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ANN Driven Dual Active Bridge based Dual Winding Solid State Transformer for Power Quality Improvement

Saju N[1], Dr. Jegathesan V[2]
[1]Research Scholar, Karunya Institute of Technology & Sciences, Coimbatore, India.
[2]Associate Professor, Karunya Institute of Technology & Sciences, Coimbatore, India.

ABSTRACT

Solid State Transformers (SST) are aility. These transformers are devices in three stages viz. input rectification stage, intermediate Dual Active Bridge (DAB) and output inverter stage. In this paper, Artificial Neural Network (ANN) driven three stage DAB based SST with dual secodnary winding has been proposed. Simulation studies of the proposed ANN-SST system has been carried out and the results are presented. A comprative analysiz on the power quality aspects viz. voltage sag, swell, THD and power factor is made with the proposed ANN-SST and uncompensated system, to investigate the suprriortiy of the proposed scheme.

Key words : Solid State Transformer, Dual Active Bridge, Artificial Neural Networks, Power Quality, Power Factor, Voltage Sag, Voltage Swell, THD.

1. INTRODUCTION

Size, volume, weight and space occupied by transformers vary with operating frequency of it. Higher the operating frequency lowers the value of these parameters, for the same power rating of transformers. Normally, transformers operate at 50 or 60 Hz. These transformers are called as conventional transformers which suffer from increased size, weight, volume and more space occupancy problems. To overcome these drawbacks semiconductor based transformers were developed [1]. These transformers are called solid state transformers as they work with power electronic switching devices. They have power transformation phases viz. AC/DC and DC/AC. DC converter for high power density applications was suggested [2]. This converter operates by soft switching principle. A Dual Active Bridge (DAB) based SST suggested [3] operated at 100 kHz frequency occupied less size and volume. DAB enables bidirectional power flow capability and is studied [4].

SST for power distribution applications was proposed and analyzed [5]. It addressed a SST with high switching frequency and proved its economical viability [6]. Power quality analysis of DAB based bidirectional SST system was examined [7]. [8] Suggested the optimal design parameters for converters in SST system. Applications of SSTs are widely in distributed generation and smart grids. SST aimed for this application was designed [9]. Three stage DAB based SST system was designed and simulated [10] for grid connected photo-voltaic systems. A high frequency SST system with dynamic current characteristics is recommended [11]. THD, voltage sags and voltage swell are the power quality parameters considered for study in the research work [12].

Conventional transformers of wind energy conversion systems are replaced with SST [13]. Compact SST models were developed [14]. Multi-level inverters based SST for traction system applications were suggested [15]. In the research work of [16] a SST system with reduced number of devices was developed. A fuzzy logic fed modified DAB with dual secondary winding SST system is proposed [20].

The organization of this paper is as follows: Section 2 illustrates the modified SST with dual secondary windings based on DAB. ANN driven modified SST is discussed in Section 3. The simulation studies and its results of the proposed ANN-SST system is detailed in Section 4. Section 5 deals with the comparative analysis between the uncompensated and proposed ANN-SST system. The superiority of the proposed ANN-SST system is briefed and concluded in Section 6.

2. MODIFIED DUAL SECONDAY WINDING SST SYSTEM

2.1 Conventional Three Stage SST System

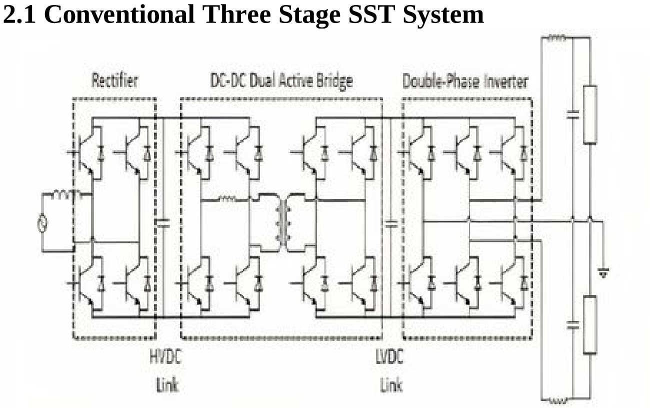


Figure 1: Conventional Three Stage Solid State Transformer

The three stages of DAB based conventional SST system is shown in Figure 1. The three stages are input stage, intermediate stage and output stage. The input stage consists of a uncontrolled rectifier which converts AC to DC. This DC is fed as input to the intermediate stage, where it is converted into high frequency AC through an inverter. This high frequency output is the operating voltage and frequency of the transformer in the intermediate stage. The secondary of the transformer consists of a rectifier where high frequency AC is converted to DC. This entire stage where the DC is converted back to DC via inverter-transformer-rectifier is collectively called as Dual Active Bridge (DAB). Thus the output of DAB is a DC and DAB converts DC - DC. This DC is fed to the inverter of the output stage, which converts the DC to AC at required voltage and power frequency level. This conventional three stage SST system is not suitable for power quality [21, 22] enhancement applications.

2.2 Modified Three Stage SST System

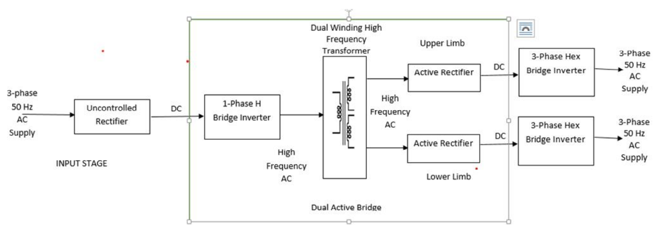


Figure 2: Modified DAB based 3 Stage SST

The modified three stage SST system was proposed [20]. It is similar to the conventional system but varies with operation. The input stage has a 3-phase uncontrolled rectifier which converts three phase AC to DC. This uncontrolled DC is fed as input to the inverter of the DAB stage. The inverter used in DAB stage is a H-Bridge single phase inverter that converts uncontrolled DC to high frequency AC. The switching frequency of this inverter is 25 kHz. This high frequency converter is fed to the dual secondary winding transformer, which induces the secondary voltage at same 25 kHz frequency. The dual secondary winding assists the system for load sharing. The induced secondary high frequency AC voltage is fed to the active rectifiers available at both the limbs of the transformer. They produced DC output voltage. This intermediate DAB stage converts DC – DC. In the output stage, there is a hex bridge three phase inverter.

Table 1: System Specifications

Input Voltage	11 kV
Total Capacity	100 kW
Output Voltage	415 V, 3-Phase
Operating frequency of transformer	25 kHz
Minimum loads connected in secondary	Total 50 kW (25 kW each in upper and lower limbs)

It converts the DC from DAB to AC at desired voltage level and frequency. The AC voltage thus produced at the power frequency level is applied to across the load terminals. This is the operating principle of modified three stage DAB with dual secondary windings. The proposed system was simulated with the specifications given in table 1, in order to study its performance.

3. ANN-SST SYSTEM

3.1 Background of ANN-SST System

ANN is an artificial intelligence technique, which utilizes human expertise to produce desired results. Many researchers have proposed ANN based SST for various applications. An ANN based Series active power filter based SST system for self-excited induction generator is presented [17]. The performance of neuro-fuzzy controller based power electronic transformer is analyzed [18]. ANN-PI based hybrid SST system with reduced switch cascaded multi-level inverters are presented [19]. In this paper, the ANN-SST system was proposed to achieve desired voltage and enhanced power quality parameters [23].

3.2 ANN-SST System

ANN-SST system developed in this paper is based on Levenberg ANN model. It determines the error between the set and actual load voltages. Based on the error, the ANN system generates the required change in frequency level to modify the switching frequency of the input inverter in the DAB stage. The proposed Levenberg ANN-SST model is a simple which consists of one hidden layer with 10 neurons. 57 input and output data sets trained the ANN-SST system. The input function is the voltage error and the output function is the change in frequency required. The block diagram of the proposed ANN-SST system is depicted in Figure 3.

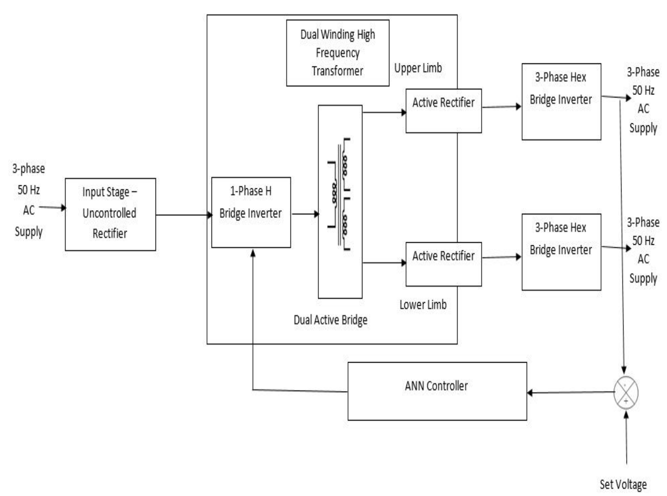


Figure 3: Block Diagram of Proposed ANN-SST System

4. SIMULATION STUDIES

The simulation model of the proposed ANN-SST system is shown in Figure 4. The system measures the voltage error function and feeds it as input to the ANN system. The weights and bias functions of the input adjust themselves based on the error values. Then they are fed to the hidden layer, where they produce the required output as pet the data by which they are trained. ANN system, selection and progress of Levenberg ANN model are illustrated in Figure 5.

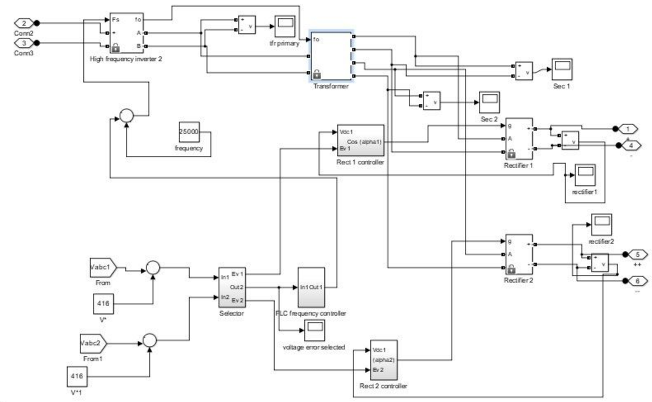
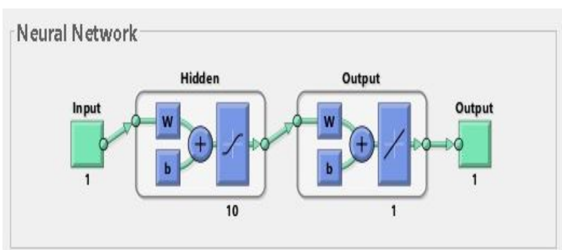
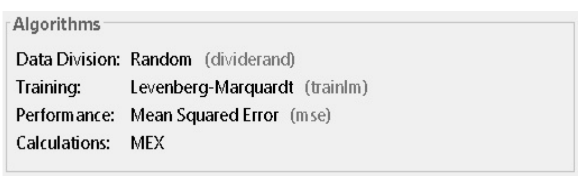


Figure 4: Simulation Model of proposed ANN-SST System



(a) ANN Network



(b) Levenberg Algorithm Selection

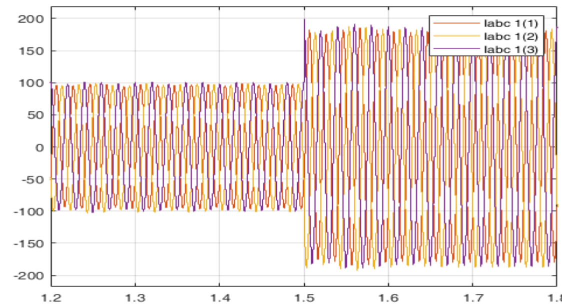
(c) Progress of Simulation

Figure 5: Levenberg ANN Model of Proposed SST System

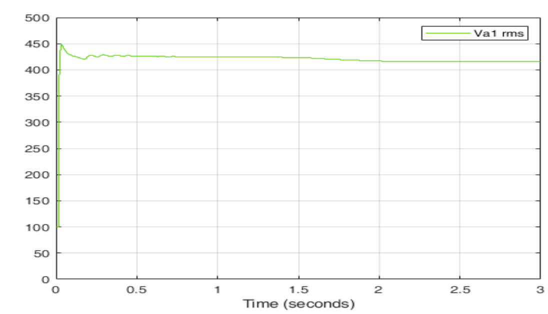
The bias and weightage functions of the ANN model are automatically updated. The mean square error obtained at the end of 152 epoch is found to be 0.415 which is less than 1. As the MSE and time are less, Levenberg model of ANN-SST system is found to be an effective system.

4.1 Simulation Results

ANN-SST system is simulated with equal load of 25 kW on each limb, at t t = 0 seconds. Then at t = 1.5 seconds, the load on the system is varied to study the voltage sag and swell compensations. When load is increased it causes voltage sag and when load decreases, it causes voltage swell. The load voltage on these conditions are observed and presented as in Figure 6. The results infer that the system provided sufficient compensation, such that both voltage sag and swell are mitigated in this proposed ANN-SST system. The THD and power factor of the simulated ANN-SST system is portrayed in Figure 6.

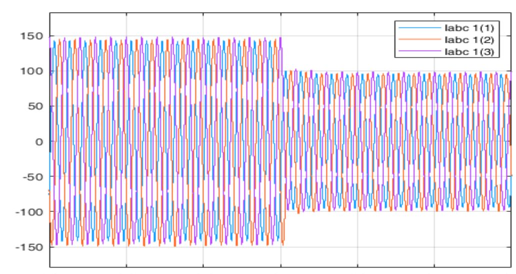


(i) Load Current

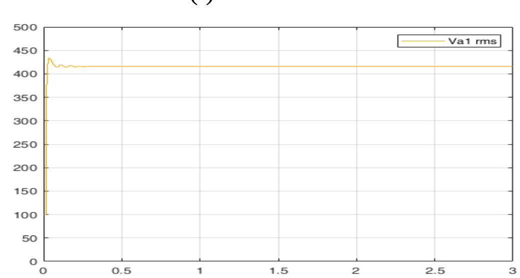


(ii) Load Voltage

(a) Sag Condition

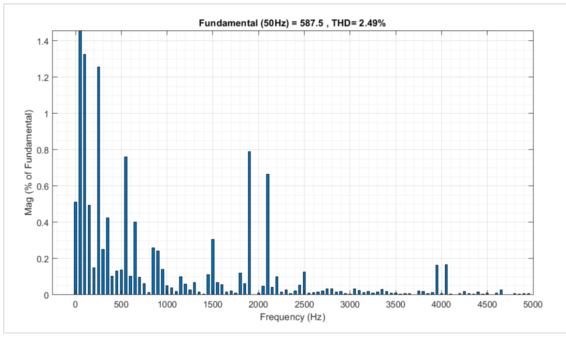


(i) Load Current

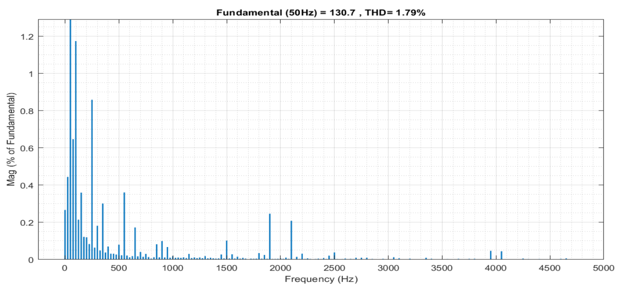


(ii) Load Voltage

(b) Swell Condition

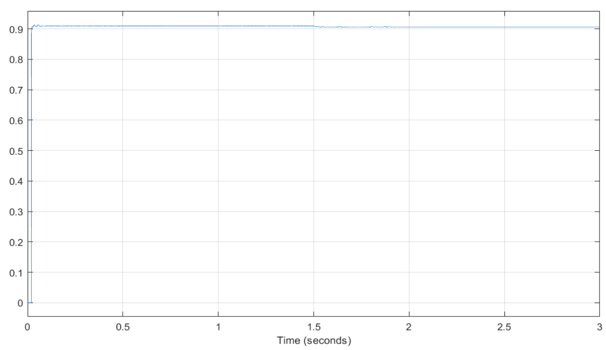


(i) Voltage



(iii) Current

(c) THD



(d) Power Factor

Figure 6: Simulation Results

5. COMPARATIVE ANALYSIS

A comparative analysis is made between the uncompensated and proposed ANN-SST system on the parameters of rms value of load voltage, rms value of load current, THD and power factor. The comparative analysis is made from the simulated results as tabulated in Table 2.

Table 2: Comparative Analysis

Parameter	Uncompensated System	ANN-SST System
Load Voltage (V)	404.5	415.5
Load Current (A)	95.4	92.4
THD – Voltage	3.02	2.49
THD – Current	2.5	1.79
Power Factor	0.83	0.907

The rms value of load voltage of ANN-SST system is found to be 415.5 v, whereas the uncompensated system produced only 404.5 v. This shows that desired output voltage as per Table 1, is not achieved with the uncompensated system. But the proposed ANN-SST system provided better desired load voltage. The rms value of load current of the ANN-SST system is 92.4 A, which is lower than the uncompensated system as 95.4 A. The reason is the improvement in the power factor of the ANN-SST system. It resulted in power factor of 0.907, whereas the power factor of the uncompensated system is 0.83, less than 0.9. The THD offered by both the systems of study is less than 5% as per IEEE 515 2014 standard. The ANN-SST system still offered lesser voltage and current THDs as 2.49% and 1.79% respectively, compared to uncompensated system. The uncompensated system showed THD of 3.02% and 2.5% for voltage and current functions respectively. These results infer that the ANN-SST system offered better power quality parameters.

6. CONCLUSION

ANN driven modified three stage DAB with dual secondary winding SST system has been proposed. The working principle and the simulation model of the proposed system are detailed. The simulation studies are carried out on the power quality aspects. A comparative analysis has been made between the uncompensated and proposed ANN-SST system. The ANN-SST system resulted with higher load voltage of 415.5. V, which is at the desired level. The voltage of uncompensated system was only 404.5 V. The rms value of load current of ANN-SST is reduced as 92.4 A, but the uncompensated system resulted with 95.4 A. The power factor of the ANN-SST system improved as 0.908 whereas the uncompensated offered only 0.83. The THD values of the ANN-SST system are less than uncompensated system and is within the permissible limit as per IEEE 515 2014 standard. These results infer that the proposed ANN-SST has an edge over its counterpart and can be suggested for enhanced power quality applications.

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