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Fuzzy Logic Fed Novel Dual Winding Solid State Transformer based on Dual Active Bridge for Power Quality Improvement

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ABSTRACT

Solid State Transformers (SST) are based on power electronic compoenents. They operate at very high frequency thereby possesing reduced size and volume. Their high frequency operation is realized through power conversion stages in the dual active bridge (DAB). These transformers are aimed for power quality enhnacemnt. A novel two winding SST driven by fuzzy logic is proposed in this paper. The proposed SST has been simualted and analyzed through MATLAB/Simulink. The simulation results infer that the proposed SST scheme mitigated voltage sag, swell and provided better THD thereby improving the power quality of the system.

Key words : Solid State Transformer (SST), Dual Active Bridge (DAB), Dual Windings, Voltage Sag, Swell, Total harmonic Distortion (THD)

1. INTRODUCTION

Transformers are used for power transfer without change in frequency. Wide range of power transmission to several kilometers of distance are made feasible with the help of transformers. Generally transformers are operated at power frequency say 50 Hz or 60 Hz. Those which operate in any of these frequencies are called as conventional transformers. The problems associated with conventional transformers are size, weight and volume. When conventional transformers are employed for large distance power transmission or distribution, their size increases with increase in the capacity. This in turn increase their volume and space occupancy. Development of power electronic devices and their high frequency operations can replace the conventional transformer. Already developed a transformer based on semiconductor devices. This transformer has various power conversion stages like AC/DC and DC/AC. Soft switching is developed based DC/Dc converter for high power density applications. Soft switching is applied for high frequency and power applications. The Dual Active Bridge (DAB) based SST operating at 100 kHz frequency is proposed. Enhanced the operation of this DAB with bidirectional power flow capability is already done [1].

Increasing the frequency reduces the size, weight and volume of the transformer was analyzed. They suggested such transformers for power distribution systems. A high frequency switched transformer was found to be economically viable as its maintenance cost was low and also it provided higher efficiency even at 50% of loads. High frequency AC link matrix converters well suit the SST applications. The bidirectional capability of power flow and enhanced power quality of such transformers demonstrated. Optimum design of converters for SST was proposed.

Distributed generation and the concept of microgrids are upcoming since the early 2000s. A SST for grid connected photo voltaic systems are developed earlier. A three sate SST with Dual Active Bridge (DAB) and tested it for power quality issues of residential PV system are simulated. Dynamic current referred high frequency SST [2] finds well suited for isolated battery charges, and integration of distributed energy resources. The SST on power quality aspects of total harmonic distortion (THD) is examined [3], voltage sag and swell parameters. Conventional transformer was replaced by [4] wind energy system with SST. A novel compact SST with inductors was proposed [5]. AC-DC isolated multilevel inverters based SST topology was proposed [6] for traction systems. Modified DC power electronic transformer based on series connection of full-bridge converters suggested by [7] has reduced number of power electronic devices and resulted with enhanced power quality improvement [8]. All these studies revealed the necessity for a solid state transformer with dual active bridge configuration [9].

The further sections of this paper are organized as follows. Section 2 deals with the SST topology. Modified SST with dual winding transformer and DAB is discussed in Section 3. Fuzzy driven SST with DAB is detailed in Section 4. The Simulink model and the results were presented in Section 5. The proposed system and its capability to enhance power quality are briefed as conclusion in Section 6.

2. SST TOPOLOGY

SST is developed for power quality improvement. SST was develop in various topologies as single stage, two-stage and three-stage. The most commonly used topology is three stage topology which is depicted in Figure 1. It consist of an input rectifier stage, DC-DC Dual Active Bridge (DAB) and output inverter stage. The DAB provides DC isolation between the power conversion stages and has a transformer which operates at high frequency.

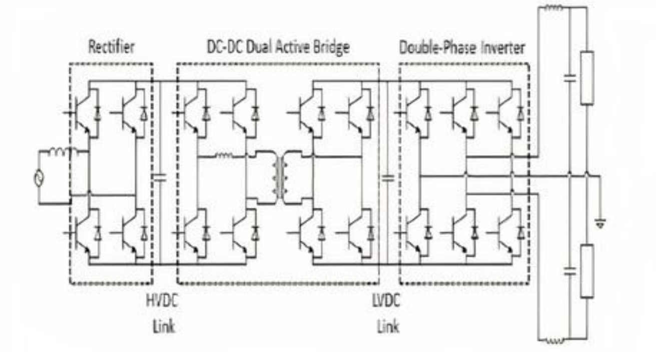


Figure 1: Three Stage Solid State Transfromer

2.1 Conventional Three-Stage SST

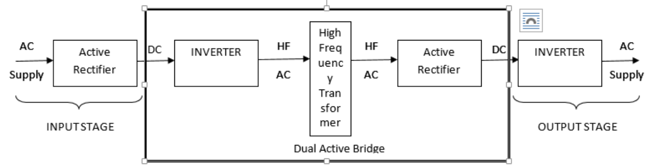


Figure 2: Conventional 3 Stage SST

The block diagram of conventional three stage SST is displayed in Figure 2. As mentioned earlier, the conventional 3 stage SST system has the input rectifier stage with active controlled rectifier. Rectified DC is converted into high frequency AC through the inverter. This is the first conversion of the DAB. The high frequency AC is transformed via transformer and fed to the active rectifier. Thus the output of DAB is also DC. This DC is converted to AC through inverter in the output stage and fed to the loads. Too many switching devices are employed in the system, which results in increased switching losses. It also affects the power factor and the THD of the system. To enhance the power quality improvement, a modified SST is proposed in this paper.

3. MODIFIED SST WITH DUAL WINDING TRANSFORMER

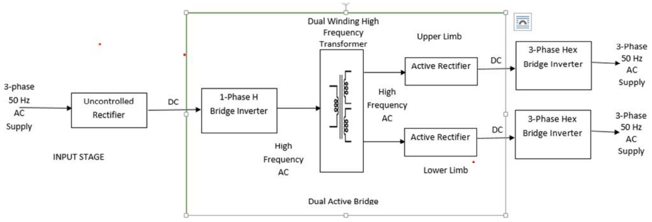


Figure 3: Modified 3 Stage SST

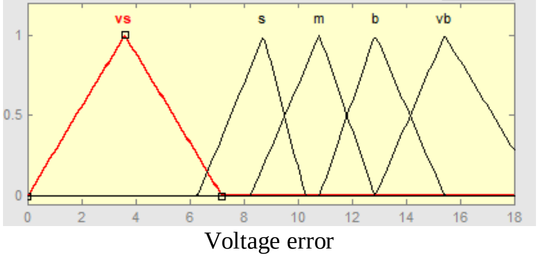
Figure 3 illustrates the proposed mdofied 3 stage SST. It consists of an uncontrolled rectfier in the input rectifier stage, which converts AC supply to DC. The DC is converted to AC in the signle phase H bridge inverter operating at freqeuncy of 25 kHz. This AC is fed to a single phase high frequency transformer whose operating frequency is 25 kHz. High frequency transformer used here has a dual winding in the seocndary. This enables the load sharing among the secondary windings. Both the upper and lower limbs of the high frequncy transformers are connected with loads through active rectifiers and three phase hex bridge inverters. The output of the hex bridge inverters are 3-phase AC with power frequency of 50 Hz or 60 Hz, to which the loads are connected. These mdofications of the proposed thre stage SST assists the system by providing improved power quality parameters under various test condiitons. The specifications of the system are given in Table 1.

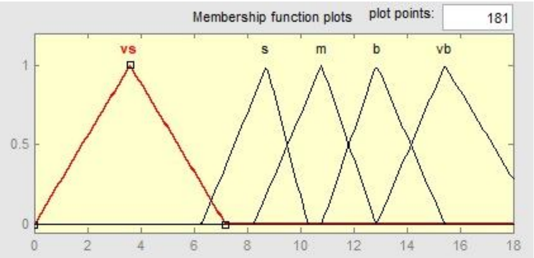
Table 1: System Specifications

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)

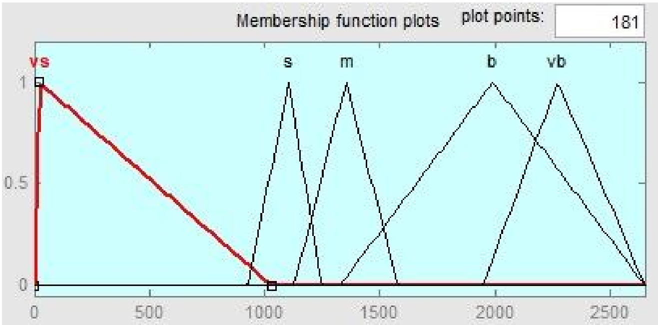
4. FUZZY LOGIC FED MODIFIED SST

In the proposed modified 3-stage DAB based SST system, fuzzy technique has been applied to drive the single-phase H bridge inverter. According to the load variations, the switching frequency of the system is varied, there by the voltage remains stable. The fuzzy logic approach aimed here is a mamdani fuzzy model. The voltage error and change in voltage error are measured from both the upper and lower limbs and are taken as input to the fuzzy system. Desired change in the frequency is the output obtained from the fuzzy block. This in turn drives the single phase H bridge inverter and operates it at the required frequency, thereby enhancing the voltage level. Triangular membership functions are used to define the input and output of the fuzzy rule base. The fuzzy rule based formed from the membership functions are shown in Table 2. The input and output membership functions are depicted in Figure 4. The membership functions are defined as Very Small (VS), Small (S), Medium (M), Big (B) and Very Big (VB).





Change in Voltage error
(a) Input



Change in frequency
(b) Output

Figure 4: Fuzzy Membership Functions

Table 2: Fuzzy Rules

Input Function		Output Function
Voltage Error	Change in Voltage Error	Change in Frequency
VS	VS	VS
S	S	S
M	M	M
B	B	B
VB	VB	VB

Based on the rules formed from Table 2, the change in frequency is determined. This is the frequency at which the single phase inverter in the input side of DAB is to be switched.

5. SIMULATION MODEL

The simulation model of the proposed modified system is shown in figure 5. The proposed Fuzzy Logic based system is simulated at various load conditions. The base switching frequency is 25 kHz. Loads of 25 kW each are connected in the upper and lower limbs of the secondary of the transformer. Additional loads are connected to the system and based on them the power quality parameters viz. voltage sag, swell and THD are measured.

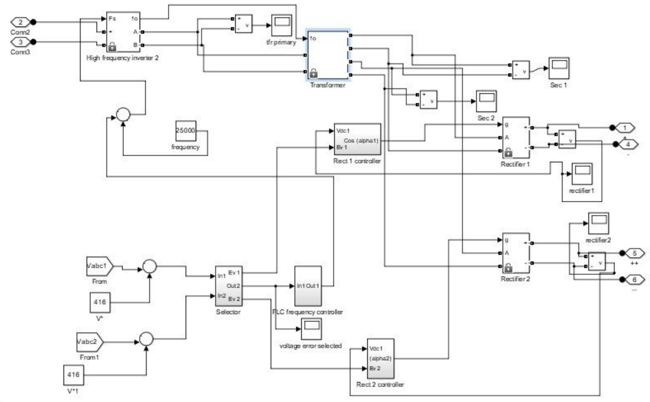
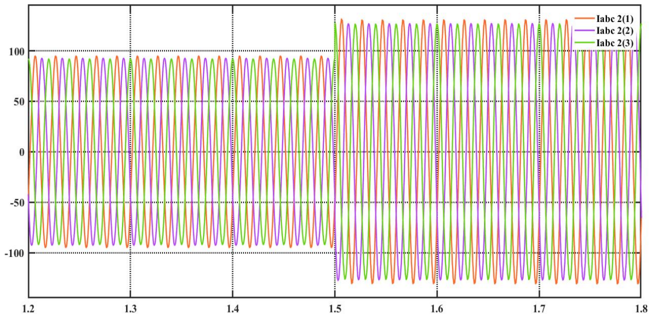


Figure 5: Simulation Model

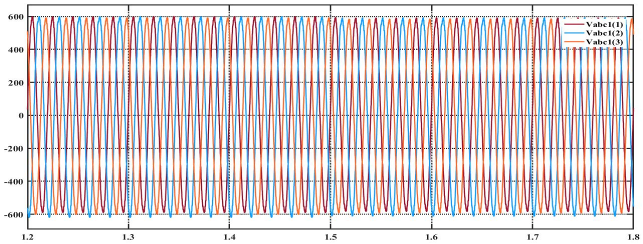
The output voltages of both the limbs are measured and error is generated with the reference. When the load is increased, the load voltage gets reduced. This causes voltage sag. Accordingly the input frequency is increased so the output voltage increases. There by the voltage sag is mitigated. When there is a sudden decrease in the load, voltage swell occurs. Based on the output voltages, the system frequency is reduced, so that the output voltage is also reduced. By this the voltage swell is compensated in the system.

5.1 Simulation Results and Discussions

Figure 6 shows the current and voltage waveforms mitigated due to voltage sag and swell. When the load increases, the load voltage decreases causing voltage sag. It is determined from the current and voltage values of the system and accordingly the frequency of the inverter is increased and so the voltage is restored. Swell occurs when the load decreases. At that time, the frequency is reduced to restore the required voltage. These are evidenced from the waveforms depicted in Figure 6.

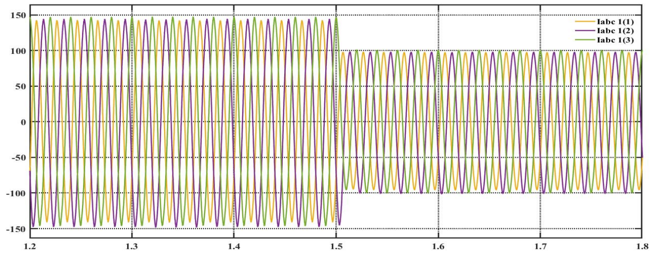


(i) Current Waveform

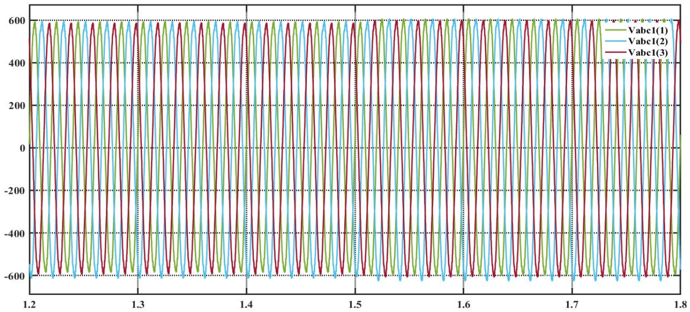


(ii) Voltage Waveform

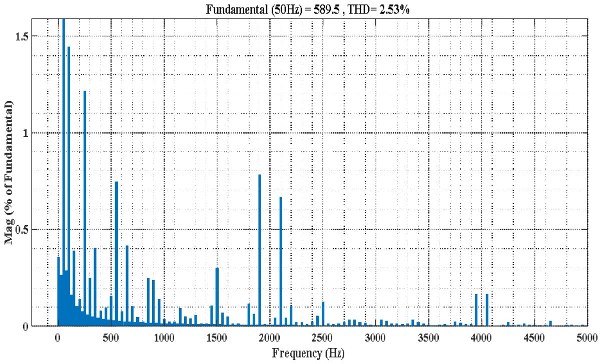
(a) Sag Condition



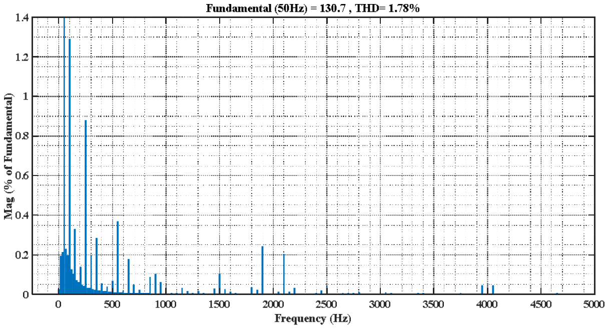
(i) Current Waveform



(ii) Voltage Waveform
(b) Swell Condition



(i) Voltage THD



(ii) Current THD
(c) THD Values
Figure 6: Simulation Results

The THD values of the system are measured at fundamental power frequency of 50Hz and 50% load conditions. The voltage and current THD functions are found to be 2.53% and 1.78%.

6. CONCLUSION

A fuzzy logic driven novel solid state transformer with dual winding transformer fed by dual active bridge has been proposed. The MATLAB/Simulink model of the proposed system has been developed and the simulation results have been analyzed. The simulation results shows that the proposed SST system mitigated effectively the voltage sag and swell conditions. The THD analysis at the fundamental frequency was found to be 2.53% for voltage and 1.78% for current. The THD values are within the standards of less than 4%. These results evident that the proposed fuzzy driven SST with dual winding transformer can be effectively used for power quality enhancements.

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