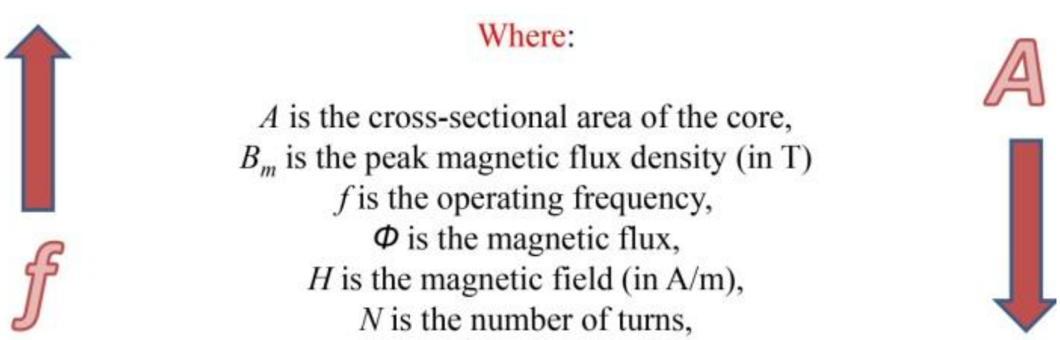
Fig. 3. Transformer core [5]

- Area Product: $A_{Core}A_{Wdg} = \frac{\sqrt{2}}{\pi}\frac{P_t}{k_W J_{rms} \hat{B}_{max} f}$
- **Volume:** $V \propto (A_{Core}A_{Wdg})^{\frac{3}{4}} \propto \frac{1}{f^{3/4}}$ (1)

The volume of the core reduces as the frequency rises. Frequency conversion necessitates the use of power electronics. As can be seen from the area product, increasing the operating frequency of a transformer allows for a reduction in volume and weight without increasing the winding current density J_{RMS} and/or the overall core flux density B_{MAXT} (and thus degrading the efficiency).ie the product of the central cross section area A_{CORE} and the winding window area A_{WDG}, which determines the relationship between the physical size and/or volume of a transformer and the power to be transmitted, as seen in equation-1. where f denotes the transformer operating frequency and k_W denotes the winding window filling factor.[6]

The design equation of the transformers is shown in equation -2.

$$V_{pri} = \sqrt{2} \cdot \pi \cdot f \cdot N_{pri} \cdot \varphi_m = 4.44 \cdot f \cdot N_{pri} \cdot B_m \cdot A \quad (2)$$



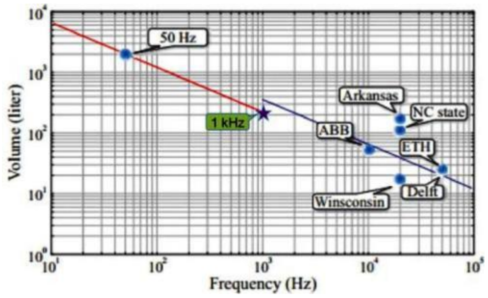
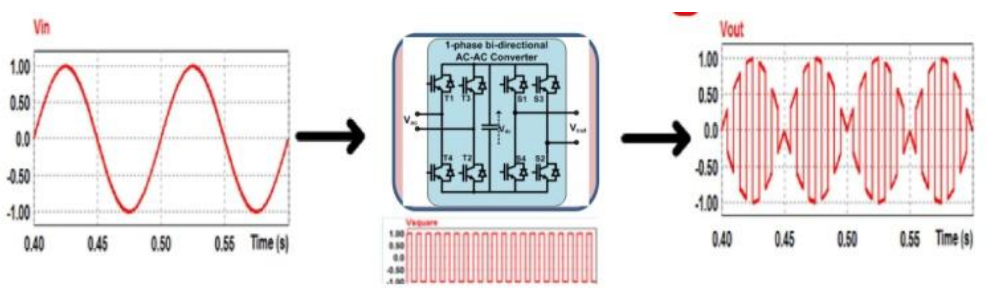


Fig. 4. For different designs ,volumes [7]

SSTs are ideally suited to systems with volume and weight constraints, as well as higher power transfer efficiencies. link to MV (as opposed to other discrete power electronic converters that use a low-voltage (LV) input controllability of future differentiation with MF transformers (as opposed to conventional LF transformers). Controllability is a function of an SST, which means it can regulate the input and output voltages and currents (and, in most cases, the output frequency) as well as power flows, and it can shield loads from power system disruptions or the power system from load disturbances. In **Figure 5** the red line uses the silicon steel core and the blue line uses other core materials like ferrite etc. Using silicon core material we can go to frequencies of 1 to1.5 KHZ.

III. Mathematical modelling single phase: (low frequency AC to high frequency AC transformation)



$$V_{in} = \sqrt{2} \cdot V_{in,rms} \cdot sin(\omega_s \cdot t) \times S_{square} = \frac{4}{\pi} \cdot \sum_{n=1,3,5...}^{\infty} \frac{1}{n} cos(n \cdot \omega_{sq} \cdot t)$$

$$= V_{out} = V_{in,rms} \cdot \begin{bmatrix} 0.9 \cdot sin(\{\omega_{sq} \pm \omega_s\} \cdot t) \\ +0.23 \cdot sin(\{3\omega_{sq} \pm \omega_s\} \cdot t) \\ +0.15 \cdot sin(\{5\omega_{sq} \pm \omega_s\} \cdot t) \\ + high\ order\ terms \end{bmatrix}$$

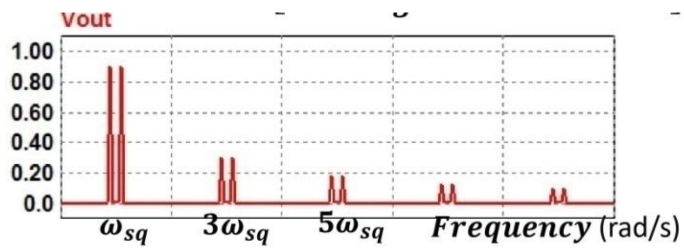


Fig .5. Output voltage vs Frequency[8]

IV. Methodology

The proposed system was modelled in MATLAB and simulink [9].In the proposed battery management system string 1 and string -2 are charging the batterys from grid of 11Kv and they give a voltage of 800V DC they are ready for charging the electric vehicles .The EVs can be flipped such that which string is having energy is engaged This increases the reliability and efficiency as the number of converters reduced between the EV and battery storage.

V.1 MVA, 11 kVAC / 415 V AC and 800V DC Solid-State Transformer:

For voltage scaling and galvanic separation, today's power grids depend on passive transformers operating at 50 Hz or 60 Hz. Although these components succeed in terms of performance and dependability, their passive design severely restricts control options. SSTs are power electronic networks that link medium-voltage grids to local low-voltage AC or DC delivery systems or microgrids. SSTs offer voltage level translation and galvanic separation, as well as a high degree of controllability and stability, allowing for additional features such as reactive power compensation, active harmonic filtering, peak load sharing, and so on.Here i considered the performance and power density of the considered bidirectional distribution-level SST systems. Grid voltages of 11 kV and 415 V are considered, with a power spectrum of about 1 MVA. The optimum Si IGBT blocking voltages for the described voltage levels in terms of efficiency and power density have been discovered to be 1200 V or 1700 V. One fully rated 80 kW converter cell has been realised, despite the fact that four cascaded converter cells are needed per phase[10]

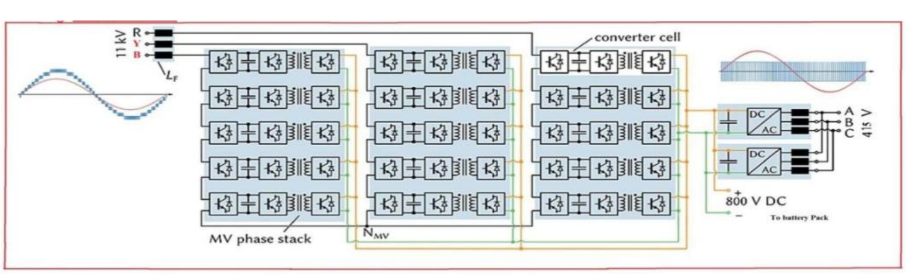


Fig. 6. circuit topology of SST.[10]

VI. Simulation-Results

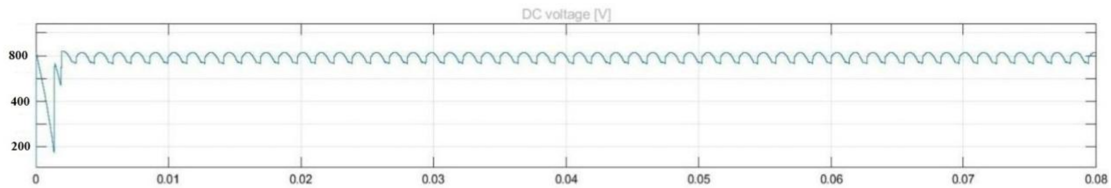


Fig. 7. DC output voltage of SST[9]

VII. Implementation in solid state tranformer based conductive charging method :

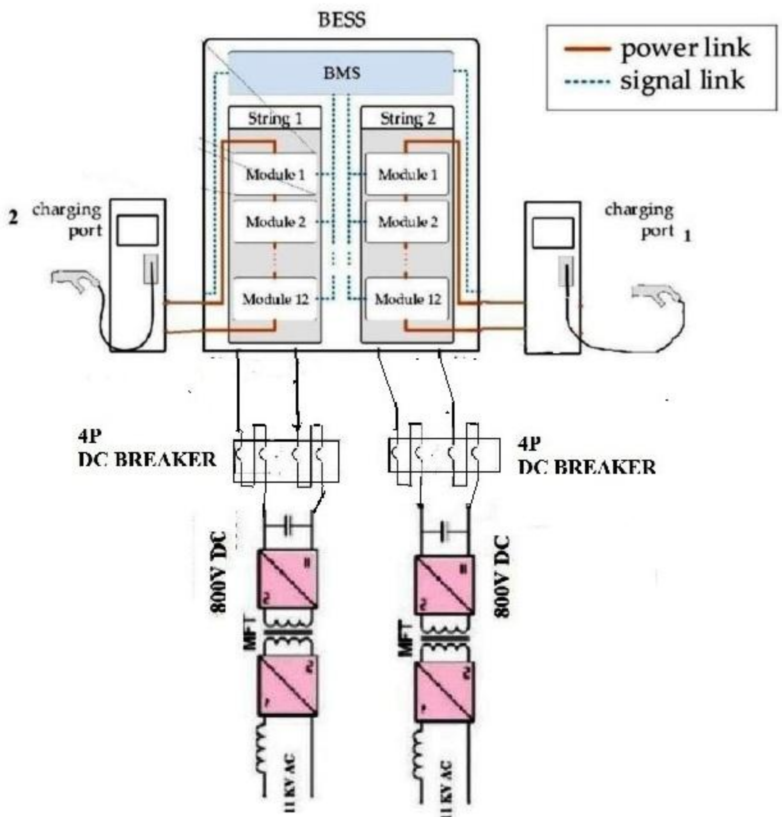


Fig .8. SST Based conductive charging with 4P DC breaker[11]

In figure 8 Evs are plugged in at the charging port which serves as a interface to the BESS.String-1 is charging the EV and string-2 is recharged through a grid connected[11] SST. We know the fact that the LFT which supplies the power in the charging infrastructure substation is bulky and it does not have any fault handling .soild state transfomer can do above defects .It will charge the strings and then strings supply the DC power to Evs.But proposed design shown in fig 8 supply power to Evs thru strings mainly to reduce the waiting times of the Evs as the

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number is incresing year by year and reduce the burden on grid and avoid the charging infratsruture upgrade .This also reduces the cost of paying charge to the grid owners beacuse of the storage provided.In SST based conductive charging system, 4P DC breaker is used ,in this two poles are made in series each such that resistance of the arc increases then it is quenched .The fig 8 consists of two 4P dc breakers for each SST They are two SSTs for enhancing the reliability of the system.

VIII.**Implementation in solid state tranformer based wireless charging method**

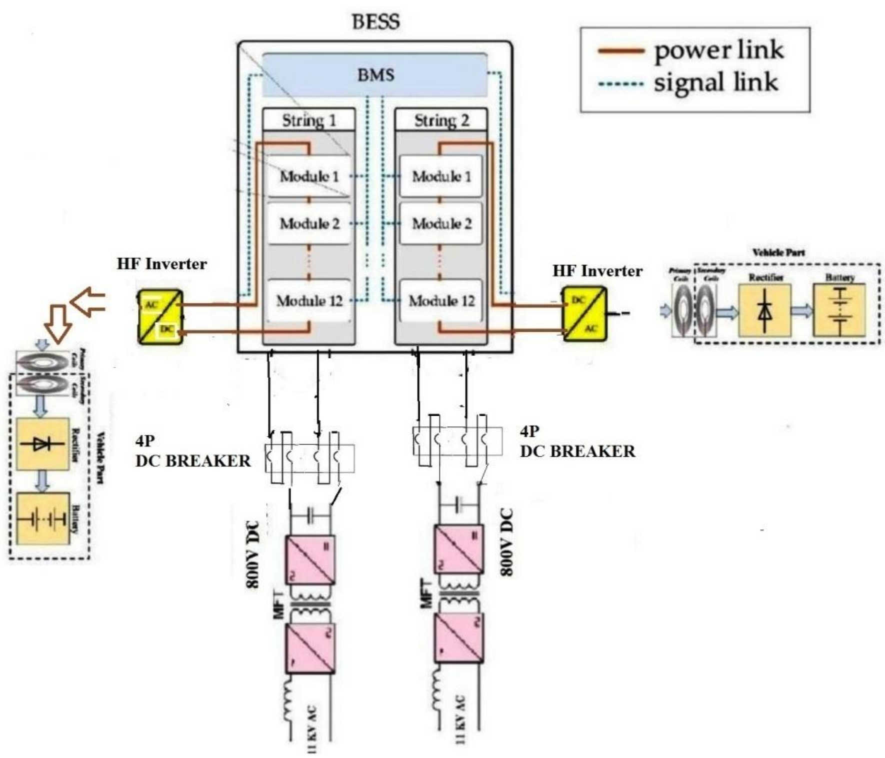

Fig.9.SST based wireless charging with 4P dc Breaker[11-12]

Here the AC power is transferred to electric vehicle using the principle of mutual induction or transformer action.[12] .LFT is replaced by SST for better controllability and compactness and good regulation of output DC voltage In this two solid state transformers are used one is to convert the grid voltage to DC and to charge the battery string-1 and the other is to supply the dc power to electric vehicle .This reduces the grid burden.F**ig 9 shows wireless ch**arging system with 4P DC breaker .Two SST were used with 4P DC breaker each .This will enhance the reliability of the charging system.

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IX.Implementation in Dynamic charging of electric vehicles

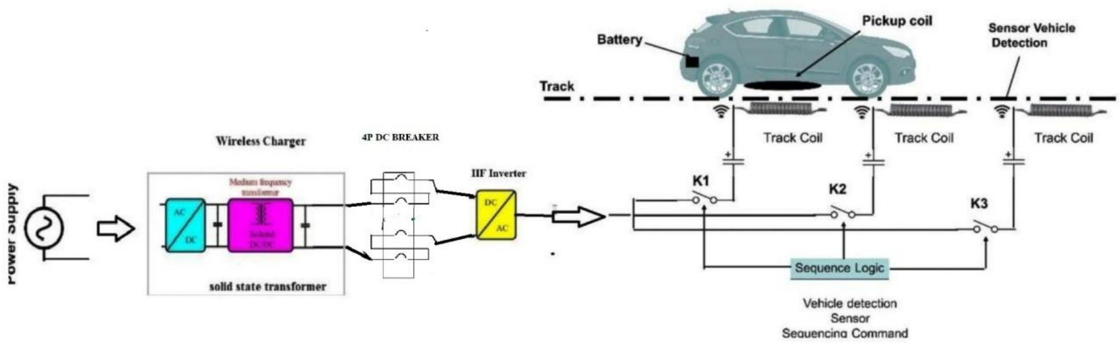

Fig.10 .SST based dynamic charging with 4P DC breaker.[12]

While driving, the EV is charged via dynamic wireless charging. There's no need to come to a halt and wait for the battery to charge. This was proposed by j.G.Bogler in 1978 [13]. Most of the issues with electric vehicles, such as range anxiety, battery size, battery expense, and so on, are solved with dynamic wireless charging. Inductive wireless power transmission is used in current types of dynamic wireless charging.[14].In fig 10 dynamic charging consist of SST and 4P DC breaker and it protects the converters from the faults occurring in the charging system.

X.Analysis and Discussions

The proposed 4Pole dc beaker is taken from the ABB manufacturer ,this give protection to converters and Battery energy storage system(BESS) .In AC power for every half cycle the current reaches the zero value such that the circuit breaker will open at that point and arc is quenched easily .But in DC breaker there is no natural current zero occuring so the DC power is a constant value .It is difficult to break the arc ,many old techniques in literature proposed were not effective in operation nor it is commercial success .This 4P DC breaker were used and two poles were added in series for positive pole and another two poles were added in series for negative pole .This will increase the resistance of the arc and quench the arc for clearing the faults .Two breakers were used for each SST used in the figures above this really increased the reliability of the proposed system .

XI. Conclusion

This paper first uses solid state transformer instead of low frequency transformers for charging the electric bus battery pack and secondly for protecting the solid state transformer 4P DC breaker is used in conductive charging of electric vehicles then discussed about protection in wireless charging method and finally discussed protection in dynamic charging of electric vehicles . Finally, it showed the architecture charging type of 11KV AC/ 800v DC system for electric vehicles and simulation results .The new archiecture has enhanced protection of charger system of Evs.

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