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PEMFC based Quasi Y-Source DVR for Power Quality Improvement

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ABSTRACT: DVR (Dynamic voltage restorer) is a series connected voltage controlled based custom power device for power quality improvement. Power quality is a big problem in this present era. Voltage sag, swell etc. are the major issues for poor power quality in distribution side. DVR is very fast, dynamic and most economic device than other custom power devices for mitigation of voltage sag and swell. In this paper, A DVR is modelled with PEMFC (Proton Exchange Membrane Fuel Cell), Ultra capacitor, Quasi Y-source Inverter with Passive filter and fuzzy logic controller is proposed. Simulation results are carried out with MATLAB/SIMULINK to verify and compare the performance of the proposed model with existing one.

KEYWORDS: DVR, Ultra capacitor, PEMFC, Quasi Y-Source Inverter, fuzzy logic controller.

I.INTRODUCTION

Due to introduction of various non-linear industrial loads and power electronic devices, power quality improvement has become a serious concern. Voltage sag or swell are the major issues that occur in the shape of sudden voltage fall or rise, which happens greatly due to short circuit conditions. [1] There are many different types of custom power devices for improvement of power quality but DVR is very fast, dynamic and economic device for mitigation of voltage sag and swell. [2] The main parts of DVR as inverter, Filter, energy storage device, controller and isolation transformer to inject or eject the appropriate voltage to clear the power quality problem. [1] The most conventional inverters as voltage source inverter (VSI) and current source inverter (CSI) has two major drawbacks: first drawback as AC output power is less than input DC power so only operated in buck mode, and the second drawback as Two switches in same phase leg cannot turn on simultaneously. Since this will create a short circuit. To solve this problem, a high impedance network has been created between the voltage source and the inverter bridge. So the impedence network employed between voltage source and inverter bridge. In Z-source inverter the voltage can be changed by changing modulation index (MI) and shoot through duty ratio (Dst), So it has two degree of freedom. A proper implementation of Z-source networks with proper switching configurations. And proper modulation and control methods reduce the number of power conversion stages in the power conversion chain. This improves the reliability and performance of the power electronic systems. [5] There are so many modified topologies with active and passive elements have been added in the impedance networks to improve the voltage gain and stress in the network components. By modifying the impedance networks for improving voltage gain etc., So many improved impedance networks has been introduced as magnetically coupled impedance source (MICS) are mostly two – winding including the Γ-Z source, T-source, Trans Z-source, TZ – source, LCCT-Z-source and Quasi-LCCT-Z-source and high frequency – transformer-isolated Z-source. Among these networks, Only LCCT-Z –source and Quasi-LCCT-Z-source draw continuous currents from their sources. Discontinuous input currents from the other networks can create problems when used renewable sources as PV, Fuel cells etc…Various techniques have been introduced for smoothing the currents drawn from the sources. To solve these or other modified network Problems as discontinuous input current, and smoothing the current etc. three winding network is introduced called Y-source Network. Y- Source inverter has three degree of freedom as modulation index (MI), shoot through duty ratio (Dst) and one extra term called winding factor (K). [4] In this paper a Quasi Y-source inverter is used in DVR. The Quasi Y-source Inverter receives all the advantages from original Y-source Inverter. But it is also able to produce a very high voltage gain continuously operating at a higher modulation index. So it can draw

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continuous input current that better suits for renewable sources etc… [5] In this paper a new DVR model implemented in MATLAB/SIMULINK is presented. The proposed DVR model employs a Y-Source inverter and PEMFC (Proton Exchange Membrane Fuel Cell) as its DC source supply with an ultra-capacitor and also using AI based Controller i.e. fuzzy logic controller. The model behaviour is investigated and compared to a more conventional DVR model.

II.DVR

DVR (Dynamic Voltage Restorer) is a very fast, dynamic and economic custom power device and also called series voltage booster (SVB) or Static series compensator (SSC). DVR is a device that utilizes static power electronic components. [4] DVR is a series connected device located between sensitive load and grid in system. It detected both sag/swell problems and injects controlled voltage in the system. To perform this process, DVR injects controlled voltage in series with the supply voltage in phase via injection transformer to restore the power quality. The basic conventional structure of DVR is shown in fig.1.

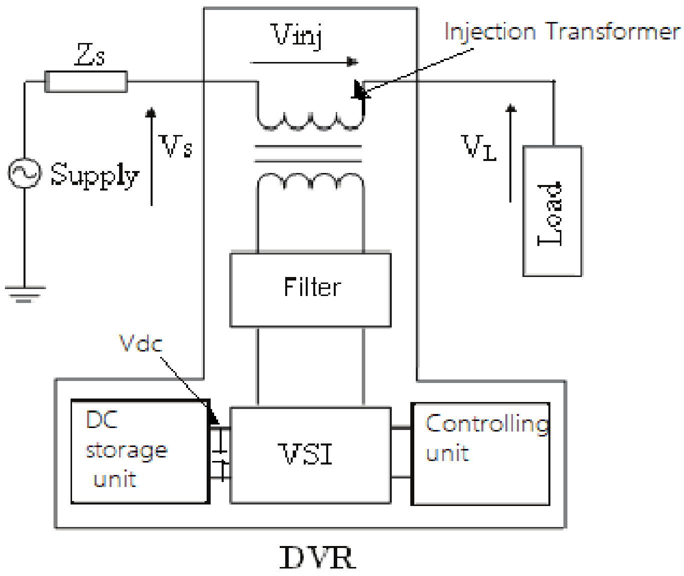

Fig.1 Basic Conventional Structure of DVR

DC energy storage device is storage unit of the DVR and capacitor increases its storage capacity. Inverter converts DC (Direct Current) into AC (Alternating Current) and filter is used for reduction of harmonics and controller is used to increase stability and reliability of the system. Injection Transformer is used to Inject (in case of voltage sag) voltage in the supply voltage in the line and Eject (in case of voltage swell) Voltage in the supply voltage in the line.

III. PEMFC

PEMFC stands for proton exchange membrane fuel cell. PEMFC mainly consists of anode, cathode and a solid state polymer electrolyte membrane. Negatively charged electrode called cathode and positively charged electrode called anode. Hydrated hydrogen ions are supplied at the anode (Positively charged electrode) and air supplied at the cathode (negatively charged electrode). Hydrogen gas is ionized in the presence of platinum (catalyst) into positive and negative charge at anode. As

$H_2 = 2H^+ + 2H^-$

The polymer electrolyte membrane permits only the positively charged Hydrogen ions to flow from anode to cathode. The basic operation of PEMFC is shown in Fig.2. [1]

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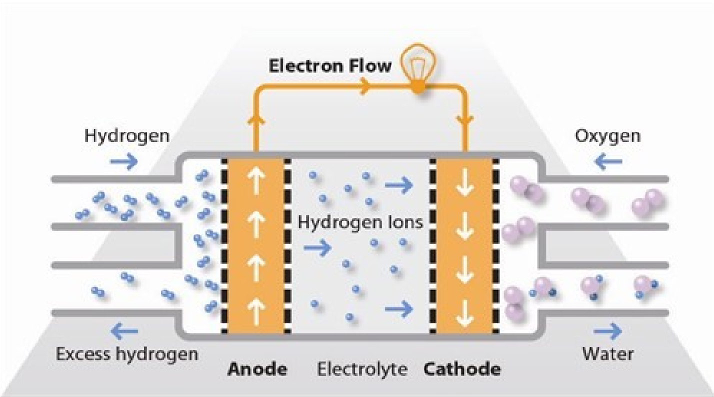
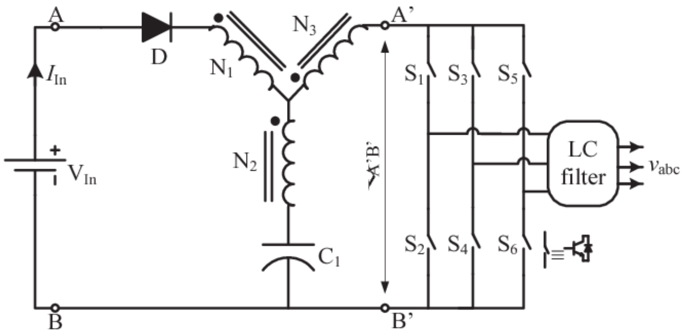


Fig.2 Basic operation of PEMFC

IV.QUASI Y-SOURCE INVERTER

Y-source inverter consists of Y-source network on the input side and a three phase bridge inverter at the output side. Filter is also connected at the output side with the three phase bridge inverter. The Y-source network consists of a passive diode D, and a capacitor C1 and a Three winding transformer (N1, N2, N3) for introducing a high boost at a small duty ratio. The transformer is connected directly to the Inverter Bridge as shown in Fig.3. [4]



(a)

Fig.3 (a) Y-source inverter

Quasi Y-source inverter is the modified form of Y-source Inverter. All advantages of Original Y-source Inverter are already presented in the Quasi Y-source inverter. But Quasi Y-source inverter has additional advantages as continuous input current, Reduce source stress, and lower component ratings as compared with Y-source inverter. So the Quasi Y-source inverter is more suitable for renewable power conditioning systems. The Quasi Y-source inverter consists of two capacitors as C1, C2 and it preserves three winding coupled inductors. I.e. The two capacitors placed such as they block DC current which flowing to the coupled inductor and hence preventing its core from the saturation. C2 is paced in the Y-Source network and additionally DC blocking capacitor C1 and Input Inductor L1 are added. The Diode D is made to switch between the negative polarity of input capacitor C1 and positive rail of the Inverter bridge as shown in Fig.4. [5]

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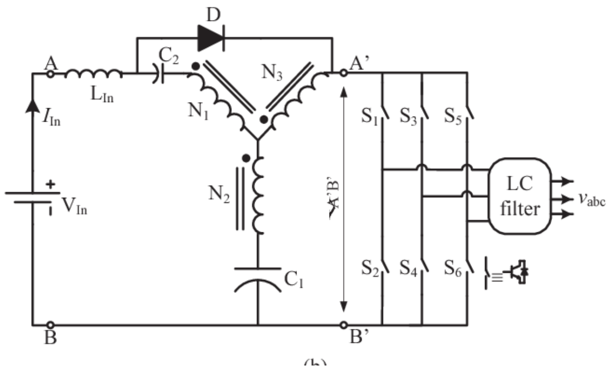

Fig.3 (b) Quasi Y-source Inverter

Like Y-source Inverter, Quasi Y-source Inverter has also an extra shoot through zero state and non-shoot through state which consists of six active states and two zero states.

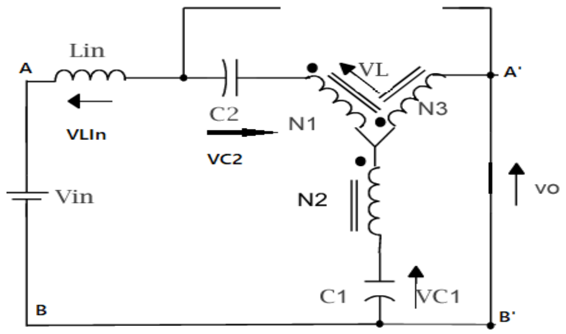

Fig.3 (c) Quasi Y-source Inverter Shoot through state

First state as the shoot through state can be achieved by short circuiting both upper and lower switching devices of any/all phase leg(s) of the inverter. It should be ensure that Equivalent circuit during shoot through across Inverter Bridge i.e. $D_{ST}T$ is shown in Fig.3(c). Form this circuit, we have n_{21}= N2/N1 and n_{31}= N2/N1 are the Turns ratio of the Transformer. The Diode D is open circuited in this interval.

$$Vc1 + n21\ VL - n31\ VL = 0$$

And it can be written as

$$Vc1 + (N2/N1)\ VL - (N3/N1)\ VL = 0$$

$$VL = \frac{N1}{(N3-N2)} Vc1 \qquad (1)$$

$$VIn - VLIn + VC2 - VL - (N2/N1)\ VL - Vc1 = 0$$

$$VLIn = VIn + Vc2 - Vc1 - \frac{N1+N2}{N1} VL \qquad (2)$$

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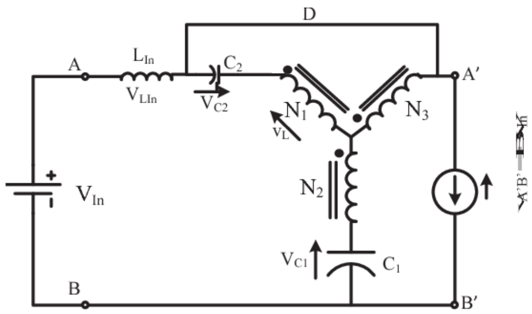

Fig.3 (d) Quasi Y-source Inverter Non-shoot through state.

For second state as Non- shoot through state the Equivalent circuit is shown in Fig.3 (d). In this state the Diode D is forced to conduct.

$$Vc2 - VL - \frac{N3}{N1}VL = 0$$

$$VL = \frac{N1}{(N1+N3)}Vc2 \qquad (3)$$

$$VLIn = VIn + Vc2 - \frac{N1+N2}{N1}VL \qquad (4)$$

$$VIn - VLIn - V0 = 0$$

$$V0 = Vc1 - Vc2 + \frac{N1+N2}{N1}VL$$

State space averaging, for calculation Voltage ratio across C1, C2 then we have to perform with (1) and (3) as. This ratio can obviously be changed by varying dsT, which represents the shoot through time period.

$$\frac{N1}{N3-N2}Vc1\ dsT + \frac{N1}{N1+N3}Vc2\ (1-dsT)\ = 0$$

$$\frac{Vc2}{Vc1} = \frac{N1+N3}{N2-N3}\left(\frac{dsT}{1-dsT}\right) \qquad (6)$$

Repeating state space averaging again as (2) (4) and we got a new expression. So this new expression performs with (6) which derive expressions for individual capacitor voltages.

By performing (2) and (4) we have

$$Vc2 = Vc1 - VIn \qquad (7)$$

By performing (6) and (7) we got some results as

$$Vc2 = \frac{\frac{N1+N3}{N2-N3}\ dsT\ VIn}{1-\frac{N1+N2}{N2-N3}dsT}(8)$$

$$Vc1 = \frac{(1-dsT)VIn}{1-\frac{N1+N3}{N2-N3}dsT} \qquad (9)$$

Dc link voltage across the inverter bridge (V dc-link = VA' VB' and its peak value V*dc-link during the non-shoot through state can be obtained using (3) (5) (8) (9). From which the network voltage boost B =V*dc link / VIn can be determined in terms of transformer winding factor (δ).

Winding factor (δ) is defined as

$$(\delta) = \frac{\mathrm{N1+N2}}{\mathrm{N2-N3}}$$

$$V * dc - link = \frac{1}{\left(\frac{1(N1+N2)}{(n2-N3)}dsT\right)}VIn = \frac{1}{1-\delta\mathrm{dsT}}VIn = BVIn \qquad (10)$$

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Where the boost factor is

$$B = [1 - \delta dsT) - 1 \qquad (11)$$

The peak value for the ac voltage per phase from the inverter output can be derived as

$$V * ac = MB\frac{VIn}{2} = \frac{MVIn}{2(1 - \delta dsT)} \qquad (12)$$

It should be noted that the winding factor of the Quasi Y-source Inverter is deferent from the Y-source Network. However the gain of either network is same for the particular value of the winding factor. [5]

V.SUPER CAPACITOR

Batteries can hold very large amount of power but it takes hours to charge up. But capacitors, charge almost instantly and store only little amount of power. If we need large amount of storage and very fast charging then we have to turn to super capacitor. Super capacitor is also known as Ultra-Capacitor. In batteries electricity stores by conversion of chemical energy into electrical energy. But capacitor uses static electricity i.e. inside a capacitor; there are two conducting metal plates, with an insulating material called dielectrics between them. Positive and negative electrical charges build up on the plates and the separation between plates prevents them coming into contact. I.e. charge stores. And the dielectric allows a capacitor of a certain size to store more charge at the same voltage. The super capacitor is different from ordinary capacitor. Because its plates have much bigger area and the distance between them is much smaller because the separator between them works in a different way to a conventional dielectric.

As in ordinary capacitor, a super capacitor has two plates that are separated. These plates are made from metal coated with a porous substance such as powdery activated charcoal, which effectively gives them a bigger area for storing much more charge. As in ordinary capacitor, The plates are separated by a thick dielectric made from mica etc… When the capacitor is charged, Positive charges form on one plate and negative charges on other plates, which creating a n electrical field between them. The field polarizes the dielectric, Sao its molecules line up in the opposite direction to field and reduce its strength. I.e. the plates can stores more charges at a given time.

In a super capacitor, there is no dielectric like ordinary capacitor. In super capacitor the plates are soaked in an electrolyte and separated by a very thin insulator. When the plates are charged up, an opposite charge forms on either side of the separator, which creates double layer. That's why super capacitor is also called electric double layer capacitors (EDLC). [6] The capacitance of a capacitor increases as the area of the plates increases and the distance between plates decreases. If the combination of plates with large effective surface area (because of their activated charcoal construction) and less distance between them (because of the very effective double layer) then the capacitance of super capacitor increases. The schematic diagram of the super capacitor is shown in Fig.5.

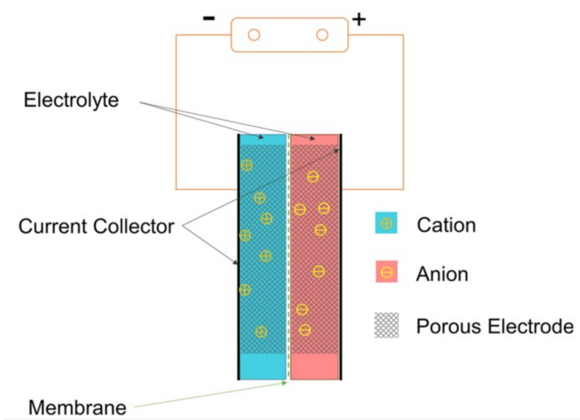

Fig.5 Schematic diagram of Super capacitor

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VI.FUZZY LOGIC CONTROLLER

In the Fuzzy Logic Controller, There are three main elements as Crisp Input, Membership Function and Crisp Output. PI, PID controllers etc. are conventional controllers and Fuzzy Logic controller is AI based i.e. Artificial Intelligence based. Fuzzy Logic Controller increases the efficiency and reliability of the system. In DVR the phase of the Voltage of the Network can be detertmined using PLL (phase lock loop). Determine the phase and consider reference signal as unity at normal supply for each phase of the system. Difference between reference signal of PLL and actual supply voltage gives the error signal. The output of fuzzy logic controller passing through PWM then it generates pulse. And this pulse goes to Inverter bridge for further process.[7]

VII.PROPOSED MODEL

The Proposed DVR model for Voltage sag Compensation is shown in Fig.6 and proposed DVR model for Voltage swell compensation is shown in Fig.7. All internal parts of Proposed DVR model for Both Voltage sag/swell compensation are shown in Fig.8, Fig.9, Fig.10, Fig, 11 and in Fig.12. In this proposed DVR model PEMFC is used as a DC source and Super capacitor is connected with it to Increase the storage capacity of the system. Quasi Y-source Inverter is used with Passive filter and Controller is AI based i.e. Fuzzy logic controller.

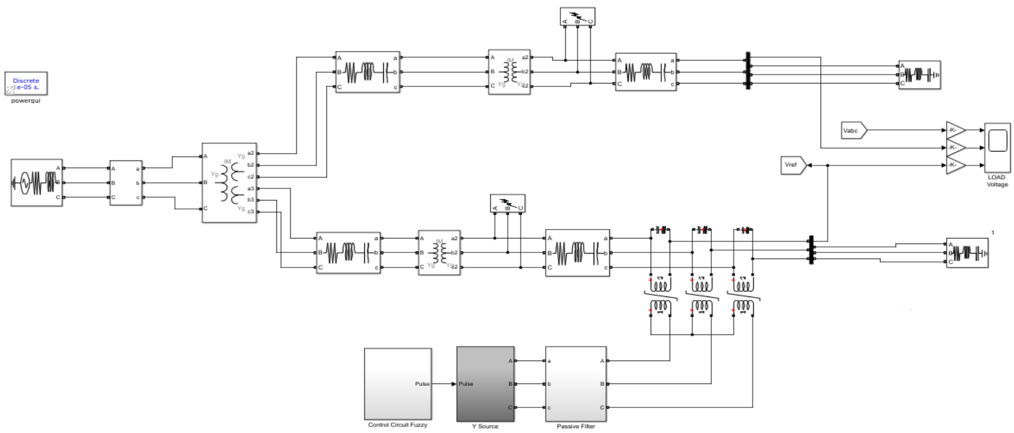

Fig.6 Proposed DVR model for voltage sag Compensation.

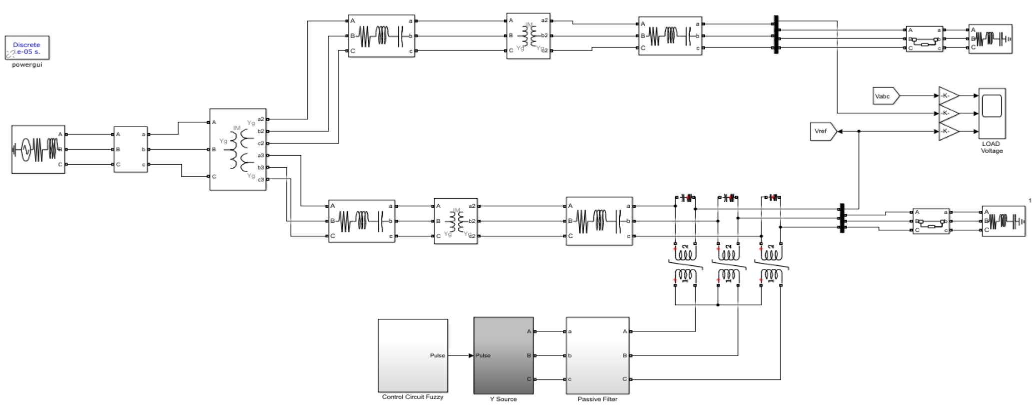

Fig.7 Proposed DVR model for Voltage swell Compensation.

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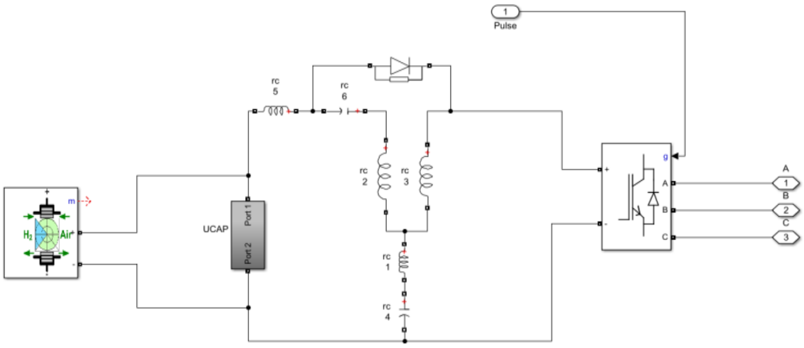

Fig.8 Quasi Y-source Inverter in DVR with PEMFC and Supercapacitor.

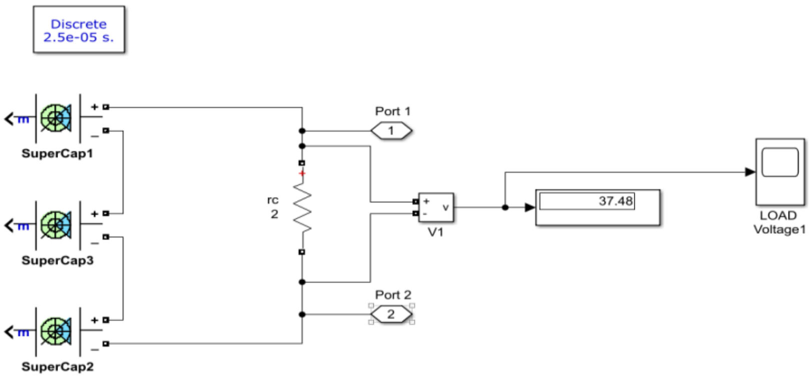

Fig.9 Super capacitor

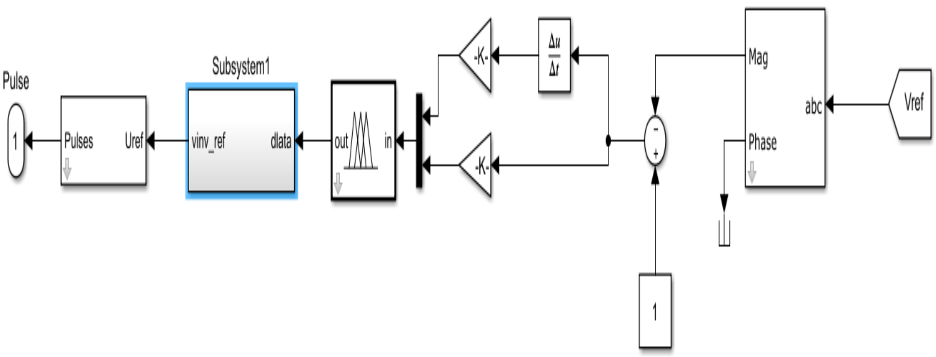

Fig.10 Fuzzy Logic Controller

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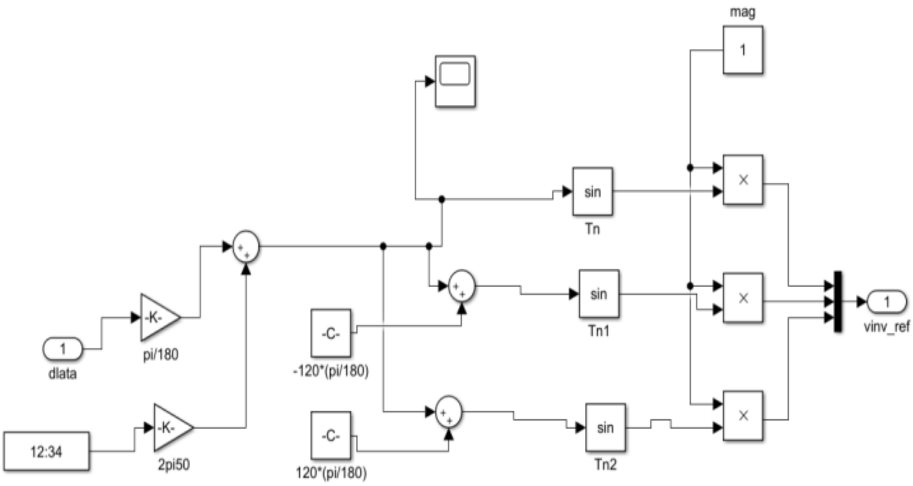

Fig.11 Subsystem 1

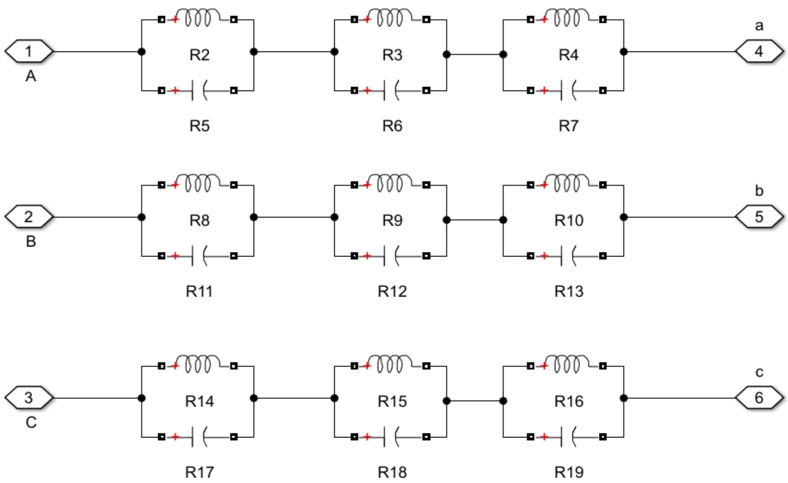

Fig.12 Passive Filter

VIII.SIMULATION RESULTS

The profile of supply input voltage, Profile of load voltage network 1(Faulty network) and Profile of load voltage network 2(DVR connected network) are shown below. The profile of single phase sag, Two phase sag and Three phase sag without DVR and With DVR are shown in Fig.13, Fig14, Fig.15. The profile of Single phase swell, Two phase swell and Three Phase swell without DVR and with DVR are shown in Fig. 16, Fig.17, Fig.18. The comparison of this proposed Quasi Y-source DVR model results with existing (7) Z-source DVR model results are shown in Tabular form in Table1 and Table11. In Table 1 the Comparison of Voltage sag compensation and in table 11 Voltage swell compensation between the proposed model as Quasi Y-source DVR and existing (7) model as Z- source DVR are shown. Abbriviations used In table 1 and table 11 are SLG (Single line to ground), DLG (Double line to ground), TLG (Tripple line to ground) and SLS (Single line switching), DLS (Double line switching), TLS (Tripple line switching).

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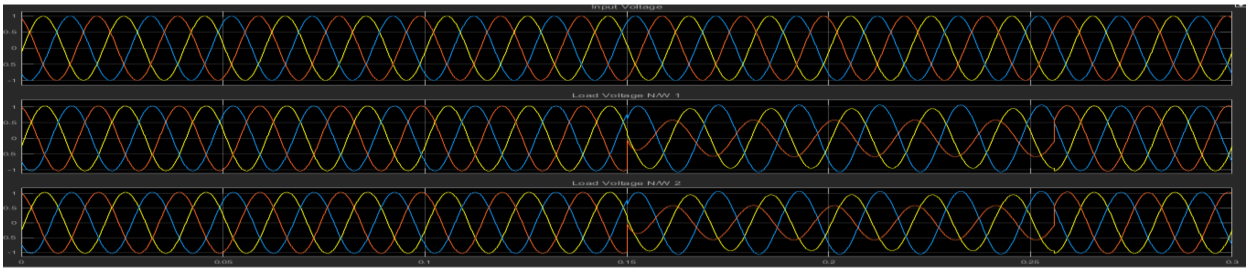

Fig.13(a) Single phase voltage sag without DVR

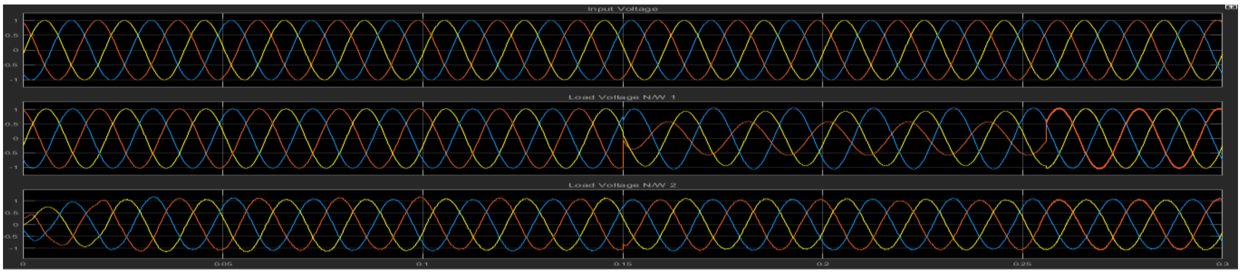

Fig.13(b) Single phase Voltage sag compensation with DVR

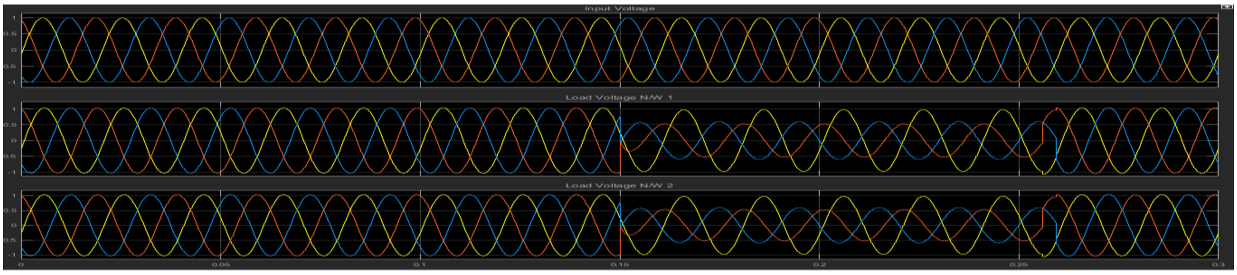

Fig.14 (a) Two phase voltage sag without DVR

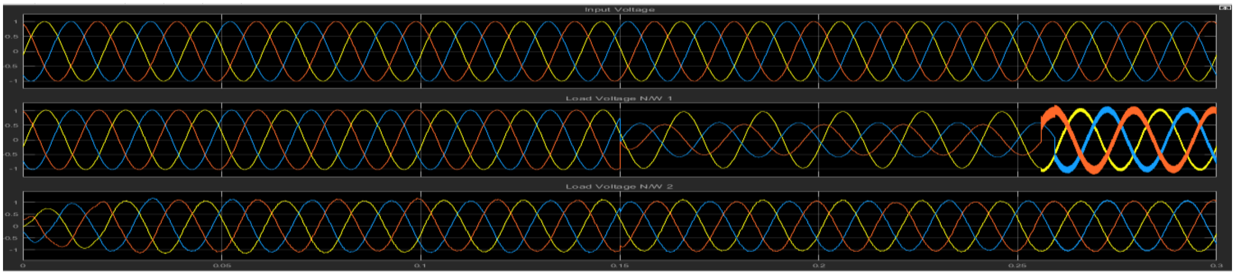

Fig.14(b) Two phase voltage sag compensation with DVR

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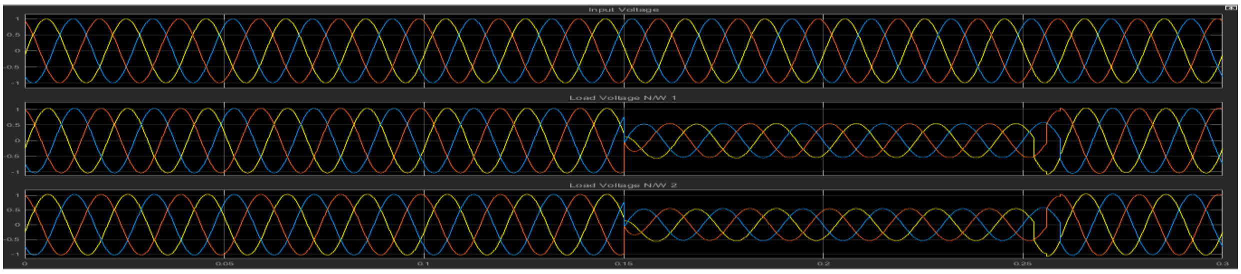

Fig.15 (a) Three phase Voltage sag without DVR

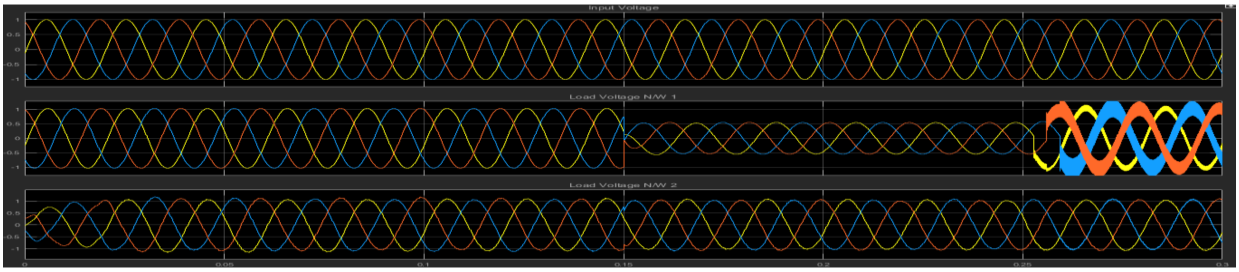

Fig.15 (b) Three phase Voltage sag Compensation with DVR

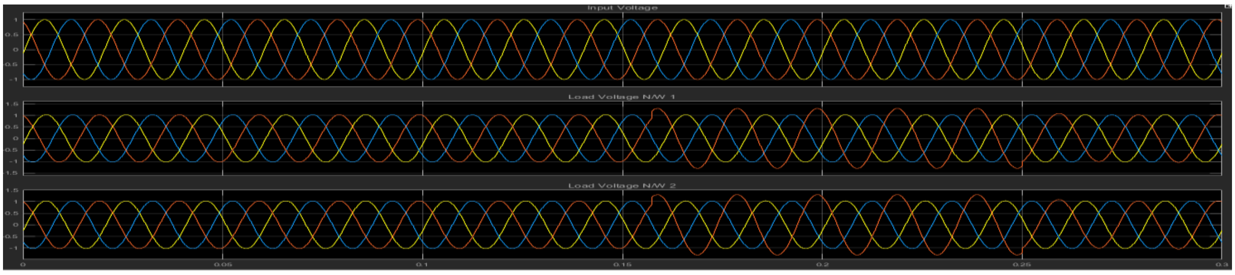

Fig.16 (a) Single phase Voltage swell Without DVR

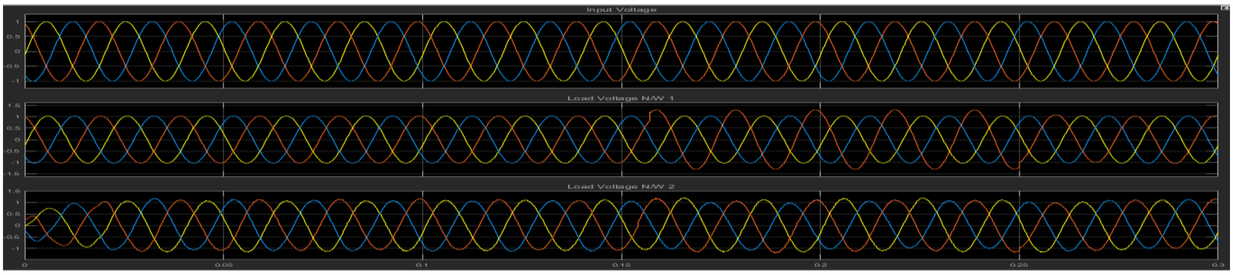

Fig.16 (b) Single phase Voltage swell compensation with DVR

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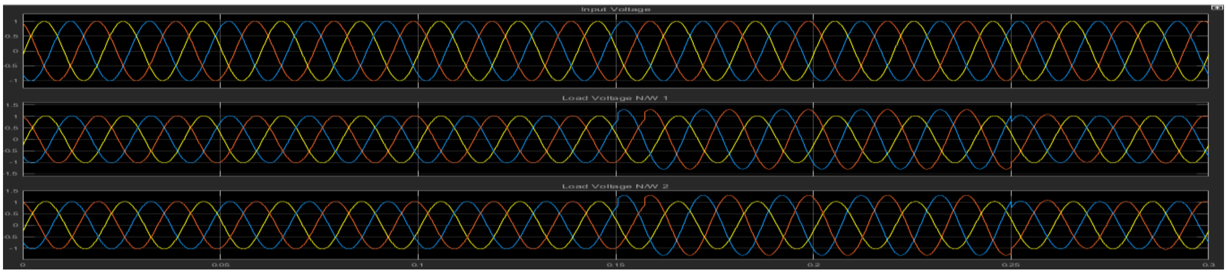

Fig.17 (a) Two Phase Voltage swell without DVR

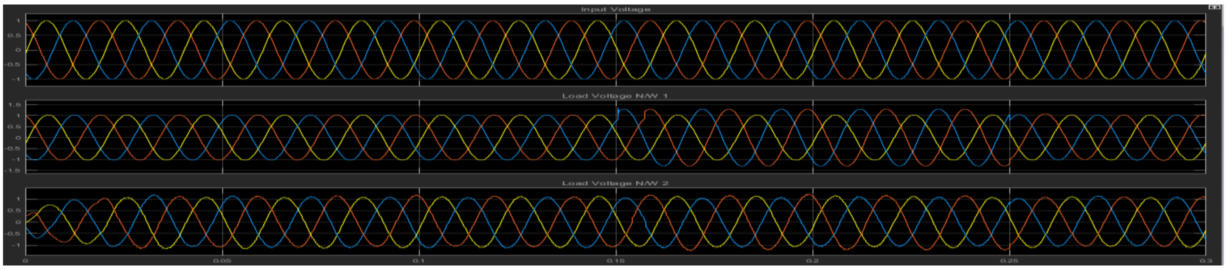

Fig.17 (b) Two phase Voltage swell Compensation with DVR

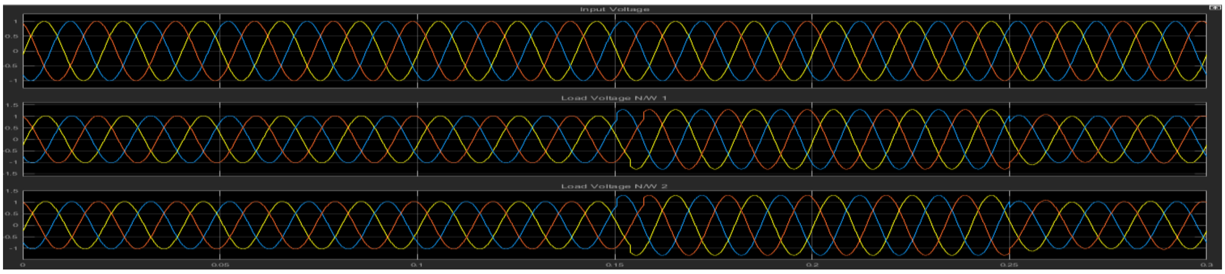

Fig.18 (a) Three phase Voltage swell without DVR

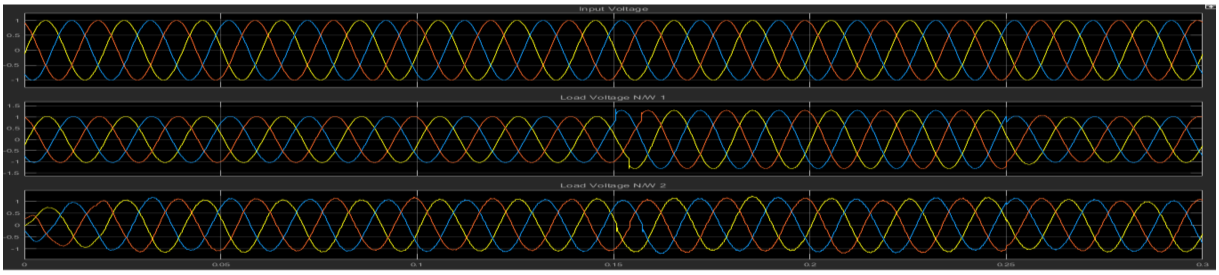

Fig.18 (b) Three phase Voltage swell Compensation with DVR

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TABLE1 COMPARISON TABLE

Fault	Phase	Voltage sag ($V_L/\sqrt{3}$)	Z -source DVR ($V_L/\sqrt{3}$)	Quasi Y-source DVR ($V_L/\sqrt{3}$)
SLG	R	240	175	240
	Y	240	175	240
	B	120	175	240
DLG	R	240	175	240
	Y	120	175	240
	B	120	175	240
TLG	R	120	175	240
	Y	120	175	240
	B	120	175	240

TABLE 11 COMPARISON TABLE

Switching	Phase	Voltage Swell ($V_L/\sqrt{3}$)	Z -Source DVR ($V_L/\sqrt{3}$)	Quasi Y-source DVR ($V_L/\sqrt{3}$)
SLS	R	240	199	240
	Y	240	199	240
	B	299	199	240
DLS	R	240	199	240
	Y	299	199	240
	B	299	199	240
TLS	R	299	199	240
	Y	299	199	240
	B	299	199	240

IX.CONCLUSION

The Proposed Model is simulated in MATLAB/SIMULILNK. In this DVR, A Quasi Y-Source Inverter with Fuzzy Logic Controller gives Improved results in Voltage sag and swell compensation as comparison with existing (7) Z-Source DVR model. Because Quasi Y-Source Inverter has Three Degree Of freedom and Z-Source inverter has two degree of freedom. A Quasi Y-Source inverter is Modified form of Y-Source Inverter. All the advantages of original Y-source inverter is already presented in Quasi Y-source Inverter but additionally draw a continuous input signal that better suits for renewable sources as PV, fuel cells etc. And this inverter is able to produce very high voltage gain while simultaneously operating at high modulation index. Hence it has been observed that A DVR with PEMFC, Super capacitor and Quasi Y-source inverter with Fuzzy Logic Controller is very efficient and reliable for power quality improvement.

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