Journal of Science and Technology
ISSN: 2456-5660 Volume 06,Special Issue 01, August 2021,

www.jst.org.in *DOI: https://doi.org/10.46243/jst.2021.v6.i04.pp188-195*

Design and analysis of solid state transformer

Prof. P. M. Wararkar, Sourabh A. Naradekar, Kaushik, M.Khare,
Prathamesh M. Namjoshi, Pavan B.Narale

(Electrical Engineering Department, NBN Sinhgad School of Engineering, AmbegaonBk.,Pune.)
(Electrical Engineering Department, NBN Sinhgad School of Engineering, AmbegaonBk.,Pune.)
(Electrical Engineering Department, NBN Sinhgad School of Engineering, AmbegaonBk.,Pune.)
(Electrical Engineering Department, NBN Sinhgad School of Engineering, AmbegaonBk.,Pune.)
(Electrical Engineering Department, NBN Sinhgad School of Engineering, AmbegaonBk.,Pune.)
Pallavi.wararkar@sinhgad.edu

To Cite this Article

Prof. P. M. Wararkar, Sourabh A. Naradekar, Kaushik M. Khare, Prathamesh M. Namjoshi, Pavan B. Narale, "Design and analysis of solid state transformer", Journal of Science and Technology, Vol. 06, Special Issue 01, August 2021, pp188-195

Article Info

Received: 15.07.2021 Revised: 24.07.2021 Accepted:10.08.2021 Published: 16.08.2021

Abstract: *This paper tries to make appoint that Solid State Transformer is an effective replacement for the conventional L F (Low frequency) transformer. The common topologies of SST are discussed. The present drawbacks of LF transformer and the advantages and future applications of Solid State Transformer are also mentioned. A Solid State Transformer is a bit complex system to barrier of universal acceptance is discussed and projected. In this paper discusses the features of power electronic based solid state transformer and its application in different electrical field, where conventional transformer can be replaced by the solid state transformer.*

Keywords: *SST- Solid State Transformer, LF- Low frequency, RER- Renewable Energy Resources,*

I. Introduction

The future smart grid is being designed to tone down or avoid consequences derived from power quality events e.g., voltage sags), improve reliability indices (e.g.,by reducing the number of interruptions and their duration), and increase the system efficiency. Integration of Renewable Energy Resources (RER) and Distributed Energy Storage Devices (DESD) into power system makes the system more reliable. Micro-grids are one such application that makes use of power electronics converters and so is Solid State Transformer (Smart Transformer). Micro grids facilitate increased integration of RER and DESD into the power network. Inclusion of RER and DESD will not only increase the reliability but will also reduce the congestion in networks and also improve the efficiency. FACTS (Flexible AC transmission system) has shown great results in the system which has made it very significant component of Ac transmission system. SST can be called as newest member of FACTS. Medium frequency has its size very compact as compare to low frequency transformer which as power electronics components. This two important features of SST makes a good option to replace Conventional (low Frequency) Transformers. In addition to the conventional features of LFT such as isolation and voltage conversion, an SST achieves better power management and power quality.

II. Background

While working on electronic wielding machine and studying its working mechanism, it sparked the idea that conversion from AC to DC and DC to AC (At medium frequency) can achieve many different things. Then with the research and study on this idea, got to know about the concept of SST. This AC to DC and DC to AC conversion helps to control voltage and current. Conversion has given the possibility of solving many drawbacks of some components of Power System.

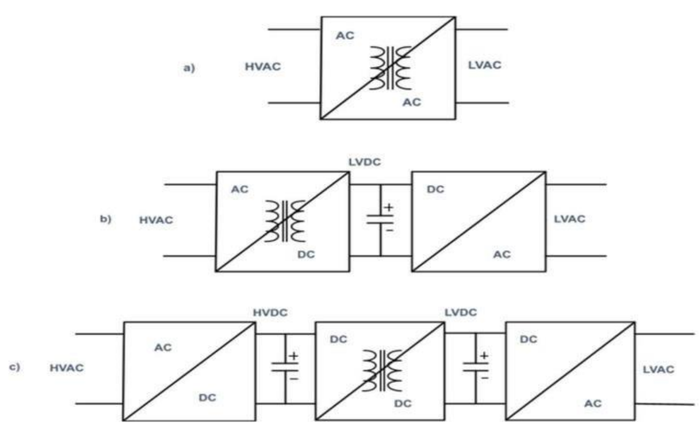
While also interning in a transformer company. It seemed that there are various drawbacks in distribution system with conventional transformer. Like, with the rated high load the system voltage seemed to be normal. But at the end of day when load is decreased due to some uncertain factors the system voltage gets swelled up suddenly. This gave the idea of providing a controlling circuit and a feedback loop in system, which will maintain desired constant system voltage. And to do so PWM scheme will be effective.

Electrical furnace has mainly three components: i) Furnace transformer, ii) Rectifier, iii) Medium Frequency inverter.

Furnace transformer are nothing but low voltage high current conventional transformers. Second component of Electrical furnace rectifies AC to DC, this is done so that this low voltage high current power can be converted into medium frequency with the help of the third component medium frequency inverter. This tremendous efforts are done by furnace just to maintain V/f ratio. V/f ratio is controlled so that appropriate metal can be melted. Along with electrical furnace there are many other systems where V/f ratio is maintained constant e.g. Drive system, etc.. To avoid these larger systems, Solid State Transformer system will prove to be useful.

III. Basic Block Diagram

Figure no 1 – Different topologies of SST.



Considering possible conversion stages, there are three basic topology configurations, as shown in Fig, namely typesa,bandc.TypeAisthedirectac–acconversionwithtransformerisolationtostep-downfromhigh-voltage ac (HVAC) to low-voltage ac (LVAC). In type a, an isolated ac–dc conversion stage provides the low-voltage dc (LVDC) followed by a dc–ac conversion stage to provide the LVAC. Type c is a three-stage conversion with high-frequency isolation in the dc–dc stage; thus both HVDC and LVDC link can be obtained. In addition, considering the limitation of the power devices and magnetic components, the aforementioned SST topologies may have to be connected in series or parallel for high voltage and high-power applications, as shown in Fig.Type c is 4 stage conversion system with Medium frequency is olation provided by ferrite core transformer. The ferrite core is to be provided with Medium frequency voltage in KHz or in MHz. So to achieve so normal supplied voltage with 50Hz/60 Hzis to be rectified into DC so that appropriate operating frequency for transformer can be used according to selection of core and other characteristics. Hence transformer will convert the voltage in desired magnitude according to turns ratio selected. Once the desired voltage is obtained only last two stages comes into play, the voltage obtained from transformer is Medium frequency voltage so to make that voltage appropriate to utility it's frequency has to be reduced to nominal frequency of 50/60 Hz. So to obtain so a set of rectifier and inverter is again used. Which will rectify the Medium frequency voltage into DC and that DC is obtained at desired frequency and desired magnitude into AC by use of appropriate inverter.

IV. Methodology

The main aim is to develop a three phase (3) Solid State Transformer system for distribution system purpose but for now single phase (1KVA) is being developed and will be ready to use. By experimenting different configurations and studying from many references ,it is evident that a three stage configuration seems to be most feasible/tactical to achieve the desired voltage with input voltage (RMS AC voltage).

With reference to above discussion, to achieve output voltage of 230V 50 Hz by processing the input power at three different stages. These three different stages are as follows:

a) *AC to DC (230V$_{RMS}$ 50Hz to 325V$_{Avg}$ DC)* – For this stage a diode bridge is been used. Or else the readymade converter/rectifierwhichisavailableinmarketcanbeused.Inadditiontotheconvertertwofiltercapacitorsneed to be connected to the output of converter with parallel configuration for the smoothing purpose.

b) *DC to MF(Medium frequency) AC(20KHz)* – This is a stage where provision for integrating DC voltage received from Renewable Energy Sources (RES) into system can be done or DC power can also be tapped out. This is a stage where Medium frequency AC power is to be obtained, to do so a H-bridge inverter having four MOSFETs is used. For designing of 1KVA Solid State Transformer system, these are two suitable examples MOSFETs namely-

i) IRF450 (N-Channel, 12A,500V) ii) 10N60 (10A,600PIV)

To obtain Medium frequency of 20 KHz switching frequency of MOSFETs is very crucial. Since the switching frequency is quite high, a specific PWM generation scheme is required. For above mentioned MOSFETs there are two PWM generation schemes available -

i) Standard PWM generation
ii) Enhanced PWM generation

Forth is SST system the Standard PWM generation scheme issued, as this is more efficient scheme than the latter one. The inverter with PWM generation has chopping frequency of 20 KHz which makes DC power converted into AC power supply having square wave with 20 KHz frequency.

c) MF (Medium frequency) AC High voltage to MF (Medium frequency) AC Low voltage–Forth is stage Medium frequency transformer is used, which is the main element of the Solid State Transformer system. In any transformer, the core area & flux density decide the energy transferred for Primary to Secondary in one cycle of supply. Since power is energy per second you can transfer more powers for the same size of the transformers if you can increase the number of cycle per second.

4.1 Magnetic Material

There number of materials can be used for the core of transformer. Here are some materials with different parameters.

Material	Composition	Loss(w/kg)(0kHz, 0.2T)	Saturation Bmax [mT]	Permeability (50 Hz)	Max working Tem[^{0}C]
Grain oriented silicon steel	Fe97 Si3	>1000	2000	2k-35k	120
Amorphous alloy	Fe76(Si.B)24	18	1560	6.5k-8k	150
High performance ferrite	MnZn	17	500	1.5k-15k	100/120
Nanocrystalline alloys	FeCuNbSib	4.0	1230	20k-200k	120/180

Table No. 1 - Different types of magnetic materials.

From the above table, it is clear that Nano crystalline alloy shave least losses among all other core materials. But taking into consideration the non-availability and high cost of nano crystalline alloys makes it bad option forth is SST system. Hence considering all the parameters along with low cost and availability in India 'High Performance Ferrite' material is the most appropriate and efficient choice for this Solid State Transformer.

For designing of Solid State Transformer's different parameters like Area of core, Cross section area of windings, Number of primary (Np) and secondary (Ns) turns, etc. different formulae can be used.

$Np = (V_{in} \times 10^4)/(4 \times F \times B_{max} \times A_c)$

Where,
V_{in} = Average input voltage
F = Preferred switching
frequency B_{max} = Maximum flux
density in Gauss
A_c = Effective cross sectional area in mm^2

$Ns = (V_{out} / V_{in}) \times Np$

More such formulae to find different parameters required to design the Transformer are in Ref. 6

Ferrite core transformer with rating of 250W operating at 10 KHz should be 1/200thsize (10000/50=200) of a 50 Hz Silicon steel core transformer of same power rating but Silicon steel transformer can operate up to flux density of 1.2 Tesla, where as Ferrite core transformer can be designed to have maximum flux density of 0.2 Tesla only. This Factor of 6 (i.e.1.2/0.2). The higher frequency tend store duce the size by 1/200 factor, but lower flux density tends to increase the size of transformer by factor of 6. Hence the net size reduction is 6 x (1/200) =1/33 times the size of Silicon steel transformer. Hence, Ferrite core transformer has an advantage of size reduction in high frequency operation in spite of lower Flux density in comparison to Silicon steel core transformer.

Journal of Science and Technology
ISSN: 2456-5660 Volume 06,Special Issue 01, August 2021,

www.jst.org.in *DOI: https://doi.org/10.46243/jst.2021.v6.i04.pp188-195*

4.2 Standard PWM generation scheme – The desired frequency at the output of system is of 50 Hz, i.e. time period of a cycle is 20m Sec. With the help two pins of a controller IC in controlling circuit ENA and ENB, two waves with 10m Sec time period each and also they are complementary to each other (i.e. 180 Phase-out). These two waves are supplied to two different pairs of MOSFETs for triggering. Since these waves are complimentary, when ENA is positive/high, which triggers the first pair of MOSFETs? Same mechanism occurs when ENB is high, triggering the other pair of MOSFETs. This all process occurs with 20 KHz of chopping frequency.

4.3 Controlling circuit and Feedback loop–

The controlling circuit can be called as a brain of this Solid State Transformer.

A feedback loop from the out put of the system is provided to controlling circuit. AC T and PT is connected in the feedback loop which continuously measures the output parameters and sends the data to controlling circuit. Then the IC of controlling circuit compares the data from the feedback loop with the desired output parameters and acts according to it to reduce the errors (if any).

System can be made smarter by adding communication module along with controlling circuit and feedback loop. This module will communicate wireless or wired with the controlling centre or Load dispatch centre. This communication module will help to read, correct and change the parameters remotely.

V. Output Waveforms

5.1 ENA and E N Boutput

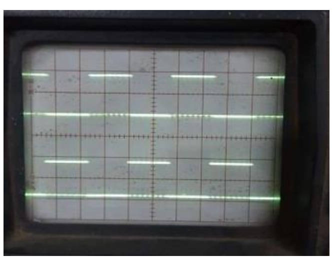


Fig.2 ENA and ENB output waveform

As mentioned above both ENA and ENB has 10mSec On period and 10 m Sec Off period. Also both are complimentary to each other.

5.2 H-bridge output

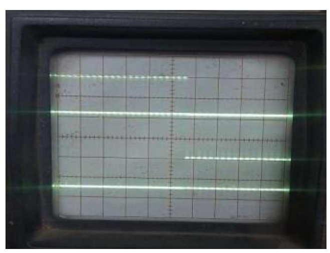


Fig.3 H-bridge output

AC output of a H-bridge inverter.

5.3 Ferrite core transformer output

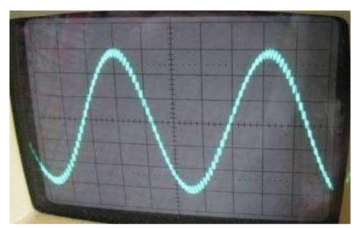


Fig. 4 Ferrite core transformer output

This is a smoothened output waveform of a ferrite core transformer.

VI. Result

Table no 2 - Specifications for the implemented prototype of the SST unit.

Parameters	Output Rating
Solid State Transformer rating	1KVA
Maximum power	1035 W
Input voltage	230V RMS/50Hz
DC link voltage	325V Avg.
Chopping frequency	20 KHz
Final output	230V RMS/50Hz

This are the specifications for the implemented prototype of the SST unit.

To understand and asses practically the operation of Solid State Transformer, small scaled prototype has been developed and tested .97% is the maximum efficiency was achieved by using above mentioned methodology. The system to achieve more optimum value of efficiency; switching losses, core losses, inertia of semi-conducting switching devices, etc. should be reduced. Core losses can be reduced by using Nano crystalline alloy material but the high cost and non-availability is a big constraint

VII. Advantages

a) Duetoincreaseinoperatingfrequency(Mediumorhighfrequency),sizeofatransformerreducessignificantly .

b) Due to controlling unit and Feedback loop–

i) Reactive power compensation and voltage compensation/stability can be achieved.
ii) Load can be protected from power supply disturbances.
iii) Voltage sag due to load transients can be reduced.
iv) Better voltage regulation is achieved.

c) Solid State Transformer can work on both AC and DC supplies.

d) Solid State Transformer is bi-directional power flow as two different forms of supply can be integrated (AC and DC) and two different types of outputs can be achieved (AC and Dc).

e) System can be completely controlled remotely. (If communication module is installed along with controlling unit and feedback loop).

VIII. Disadvantages

a) It is less efficient than the conventional transformer (90-95%).

b) It has semiconducting switching devices, making it add more harmonics into the power system.

c) High chopping frequency causes electronic interferences.

d) The designing of the Solid State Transformer is quite complex as compared to conventional transformer.

e) Since the technology is new, skilled engineers and workforce is required.

IX. Applications

a) With advantages stated above power quality of any system can improved with the use of Solid State transformer**.**

b) Solid State Transformer can be a new inclusion into FACTS family.

c) Solid State Transformer can be used in traction system .Since it has medium operating frequency, making its size and weight much lesser that a conventional transformer with same rating. Replacing conventional transformer with SST will create more room for passengers/luggage.

d) SSTcanbeveryhandfulwherespecialapplicationoftransformerisrequiredsuchasvariablevoltageo r variable frequency.

X. Future Scope

Many agreements/sanctions are been signed/imposed internationally to limit the use of fossil fuels and the increasing carbon footprints. With all these advancements, integration of Renewable Energy Sources (RES) into the traditional power grid will increase more transiently. Keeping in mind such upcoming advancements many engineers/researchers are trying to make this integration more smooth and efficient. Designing and implementation of this technology might seem to be costly but with the innovations like the online monitoring, self-healing techniques and smart controlling techniques this will be a good investment in the long run.

XI. Conclusion

By reviewing many papers and practically assessing different prototypes, the prototype mentioned in this paper can be one of the efficient system with good voltage regulation. Solid State Transformer system can not be applied rigidly to all applications; it will need to be differently configured according to the application. However, Non- linear components and electronic interferences are still main issues to be addressed. Along with advancements such issues should be efficiently addressed and resolved to make it more appropriate substitution of transformers with low frequency.

References

1) J. Huber, J. W. Kolar “Volume/Weight/Cost Comparison of a 1MVA 10 kV/400V Solid-State against a Conventional Low-Frequency Distribution Transformer.” Proceedings of the IEEE Energy Conversion Congress and Exposition (ECCE USA 2014), Pittsburgh, Pennsylvania, USA, September 14-18,2014.

2) Xu She, Alex Q. Huang, and Rolando Burgos, “Review of Solid-State Transformer Technologies and Their Application in Power DistributionSystems”,IEEEJOURNALOFEMERGINGANDSELECTEDTOPICSINPOWERELECTRONICS,VOL.1,NO.3,pp-186-198, SEPTEMBER2013.

3) J.W. Kolar, G.I. Ortiz, “Solid State Transformer Key Components for future Transportation and Smart Grid Applications”, Power Electronics SystemLaboratory.

4) Aniel Shri, “A Solid State Transformer for Interconnection between Medium and Low voltage Grid”, Master of Science thesis, Delft University of Technology, October2013.

5) D.K. Rathod, “Solid State Transformer (SST) - Review of RecentDevelopments”

6) Colonel Wm. T. McLyman, "Designing magnetic components for high frequency DC-DCconverters"

7) H.H.H.DeSilva,D.K.J.S.JayamahaandN.W.A.Lidula,"Reviewondesignandcontrolofsolidstatetransformerbasedmicrogrids"

8) NeevatikaVerma,Navdeep SinghandShekharYadav,"SolidStateTransformerforElectricalSystem:ChallengesandSolution."

9) J. Feng, W. Q. Chu, Z. Zhang and Z. Q. Zhu, "Power Electronic Transformer-Based Railway Traction Systems: Challenges and Opportunities"

10) Xu She, Rolando Burgos, Gangyao Wang, Fei Wang and Alex Q Huang, "Review of Solid State Transformer in the Distribution System: From Components to FieldApplication."

11) Boris Avdeev, AlekseiVyngra, Sergei Chernyi, "Improving the Electricity Quality by Means of a Single-Phase Solid-State TransformerQuality by Means of a Single-Phase Solid-StateTransformer"

12) "Simulation and analysis of Solid State Transformer", Sanjeeth Amminabhavi1, Dr. Gopalkrishan D.Kamalapur2 1Post Graduation Student,2ProfessorDept.ofElectrical&Electronics EngineeringSDMCollegeofEngineering&Technology, Dharwad,Karnatak,India

13) "Applicability of Solid-State Transformers in Today's and Future Distribution Grids", Jonas E. Huber, Member, IEEE, and Johann W. Kolar, Fellow,IEEE