DVR with Modified Y Source Inverter and MCFC

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***Abstract*—Power quality is a big challenge nowadays. Various disturbances present in the power system are voltage sag, voltage swell, harmonics, transients, interruptions, voltage collapse etc. To solve the problem of power quality, various custom power devices are generally used in a power system, dynamic voltage restorer (DVR) being one of them. DVR is used for the compensation of voltage sag and swell. In this paper, a model of DVR with molten carbonate fuel cell (MCFC) and Y source inverter is proposed. The proposed model is compared with the existing ones to check its performance characteristics. MATLAB/SIMULINK was been used to check and compare the performance of the proposed with existing models.**

Keywords-Y source inverter; DVR; MCFC

I. INTRODUCTION

Most conventional inverters commonly used in power systems are voltage source inverters (VSI) and current source inverters (CSI). These traditional voltage source inverters have two major drawbacks: AC output voltage is less than the DC input voltage, so it is operated only in buck mode, and two switches in the same phase leg cannot turn on simultaneously, since this will create a short-circuit in the system. To overcome these problems impedance network has proven to be more effective and efficient in power conversion between the source and the load over a wide range of electric power applications. Various impedance networks have been proposed with Z-source [1] impedance being the pioneer and prominent network. It has been used in DC-DC [2], DC-AC [3], and AC-AC [4]. In the later stages some modified Z-source inverters were proposed like quasi-Z [5, 6], embedded-Z [7, 8], series-Z [9] etc. Authors in [12] applied Z source inverter in DVR along with molten carbonate fuel cell (MCFC). This improved the performance of the system to a great extent. In this paper, Y source inverter has been used in the DVR with MCFC and its performance has been compared with existing models [10, 11]. The proposed Y-source inverter consists of a DC source, Y-impedance network and pulse width modulation (PWM). The complete model has been simulated in Matlab/Simulink. A comparison between different network topologies based on passive components count is shown in Table I.

II. PROPOSED Y SOURCE INVERTER

The proposed Y-source network in this study has a diode D, two capacitors C1 and C2 and a three winding transformers (W1, W2 and W3), as shown in Figure 1.

TABLE I. COMPARISON TABLE

Name of Inverter	Number of Capacitors	Number of Inductors	Number of Diodes
Z Source	2	2	1
Quasi Z Source	2	2	1
Γ Source	2	1 inductor, 2 windings	1
Trans Z Source	2	1 integrated, 2 windings	1
Y Source	1	1 integrated winding	1

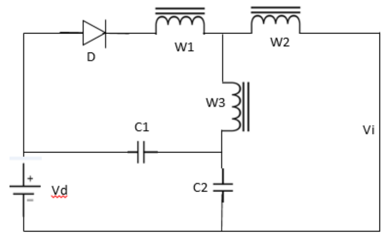

Fig. 1. Proposed Y source inverter.

The proposed Y-source network has a shoot-through and non-shoot-through operation. For shoot-through-operation the circuit is shown in Figure 2.

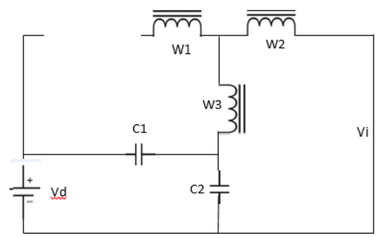

Fig. 2. Circuit for shoot-through operation.

Let V_{W1} be the voltage drop across W1. Then from the circuit of Figure 2 we have:

$$V_d + V_{C1} = V_{C2}$$

$$V_d + V_{C1} = \frac{V_{W1}}{\frac{N_1}{N_3}} - \frac{V_{W1}}{\frac{N_1}{N_2}} = \frac{V_{W1}(N_3 - N_2)}{N_1}$$

or $V_{W1} = \frac{(V_d + V_{C1})N_1}{N_3 - N_2}$ (1)

The circuit for non-shoot-through operation is shown in Figure 3. Let, V_i be the DC link voltage, *dsh* the shoot through zero state of the inverter and *M* the modulation index.

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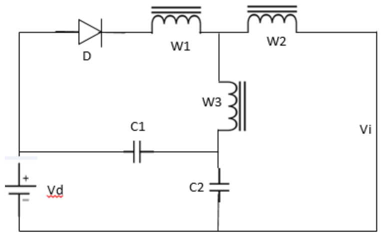

Fig. 3. Circuit for non shoot through operation.

From the circuit of Figure 3 we have:

$$V_{W1} = -\frac{\frac{N_1}{N_2}}{1+\frac{N_1}{N_2}} V_{C1} \quad \text{, or}$$

$$V_{W1} = -\frac{N_1}{N_1+N_2} V_{C1} \quad (2)$$

And

$$V_{dc} = V_i + V_{W1} + \frac{V_{W1}}{\frac{N_1}{N_2}} \quad \text{, or}$$

$$V_{dc} = V_i + V_{W1}\left(\frac{N_1+N_2}{N_1}\right) \quad (3)$$

Again, $V_{C1} = \frac{\left(\frac{1+\frac{N_1}{N_2}}{\frac{N_3}{N_2}-1}\right)dsh}{1-\left(\frac{1+\frac{N_1}{N_3}}{1-\frac{N_2}{N_3}}\right)dsh}$, or

$$V_{C1} = \frac{\left(\frac{N_1+N_2}{N_3-N_2}\right)dsh}{1-\left(\frac{N_3+N_1}{N_3-N_2}\right)dsh} \quad (4)$$

and $V_{C2} = \frac{1-dsh}{1-\left(\frac{N_3+N_1}{N_3-N_2}\right)} V_{W1}$ (5)

The peak value of the DC link voltage of the inverter is:

$$V_i(dcp) = \frac{1}{1-\left(\frac{N_3+N_1}{N_3-N_2}\right)} V_{W1} \quad (6)$$

The peak value of AC voltage per phase:

$$V_i(acp) = \frac{M}{1-\left(\frac{N_3+N_1}{N_3-N_2}\right)dsh} \frac{V_{W1}}{2} \quad (7)$$

If the values of the capacitor C_1 and C_2 are selected properly then the network can give continuous current with very little ripple.

III. CONTROL TECHNIQUE

For the proposed model, the same fuzzy controller as in [12] has been used. The Simulink model of fuzzy controller is shown in Figure 4.

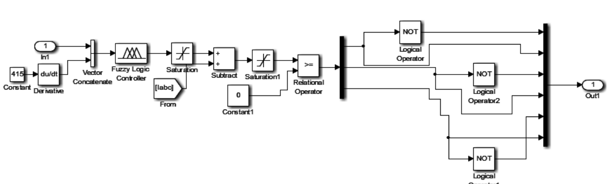

Fig. 4. Fuzzy control technique.

IV. PROPOSED MODEL

The proposed Y source inverter has been applied to the DVR model with MCFC [12]. The complete Simulink model of the DVR with MCFC, ultra-capacitor and Y source inverter is shown in Figure 5.

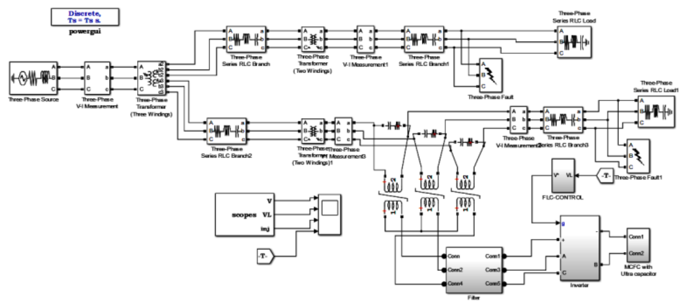

Fig. 5. Proposed DVR model with Y source inverter.

The schematic model of a MCFC is shown in Figure 6. A fuel cell converts chemical energy into electrical energy. In MCFC CO_2 gas moves from the cathode to the anode through a molten electrolyte. Here molten carbonate salt acts as an electrolyte where two porous electrodes are present. The electrode layer is formed in sub layers. Between the gas and the electrode a thin porous metal plate is inserted. This acts as a diffuser, it helps in helping the gas mixture to enter into the porous electrode. When the CO_2 combines with O_2 in the cathode gives carbonate ions and when it combines with hydrogen in the anode side it gives CO_2 and H_2O. So there will be a movement of electrolyte from the anode's side to the cathode side. The gas reaction at the anode side is:

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

The electrochemical half reaction is:

$$H_2 + CO_3^{--} \leftrightarrow CO_2 + H_2O + 2e$$

Similarly the equation of cathode side will be

$$\frac{1}{2}O_2 + CO_2 + 2e \leftrightarrow CO_3^{--}$$

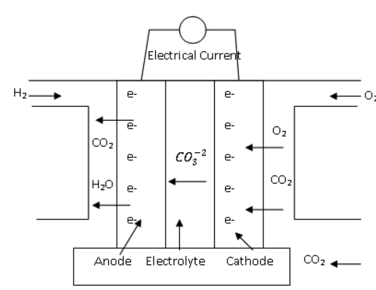

Fig. 6. MCFC

The equivalent electrical circuit of a singular cell MCFC can be seen in [13]. Authors in [12] provided the details of the operation of MCFC and the detailed Matlab/Simulink representation of MCFC and its application in DVR. In this paper the same MCFC model with DVR has been used. The new proposed Y source inverter in this paper has been applied to this model. The proposed model in this paper is compared with the model of DVR with MCFC, ultra-capacitor and Z source inverter presented in [12]. The system parameters used for testing are given in Table II.

TABLE II. SYSTEM PARAMETERS

Parameters	DVR with Z source inverter [12]	Proposed DVR with Y source inverter
Voltage	120V	120V
Frequency	50Hz	50Hz
Transformer	1KVA	1KVA
Load	R L	R L
DC source	MCFC	MCFC
Type of inverter	Z sourced	Y sourced
Filter	R=0.4Ω, L=3mH, C=25μF	R=1.3Ω, L=38mH, C=195μF

V. Simulation Results

The profile of supply voltage, load injected voltage and load voltage of the new proposed DVR with Y source inverter and MCFC is shown in Figure 7. The profile of the new proposed DVR for single phase sag and swell is shown in Figure 8. The profile of the new proposed DVR for three phase sag and swell is shown in Figure 9. The comparison of the proposed DVR with Y source inverter and the DVR model of [12] is given in Table III. The THD analysis of the model in [12] is shown in Figure 10 and the THD analysis of the proposed model is shown in Figure. 11.

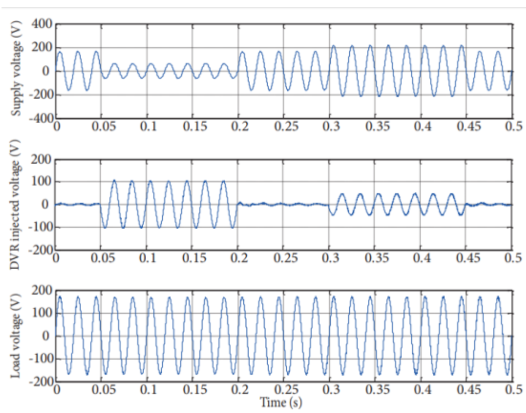

Fig. 7. Profile of proposed DVR with Y source inverter.

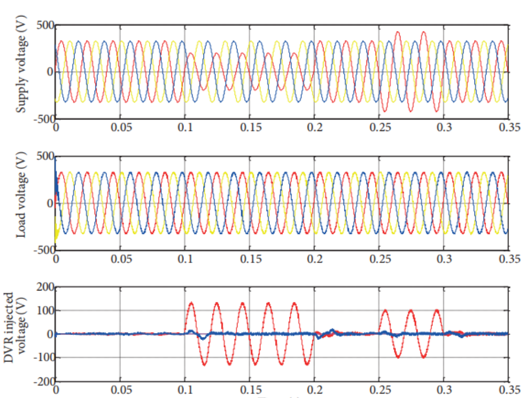

Fig. 8. Single phase sag and swell profile of proposed DVR.

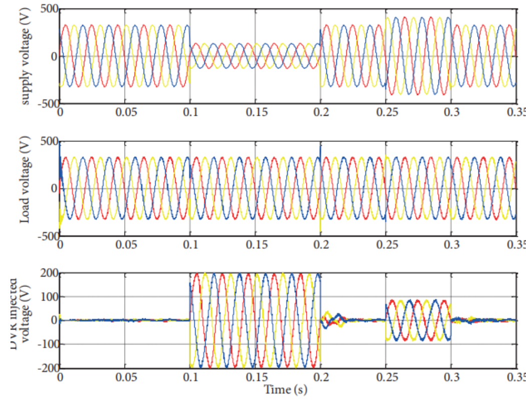

Fig. 9. Three phase sag and swell profile of proposed DVR.

TABLE III. COMPARISON TABLE

Percentage of voltage sag	DVR with Z source inverter [12]	Proposed DVR with Y source inverter
	Percentage of THD in DVR injected voltage	Percentage of THD in DVR injected voltage
10	1.5	0.58
30	2.4	0.63
50	2.3	0.72
70	2.2	0.79
90	2.1	0.67

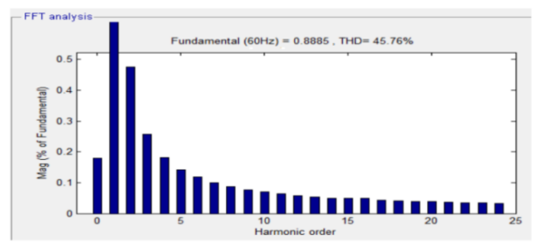

Fig. 10. THD analysis of the model of [12]

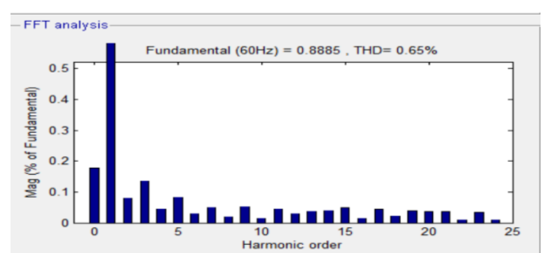

Fig. 11. THD Analysis of proposed model with Y source inverter

VI. Conclusion

The proposed model has been simulated in Matlab/Simulink and gave good convergence with ode23s. But the speed of simulation was observed to be very slow. The proposed inverter has more circuit elements which makes it more complicated. It has been observed that in Y-source inverter voltage gain is very high when operated at higher modulation index. The proposed DVR is capable of injecting appropriate voltages even when the system is subjected to deep voltage sags, without the need to have an energy source of higher rating. The proposed DVR performs robustly with reduced THD in the load voltage while keeping the stored energy requirement low. From the above analysis it is clear that MCFC based DVR with fuzzy control is the most efficient device for the improvement of power quality in the power system. The THD level of the proposed model was found to be low compared with the model proposed in [12]. The proposed model is thus much better in comparison with the model in [12].

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