



A SMART TRANSFORMER: A SOLID-STATE TRANSFORMER (SST)

JUSTINEM.L.

Lecturer,

Department of Electronics Engineering,

Govt. Women's Polytechnic College, Kalamassery, Ernakulam, Kerala.

Abstract:

A smart transformer: a solid state transformer (SST) with managerial role in the electric distribution grid is generally called smart transformer. Smart transformers work independently to constantly regulate voltage and maintain contact with the smart grid in order to allow remote administration (if needed), and to provide information and feedback about the power supply and the transformer. A smart transformer (ST) provides the exact amount of power that is needed, and response instantly to fluctuations within the power grid, acting as a voltage regulator to ensure that the optimized voltage is undisturbed. Smart transformers are programmed to, as a default; provide an voltage optimized power supply that directly addresses their facility's energy needs. Smart transformer is better than normal state solid transformer: Because a smart transformer can help large commercial facilities use power more efficiency to save money, power and go greener and also work.

Keywords: Smart Transformer, Solid-State Transformer, SST, High frequency, AC/AC transformer, SST Structure, SST In Grid

Introduction:

In recent years, the complexity of the electrical grid has grown due to the increased use of renewable energy and other distributed generation sources. To cope with this complexity, new technologies are required for better control and a more reliable operation of the grid. One of such technologies is the solid-state transformer (SST). The SST technology is quite new and therefore limited.

In recent years, the cost of power electronics knowledge on the behavior of these systems in the grid is rather has decreased, and more reliable, low loss, high power, high frequency power electronics have become available. The cheaper price and the fact that the solid-state transformer can replace certain grid components along with the conventional transformer makes the solid-state transformer potentially makes the economically feasible. This economically feasibility combined with the many advantages of the solid-state transformer made engineers to pursue further research into the development and application of these devices in the grid. In this paper SST technology and its current state of affairs is elaborated. The paper is organized as follows: The second section describes concept development structure, features & configurations of SST. Third section discusses the SST technologies appear in the reviewed literature. The Fourth section describes the specification of SST. The applications of SST are given in fifth section. Finally, the concluding section comments on the future of the SST technology.

Concept And Development

AC to AC Buck converter.

The idea of a "solid-state transformer" has been discussed for some time. Nearly 20 years ago, Navy researchers [5] proposed a power-electronic transformer that consisted of an ac/ac buck converter shown in Fig. 1. To reduce the input voltage to a lower one. This was followed in 1995 by a similar EPRI sponsored effort. Both of these efforts yielded working prototypes, but they operated at power and primary voltage levels that were orders of magnitude below utility distribution levels.

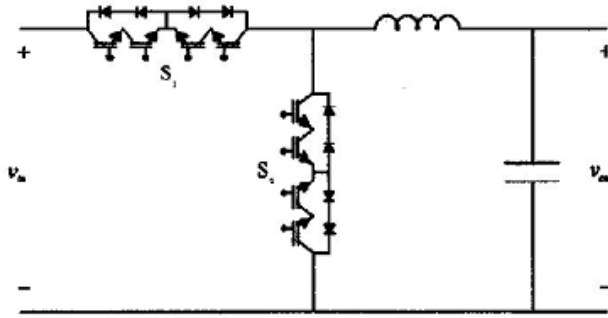


Fig. 1: AC to AC Buck converter.

High frequency modulated AC/AC transformer.

Another attempt at high-power ac/ac conversion has been proposed in [8]. For that topology, shown in Fig. 2, the incoming ac waveform is

modulated by a power electronic converter to a high-frequency square wave and passed through a small high frequency transformer. Another converter, synchronous with the high-voltage side but at a lower voltage, demodulates it.

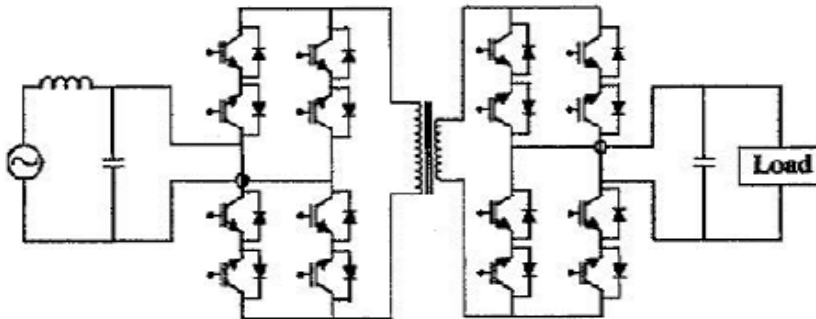


Fig. 2.High-frequency modulated AC/AC transformer.

This scheme has the benefit of reducing the transformer size and weight and the stress factor is more reasonable, but it does not provide any benefits in terms of control or power-factor improvement (5).

SST Structure

Basic Solid State Transformer Structure.

The basic structure of a SST is shown in Fig.3. SST works on the same principle as that of conventional transformer, but at high frequency. The incoming voltage is converted into a high frequency AC through the use of power-

electronics based converters before applied to the primary side of the HF transformer. The opposite process is performed on the HF transformer secondary side to obtain an AC and/or DC voltage for the load. The power transfer at higher frequency helps in reduction in weight, as well as size, of a transformer.

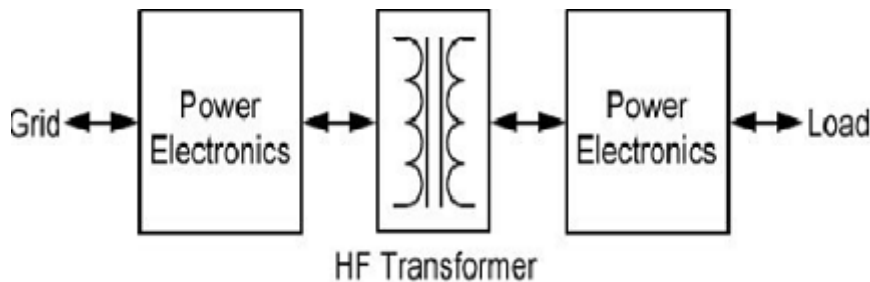


Fig. 3: Basic Solid State Transformer Structure.

Features of SST

With the addition of semiconductor devices, SST does much more than just changing a voltage ratio. The power can be supplied in ac as well as dc form as per requirements [4].

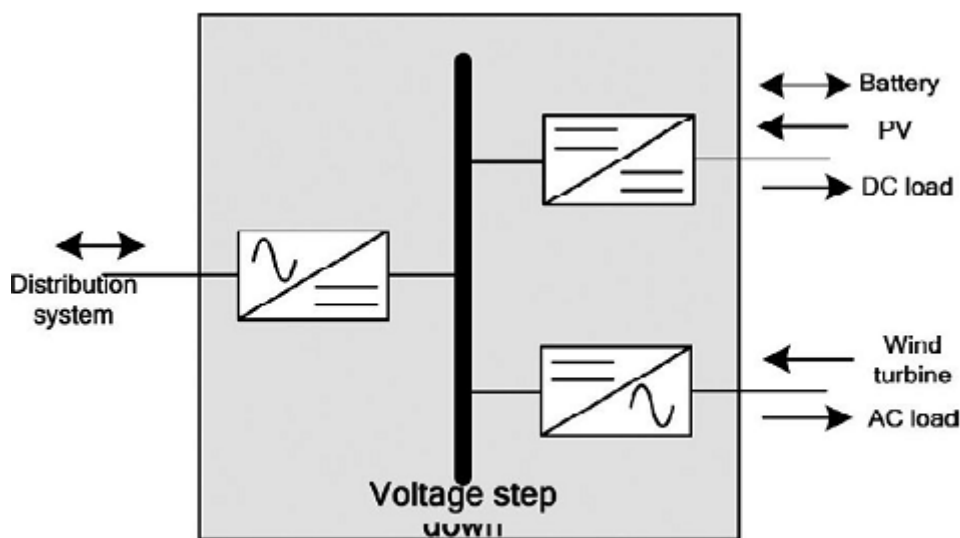


Fig.4 Functional Diagram of SST

Generally, the SST includes following three stages:

- The rectification stage first converts a high-voltage ac to dc at high voltage dc bus.
- In second stage, high-frequency transformation is used to convert higher dc voltage to lower level; generally this is called as dc/dc converter stage. At the output of this stage (at low voltage dc bus) a regulated low dc voltage at desired level is available.
- The last inversion stage helps to produce a desired, regulated low ac voltage (ac bus).

Therefore, the SST is called as a three-port energy router and power exchanger [4]. It can integrate the distribution system, residential ac

system, and envisioned dc system. In order to improve the system efficiency, the dc type sources and dc load are connected to dc port, whereas the ac type sources and ac load are connected to ac port. The three-port characteristics of SST make it very suitable to enable a new microgrid that exhibits better performance compared with conventional ac and dc microgrids [1]

SST PROPOSED TECHNOLOGY

The transformer design proposed herein is shown in block diagram form in Fig. 3. As can be seen, this is a three-part design that utilizes an input stage, an isolation stage, and an output stage. Furthermore, the input and isolation stages are themselves divided into several input and isolation modules.

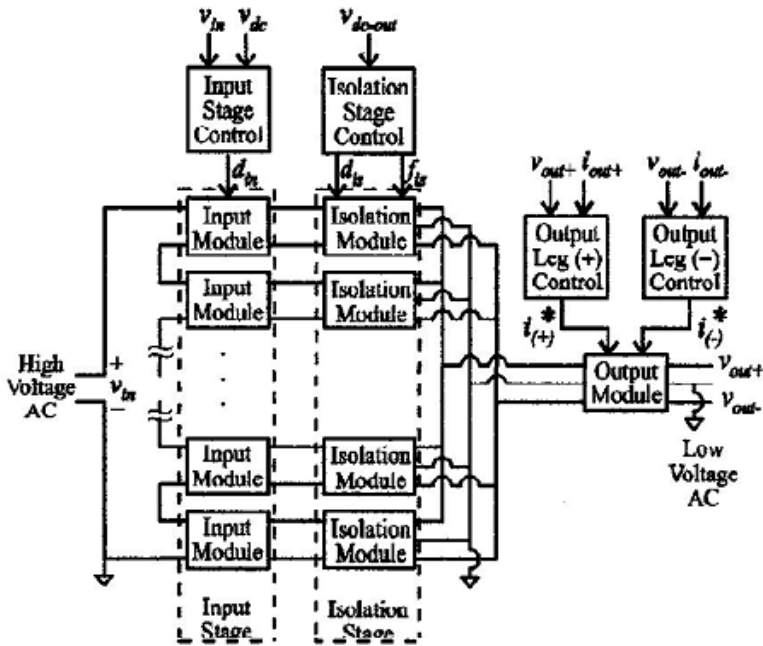


Fig. 5. Three-stage solid state transformer.

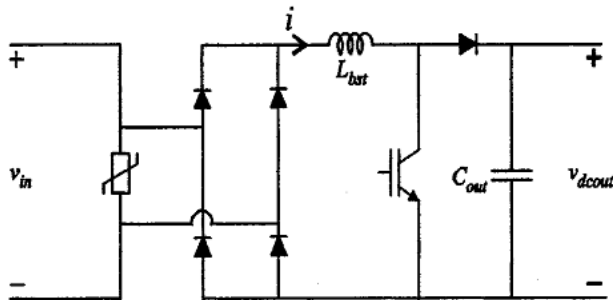


Fig.6 Input stage module.

In the input stage, the primary voltage is divided equally between the input stage modules. Each module's voltage is rectified using a unity-powerfactor rectifier. Each isolation stage module generates a high-frequency square wave from the incoming dc, transforms and isolates it,

and re-rectifies the transformer output. The bipolar dc outputs can then be connected in parallel to supply the output stage. The series to parallel connection provides the bulk of the voltage reduction

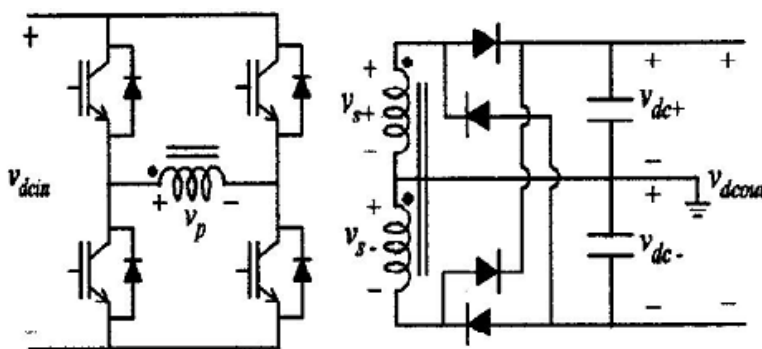


Fig.7 Isolation stage module.

Direct current from each input module is fed to a full bridge converter in the isolation stage

module, shown in Fig. 7. This converter provides a high frequency square wave to a

small air cooled transformer that reduces the voltage approximately in half while providing the needed isolation. The high frequency transformer's secondary (which is center tapped) is then rectified to form a bipolar dc supply. The output state converts the resulting bipolar low voltage dc into single-phase ac with a ground able mid-tap. The three-stage topology described herein has many attractive features. we started by working on SSTs designed to handle that lower-voltage, single-phase service. The transformers are similar in some respects to switched-mode power supplies, which are now ubiquitous as power sources for laptop computers and other appliances.

Our approach has been to build the SSTs from three modules. The first, called a front-end converter, takes incoming alternating current at, say, 7.2 kV and converts it to direct current (because of the particulars of our design, that DC current has a somewhat higher voltage). The AC-to-DC conversion is done using a set of power transistors. In the first incarnation, this was done with silicon IGBTs, and in our second SST, we did it with an early silicon carbide switch: the silicon carbide metal-oxide-semiconductor field-effect transistor, or MOSFET.

To convert the incoming electricity—which oscillates at 60 hertz in the United States—into a DC current requires two complementary sets of transistors. One set is in operation when the incoming AC electricity has a positive voltage,

and the other set is in operation when it has a negative voltage. Thanks to the way the transistors are wired up, regardless of the voltage of the incoming electricity, charge piles up on a capacitor, which is steadily discharged to create DC current. We use transistors to perform this rectification process instead of traditional diodes because we can run them at many times the incoming frequency. This lets us chop up the sinusoidal incoming current very finely so that we don't inject noise and unwanted harmonics upstream. That would create deviations from clear sine waves in voltage and current, and thus unusable energy that would be lost to heat.

In the second module, another set of transistors converts incoming DC current into an AC current with a frequency measured in kilohertz. This current is then passed through a conventional high-frequency transformer to convert the voltage down to, say, 800 V. Why the high frequency? Basically, the size of a transformer is inversely related to the frequency of the voltage it must transform. The higher the frequency, the smaller the transformer and, as a bonus, the more efficient it will be. After the voltage is reduced, a set of lower-voltage devices converts this still-high-frequency AC current back to a direct current.

The third module is an inverter, which uses yet another set of transistors to convert the DC electricity back to AC with a mains frequency, at which point it can then be safely supplied to end users.

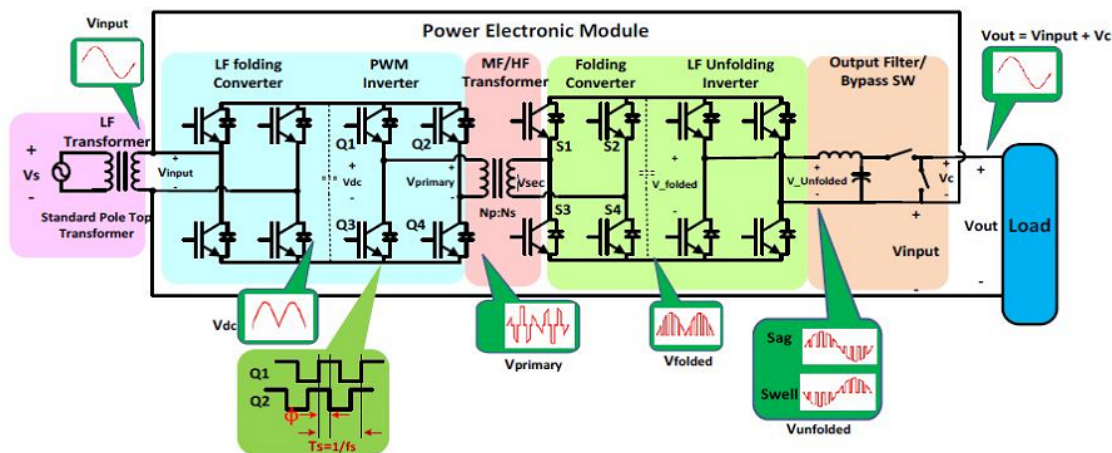


Fig. 8. Proposed MF/HF-transformer based smart distribution transformer topology

First, series-tied semiconductor devices are avoided because the voltage on the individual modules is reduced to the point where series tying of devices is unnecessary. Second, because of the three-stage topology and the unique capabilities of each stage, the total stress factor is much lower than it would be for the ac/ac chopper. Advantages of this solid-state transformer over its more traditional counterpart include the fact that the output voltages are

sinusoidal regardless of the input power quality or the output current wave shape. This is because the controls on the output stage actively suppress output voltage harmonics. Conversely, by suitable control of the input stage the input current is sinusoidal and of unity power factor, regardless of the output current wave shape. In addition, current limiting at the output and input stages is readily used to prevent secondary faults from propagating through the transformer.

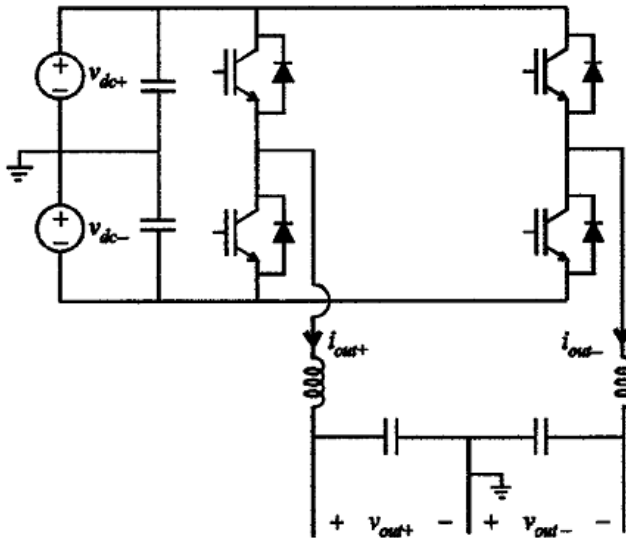


Fig 9. Output stage

Specifications Of SST

With incorporation of the solid-state technology into the distribution transformer[6], many new specifications can be realized as:

1) Voltage sag compensation - When the input source voltages compensate for the deficit and maintain constant output voltage. The total period of compensation, as a function of the amount of energy storage, can be adapted to the specific need of the customer.

2) Outage compensation - Similar to voltage sag compensation, the SST can provide full voltage compensation or the period needed by the built-in energy storage.

3) Instantaneous voltage regulation - If the input source voltage fluctuates due to power system transient or other load effects, the SST will maintain constant output voltage because it has the energy buffer.

4) Fault isolation - The SST can act as a circuit breaker to isolate the power grid from load fault and vice versa.

5) Power factor correction (and reactive power compensation) - The SST can maintain a unity power factor within its power rating. The SST can also generate or absorb reactive power as required by the system.

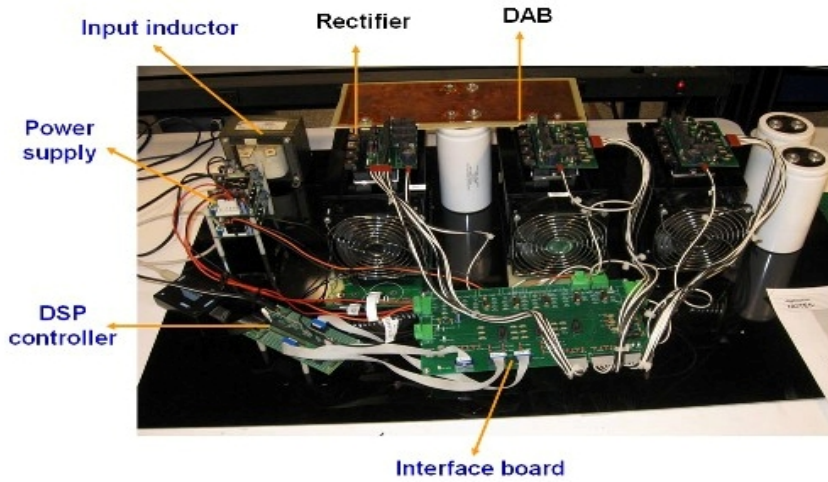
6) Harmonic isolation - Nonlinear loads produce harmonic-distorted current that tends to propagate back to the primary side of the transformer. The SST will maintain a clean input current with a unity power factor.

7) DC output - In addition to the 120/240V AC voltage, the SST has 400V DC output, which allows easier connection to distributed energies.

8) Metering or advanced distribution automation - The SST has advanced monitoring capabilities including instantaneous voltage, current, power factor, harmonic percentage, kWh and fault current or voltage information as well.

9) Environmental benefit - Unlike the conventional liquid immersed transformer, the

solid state transformer is an oil-free transformer and friendly to environment.



Prototype Smart Transformer:

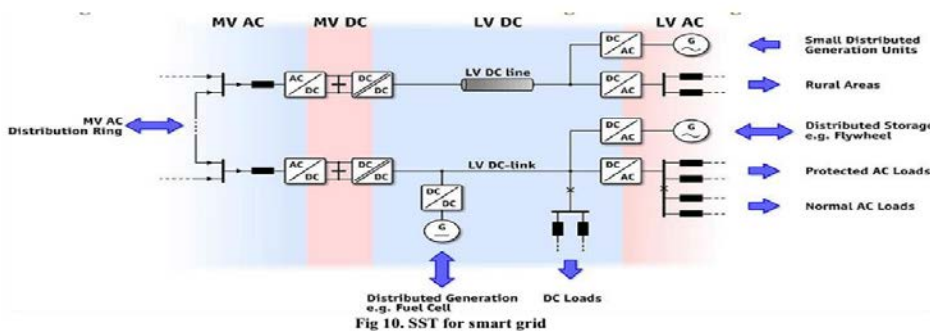
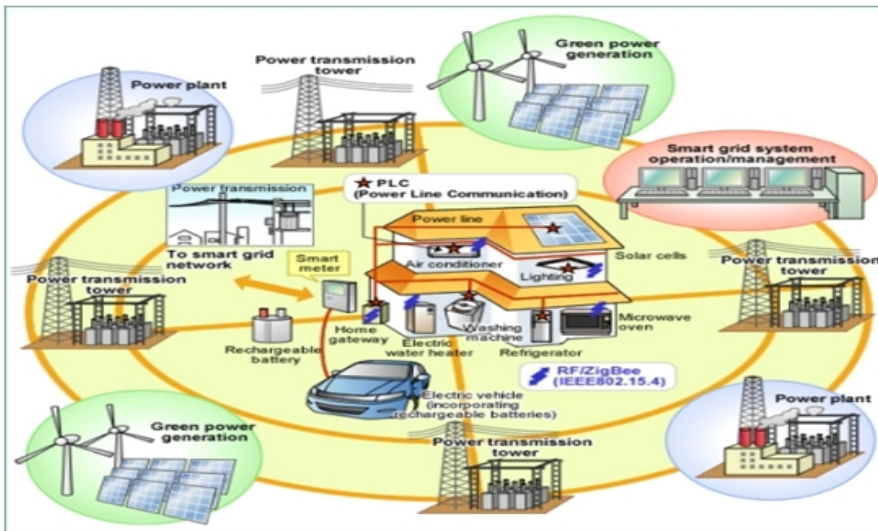
The above figure shows the project of SST done by students Ma Patel, Niridh, Krunal, Shaik, Rupak R from Gujarat.

1. Input inductor
2. Rectifier
3. Dual active bridge converter
4. Power supply
5. DSP Controller,6.Interface board

and will require an energy management scheme methods. For fast and efficient management of the changes in different loads and sources, the SST can be used to dynamically adjust the energy distribution in the grid. The function of the SST as described in this scenario is similar to that of a router, but instead of managing data, the SST will manage the flow of energy. For this reason, the SST is sometimes also called an energy router [4]

Applications Of SST In Grid

In future power systems, the usage of renewable generation is expected to increase,



The LV DC link in the SST topology provides a good and readily accessible integration point for renewable energy systems into the distribution grid. A unidirectional converter could be used when the load demand is much bigger than the renewable energy generation capabilities. Where the peak generation capabilities exceed the load demand during certain periods, the excess power could be fed back into the grid by using a bidirectional converter[7]. The SST concept is ideally suited to extend the use of DC, both in MV and LV applications. The difficulty in interrupting a DC feeder under fault conditions is often cited as a major hurdle in the acceptance of DC distribution in MV applications. The use of the power electronic interface (SST) to generate the DC is a means of controlling the system and interrupting fault currents [8].

Major Hurdles:

However, there is a major hurdle or disadvantage that has hindered its large scale production. It is based on semiconductor devices and currently there are no semiconducting material arrangements that can handle as much as 10kV grid allocation voltages.

Conclusion:

In this paper, technological review of concepts and developments in field of smart distribution transformer for the smart grid called Solid State Transformer has been shown. Also various topologies and configuration used and implemented so far has been briefly reviewed. Hence we can conclude that Solid State Transformer could be the next big thing in power electronics. When SSTs are implemented, they will radically change the way utility power is distributed. They will also become integral components in the future Smart Grid - enabling it to direct power from any source to any destination by the most efficient route possible.

REFERENCES

1. S. D. Sudhoff, "Solid State Transformer," US Patent No.5,943,229, August 24, 1999.
2. M. Kezunovic webinar, "The 21 st Century Substation Design."

3. E. R. Ronan, S. D. Sudhoff, S. F. Glover and D. L. Galloway, "A Power Electronic-Based Distribution Transformer", IEEE Trans. Power Delivery, vol. 17, pp. 537 – 543 ,April 2002
4. "Proof of the principle of the solid-state transformer and the AC/AC switchmode regulator," EPRI TR-105 067, San Jose State Univ., San Jose, CA 1995
5. International Journal of Industrial Electronics and Electrical Engineering, ISSN: 2347-6982. IEEE POWER ELECTRONICS MAGAZINE JULY 2017
6. D.K .Rathod "Solid State Transformer (SST) Review of Recent Developments" NIRMA University, Ahmedabad, Gujarat, INDIA.
7. Link <http://www.freed.m.ncsu.edu/index.php?s=2&t=news&p=121>
8. M. Liserre, G. Buticchi, M. Andresen, G. De Carne, L. F. Costa, and Z. X. Zou, "The smart transformer: impact on the electric grid and technology challenges," *IEEE Ind. Electron. Mag.* , vol. 10, no. 2, pp. 46–58,