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Simulation and analysis of Solid State Transformer

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Abstract— In the power distribution system solid state Transformer (SST) has identified as most Important technology. SST contains Transformer which is smaller in size and operates at High frequency.A (SST) is nothing but AC to AC converter; it involves such a converter that replaces a conventional transformer which is used in AC electric Power distribution. This paper presents the comparison of single phase conventional Transformer with single phase solid state Transformer (SST) similarly holds good for three phase conventional and solid state Transformer also. Futher Comparison of conventional Transformer and Solid State Transformer with respect to Voltage Regulation, Efficiency and Total Harmonic Distortion. However the challenge of SST is to prove with higher efficiency and lower voltage regulation along with less harmonic distortion. The implementation of SST is done using MATLAB/Simulink.

Index Terms— Solid State Transformer (SST), High frequency (HF) Transformer, Voltage Regulation, Efficiency and Total Harmonic Distortion, power quality performance enhance, size and weight reduction.

1 Introduction

Solid State Transformer (SST) is an essential component in the future smart grid. This concept came into existence in the year 1968 McMurray was the first person who introduced the concept called Solid state transformer.[1] It is an element consists of power electronic converters with multi stage also involves a transformer with high frequency hence power electronics play a important role in this scenario. As increasing high demand for renewable energy, high amount of renewable energy intrgration needs improvements on controllability side.[2] Smart Transformers could give solutions to the system level challenges but design and implementation of SST is a challenge itself. Smart grid is so designed for future to mitigate or avoid from power quality issues/events such as voltage dips. This SST has much more advantages compared to conventional transformer from the view point of Voltage Regulation, Efficiency and Total Harmonic Distortion.Smart transformer when compared with conventional one has higher efficiency with lower voltage reulation.

Initially Open circuit and short circuit tests are carried out to determine the parameters of transformer such as efficiency, voltage regulation and circuit constant etc. later load test on a single phase transformer has been conducted on conventional Transformer of rating 1KVA and solid state transformer is designed in matlab simulation and again OC and SC tests are conducted and obtained the results. Similarly load test on SST also conducted and obtained the results. Its proved that SST is higher efficient then ordinary one. Though SST involves power electronic devicesand harmonics are present with a exceptable range i.e (1% to 3%) the same is carried out for Three phase conventional as well as SST and results are obtained in order to meet the objectives.

2 Limitations of Conventional Distribution Transformer

This Traditional line frequency transformer so called conventional transformer are cheap and efficient method in voltage transformer from one level of voltage to another level with isolation.[5] However this direct transformation introduces some unwanted harmonic characteristics in the power grid.These traditional one are bulky in size with heavy weight. It contains transformer oil for cooling purpose but its harmful when exposed to environment. It has higher losses. Harmonic is present which exceeds 15% of the fundamental frequency. The main drawback of this transformer is these are designed for maximum efficiency under full load condition. This leads for high standing losses and more loss under no load condition.

2.1 schematic diagram of SST

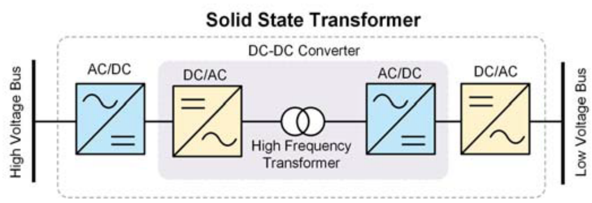

Fig. 5 General representation of single phase Solid State Transformer.

3 Functions of Solid StateTransformer[6]

- Weight and size is reduced
- Reactive Power Compensation
- Active and Reactive Power Control
- Fault Isolation
- Voltage Harmonics and sag compensations
- Protects power systems from the load disturbances
- Load transients and harmonic regulations
- Fast control of bidirectional active power flow
- Enhanced power quality performance

4 Flow Chart

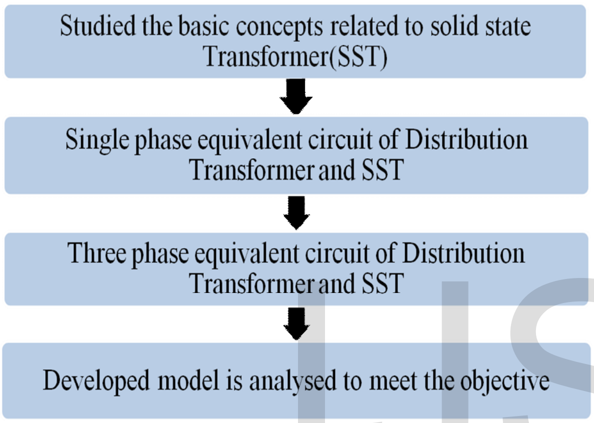

Fig. 1. Flow chart of project

5. Single Phase Equivalent Circuit of Trans-former

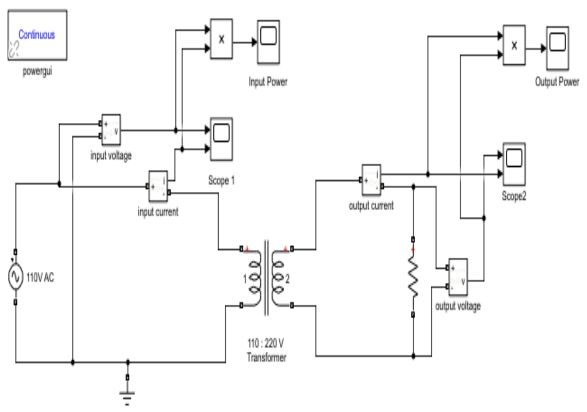

Fig. 2. Equivalent circuit of Single phase Transformer

5.1 Circuit Parameters

Taable 1

Circuit Parameters

V1=110V	V2=220V
R1=0.15Ω	R2=0.03 Ω
L1= 0.25Ω	L2=0.04 Ω
Ro=977 Ω	Xo=448 Ω
Series RLC Branch = 346.6	

5.2 Input Volatge and Current

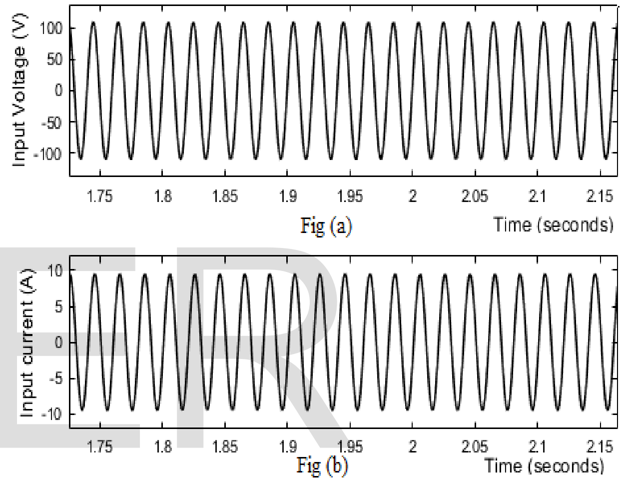

Fig 3. (a) Input Voltage waveform

(b) Input Current waveform

Fig 3 (a) represents input voltage waveform of single phase equivalent circuit of Transformer. which has magnitude 110 (V)

Fig 3 (b) represents Input Current waveform of single phase equivalent circuit of Transformer. Which has magnitude 9.56 (A)

5.3 Ontput Volatge and Current

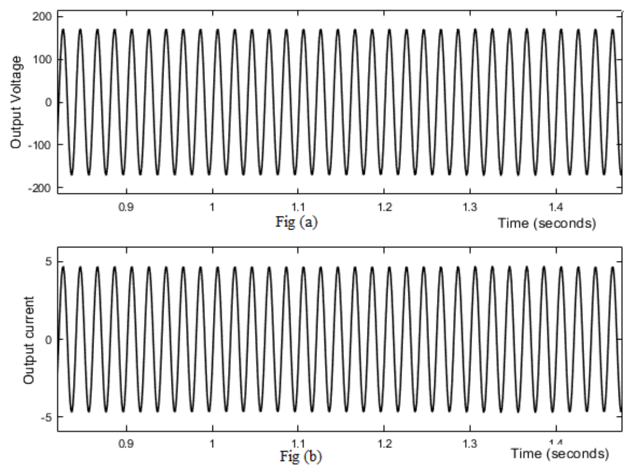

Fig. 4. (a) Output Voltage waveform

(b) Output current waveform

Fig 4 (a) represents output voltage waveform of single phase equivalent circuit of Transformer. Which has magnitude 173 (V)

Fig 4 (b) represents output Current waveform of single phase equivalent circuit of Transformer. Which has magnitude 4.7 (A)

TABLE 2
OPEN CIRCUIT AND SHORT CIRCUIT RESULTS:

Open Circuit (OC) Test:

Wo (W)	Vo (V)	Io (A)
14	110	0.6

Short Circuit (SC) Test:

Wsc (W)	Vsc (V)	Isc (A)
32	9.5	4.5

5.4 Practical Results

- **Calculation:**

Cos $\varnothing_o$ = 77.75°

Magnetizing Component (Im) = 0.58 A
Working Component (Iw) = 0.126 A

R_{01} =1.58 Ω
X_{01} = 1.40 Ω
Z_{01} = 2.11Ω

- **Formula :**

%Voltage regulation = [(I R_{01} Cos ϕ ± I X_{01} Sin ϕ) / (V_0)] *100

When I = 0.6 A and Cos ϕ = 0.8
%VR = 0.23

Efficiency (η) = [(output power) / (output power + core loss + copper loss)] *100
= [(s) * (x) * Cos ϕ] / [((s) * (x) * Cos ϕ) + W_0 + $x^2 W_{sc}$]

Where,
S= rating of Transformer
X= percentage of loading on Transformer
Cos ϕ =power factor of load

For 100% load
η = 94.56 %

For 50% load
η = 94.78 %

For 25% load
η = 92.59 %

TABLE 3
LOAD TEST ON TRANSFORMER

I_L (A)	V_L (V)	$W_{delivered}$	R_L	% Voltage Regulation
0.6	208	20	346.6	0.23
1.4	200	50	142.8	0.53
2.1	196	85	93.33	0.80
2.7	190	115	70.37	1.04
3.4	184	140	54.11	1.31
4.1	180	170	43.90	1.58
4.8	176	195	36.66	1.85

6 SOLID STATE TRANSFORMER

Single Phase Solid State Transformer hasdesigned in Matlab simulation, OC and SC tests are conducted and resuts are obtained. [7]Load test on SST is done in order to get Efficieny of SST and also voltage Regulation is calculated and results are tabulated.

6.2 Simulation Model of SST

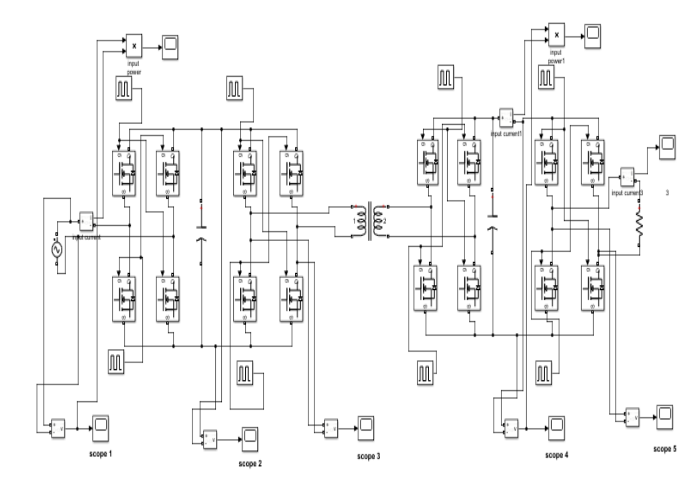

Fig.6. Simulation model of Single Phase SST with 5 Output scope

It consists IGBT switches and High frequency Transformer of 20Kz and the Load is connected of the same rating as connected for conventional one.

6.3 Simulation Results of SST

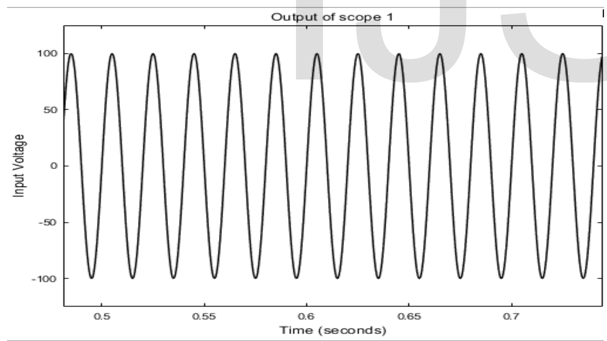

Fig. 7 Input Voltage of 100 (V)

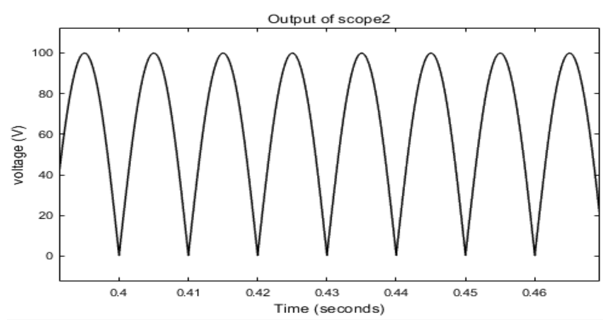

Fig. 8 AC to DC conversion with Voltage magnitude is 99.9(V)

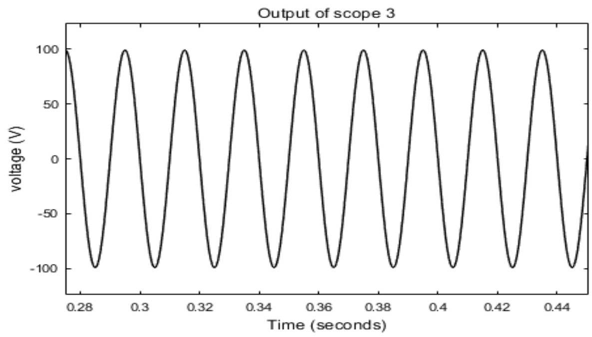

Fig. 9 DC to AC conversion with Voltage magnitude is 99.03 (V)

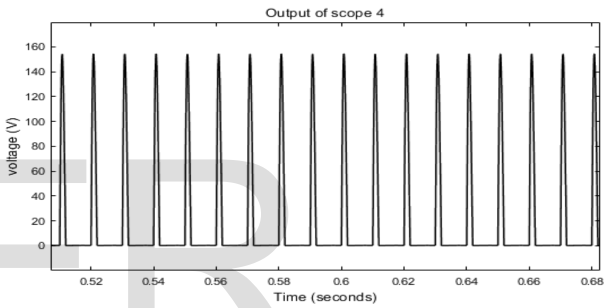

Fig. 10 AC to DC conversion after Transformer step up with Voltage magnitude is 159.8(V)

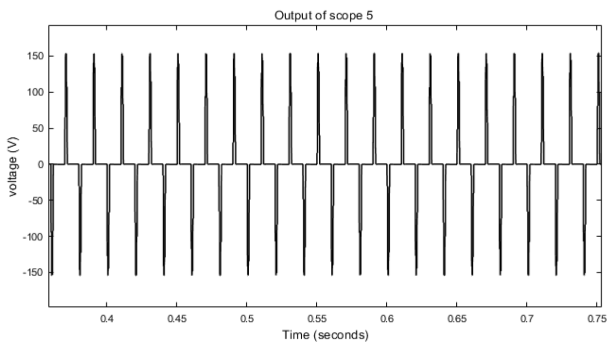

Fig. 11 DC to AC conversion after Transformer step up with Voltage magnitude is 159.8(V)

TABLE 4

OPEN CIRCUIT AND SHORT CIRCUIT RESULTS

Open Circuit (OC) Test:

Wo (W)	Vo (V)	Io (A)
573	264	6.5

Short Circuit (SC) Test:

Wsc (W)	Vsc (V)	Isc (A)
3.50	0.86	5.30

6.4 Simulation OC and SC Test Results

❖ **Calculation:**

R_{01} = 0.124Ω
Z_{01} = 0.162Ω
X_{01} =0.1045Ω
No load Volatge is V_0= 264V

%VR = $(V_0 - V_L) / V_0$= 0.17

Efficiency (ɳ) = [(output power) / (input power)] *100

For 100% load
Efficiency (ɳ) = 98.47%

For 50% load
Efficiency (ɳ) = 97.23%

For 25% load
Efficiency (ɳ) = 94.58%

TABLE 5

LOAD TEST ON SST

I_L (A)	V_L (V)	R_L	% Voltage Regulation
0.6	218	346.6	0.17
1.2	200	142.8	0.32
1.6	196	93.33	0.42
1.9	190	70.37	0.48
2.2	184	54.11	0.55
2.4	180	43.90	0.60
2.6	176	36.66	0.64

7 GRAPH FOR VOLATEGE REGULATION CURVE TO COMPARE CONVENTIONAL TRANSFORMER AND SST

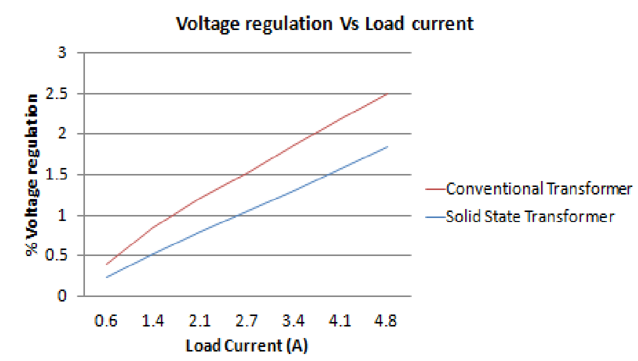

Fig. 12. Graph of Voltage regulation Vs Load current

The above figure shows the comparision of conventional Transformer and Solid State Transformer from voltage regulation Point of view. It is found that the curve of SST lies below the conventional Transformer curve. Hence Objective of the project is met.

8 BAR GRAPH FOR EFFICIENCY TO COMPARE CONVENTIONAL TRANSFORMER AND SST

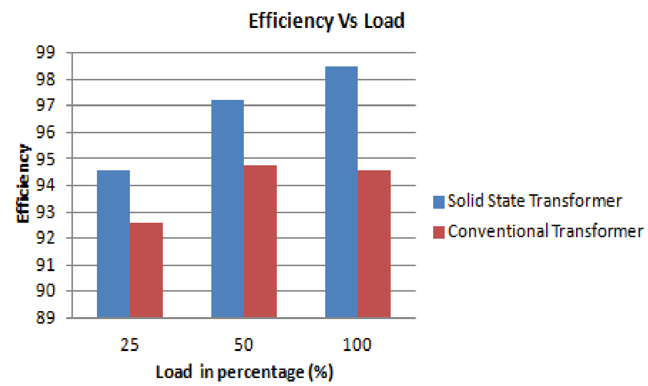

Fig. 13. Graph for efficiency

The above figure shows the comparision of conventional Transformer and Solid State Transformer from Efficiency Point of view. It is found that the Efficiency of SST is higher as compared to conventional Transformer. Hence Objective of the project is met.

9. Total Harmonic distortion comparision of conventional transformer and SST

9.1 simulation model with THD block

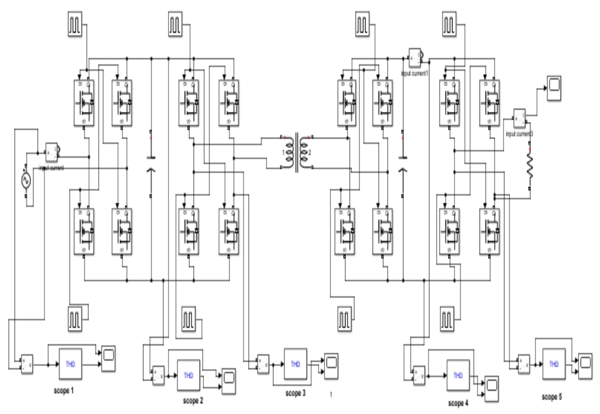

Fig. 14. Simulation Model of Single Phase SST with THD block.

9.2 Simulation result

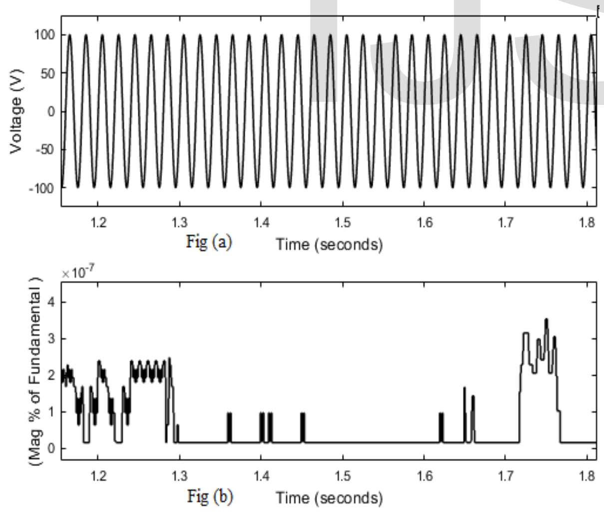

Fig. 15 Fig (a) Output voltage waveform

Fig (b) represents THD

Fig 15 (a) represents the output voltage waveform with voltage magnitude 100 (V)

Fig 15 (b) It is observed that 0.04% THD is present which is in exceptable range.

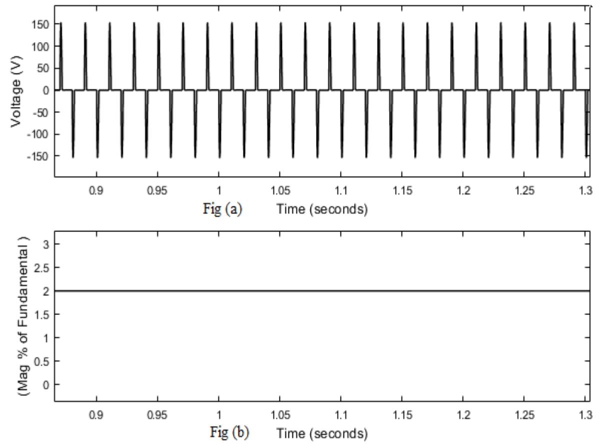

Fig. 16. Fig (a) Output voltage waveform

Fig (b) represents THD.

Fig. 16. Fig (a) represents the output voltage waveform of with voltage magnitude 99.4 (V)

Fig 16 (b) It is observed that 2% THD is present which is in exceptable range.

10 Conclusion

This paper concludes that SST is much better then conventional Transformer. SST is very important component in Power system. As it is a power electronic based transformer it has faster response, less weight and more reliable.Practical results and simulation results are obtained, by comaparing both SST and conventional Transformer it is proved that SST has higher efficiency and lower voltage regulation. As it involes Power electronic devices though Harmonics are present but within range.

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