MAT JOURNALS
Journal of Controller and Converters
Volume 2 Issue 3

PEMFC Based Z-Source DVR for Voltage Sag/Swell compensation and Active/Reactive Power Analysis

***Manmadharao Singamsetty*[1], *S.N.V.S.K.Chaitanya*[2], *B Venkateswara Rao*[3]**
[1,2]Assistant Professor, Department of EEE, V R Siddhartha Engineering College, Vijayawada, India.
[3]Associate Professor, Department of EEE, V R Siddhartha Engineering College, Vijayawada, India.

Abstract
Power quality is most essential aspect in power system environment. Voltage sags and swells are the frequently occurred disturbances in the power system which affecting the quality of power. This paper propose the new dynamic voltage restorer (DVR) called proton exchange membrane fuel cell (PEMFC) based voltage type impedance source (Z-Source) dynamic voltage restorer to compensate voltage sags/swells. Active, reactive power analysis with PEMFC Based Z-Source DVR is also studied in this paper. The results are obtained by using simulink software in MATLAB.

Keywords: *DVR, power quality, PEMFC, Voltage sag, Voltage swell.*

INTRODUCTION

In recent past majority of the power quality problems occurred due to increase in usage of more sensitive loads. The power quality problems are mainly classified as voltage quality and current quality problems. Current quality is a complementary term to the voltage quality. It is concerned with deviations of the current waveform from the ideal sinusoidal waveform. Voltage quality is the quality of the product delivered by the utility to the customers. It is concerned with deviations of the voltage waveform from the ideal sinusoidal waveform. The power quality problems are categorized as short interruptions, voltage dips, voltage swells, voltage flickers, voltage unbalance, voltage and current transients. Voltage sags and swells are commonly happened power quality problems in distribution system. To minimize these problems reactive power compensation is required. Load side problems are associated with change in current needs shunt compensation. But if load exceeds beyond the source power rating causes voltage fluctuations at load end. Similarly source side problems are associated with change in voltage, requires series compensation [1-3].

Voltage sag is defined by the IEEE 1159 as the decrease in the RMS voltage level to 10%-90% of nominal at the power frequency for duration of half to one minute. Voltage swell is defined by IEEE 1159 as the increase in the RMS voltage level to 110%-180% of nominal at the power frequency for duration of half cycle to one minute [4].Voltage deviations in the form of voltage sags and swells, can disrupt the sensitive load operation and cause a loss of production and result in significant economic loss. These problems can be minimized by using recently developed custom power device, called the dynamic voltage restorer (DVR) Irrespective of the causes of occurrence of voltage disturbances, DVR has to protect the critical loads by maintaining the load voltage at its desired level. This paper propose the new dynamic voltage restorer (DVR) called proton exchange membrane fuel cell (PEMFC) based voltage type impedance source (Z-Source) dynamic voltage restorer. Usage of this DVR makes it multifunctional, such as compensation for voltage sag, swell,

MAT JOURNALS
Journal of Controller and Converters
Volume 2 Issue 3

Active and Reactive Power Analysis. The validation of this device is verified threw MATLAB/SIMULINK simulation results.

PROTON EXCHANGE MEMBRANE FUEL CELL

Many papers have researched in the mechanism and experience models of the fuel cells. Different modeling methods have different complexities according to the number of parameters that may be discussed. All in all, the most specific experience model we can refer. The output voltage of the single cell is given by equation (1) according to the PEMFC output characteristic empirical equation[5].

$$V_{cell} = E_{Nernst} - V_{act} - V_{ohmic} - V_{ohmic} \quad (1)$$

$$E_{Nernst} = \frac{1}{2F}\left(\Delta G - \Delta S(T - T_{ref}) + RT\left(lnP_{H_2} + \frac{lnP_{O_2}}{2}\right)\right) \quad (2)$$

The activation loss of PEMFC is caused by the inactive kinetics of the reactions taking place on the active surface of electrodes and it can be computed by the following equation

$$V_{act} = \xi_1 + \xi_2 T + \xi_3 T[\ln(C_{O_2})] + \xi_4 T[\ln(i)] \quad (3)$$

In this model, all the parameters are obtained experimentally, and are listed in Table.1

***Table.1:** Parameters of PEMFC Dynamic Model*

Parameters	Value	Parameters	Value
N	20	ξ_1	-0.9514
T(K)	323	ξ_2	0.00312
P_{H_2}	0.5	ξ_3	7.4*10^-5
P_{O_2}	0.5	ξ_4	-1.87*10
ΔG	237180	*l(μm)*	51
A(cm^2)	150	λ	20
$\Delta S(mol)$	-163.15	*B(V)*	0.016
T_{ref}	298.15	*C(F)*	2.5
F(C/mol)	96486.7	$J_{max(A/cm^2)}$	1.5
R(J/mol K)	8.314	$R_{c(\Omega^2)}$	3*10^-4

$$C_{O2} = \frac{P_{O_2}}{5.08*10^6 exp^{(-\frac{498}{T})}} \quad (4)$$

Empirical equations for ohmic losses calculation has been presented above. In this paper ohmic losses occurred due to the equivalent membrane resistance (RM) and contact resistances (Rc) has been considered. These values are constant once the cell is fabricated. It can be shown as

$$V_{ohmic} = iR_{ohmic} = i(R_m + R_C) \quad (5)$$

The equivalent membrane resistance *RM*, can be expressed via Ohms law

$$R_M = \frac{r_{ml}}{A} \quad (6)$$

The resistivity r_m of a Na-f ion series proton exchange membrane can be calculated by

$$r_m = \frac{181.6[1+0.03(i/A)+0.062(T/303)2(i/A)2.5]}{[\lambda-0.634-3(\frac{i}{A})]\exp[4.18\{\frac{T-303}{T}\}]} \quad (7)$$

Where λ is the water content of the membrane, which is an adjustable parameter and a function of the relative humidity of the gas in anode, and has a value. In this model, the effect of concentration losses is also considered which is different from previous models. Concentration losses are caused by mass transportation, which in turn affects the concentration of the hydrogen and oxygen at high current density. This term is ignored in some models perhaps because it is not desirable to operate the stack at regions where concentration losses are high (efficiency is low). However if the stack operates at high current density, this term needs to be included. The concentration losses can be expressed as

V_{con} =B ln (1-$\frac{J}{J_{max}}$) (8)

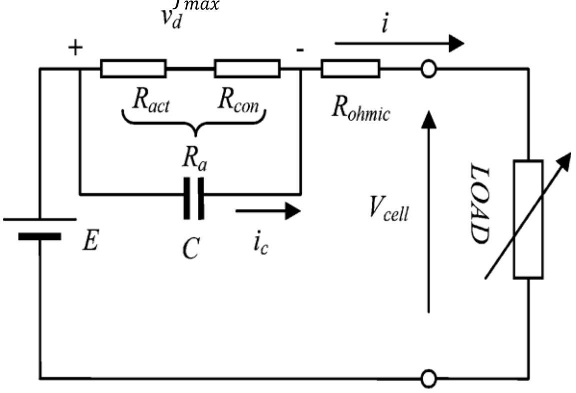

***Fig.1:** Electrical model of PEMFC*

Circuit model of the PEMFC in which an electrical capacitor can be considered as the layer of charge on or near the electrode–electrolyte interface, which is a store of electrical charge and energy as shown in Fig.1.*Ra* is the equivalent resistance that includes the activation equivalent resistance *R*act and the concentration equivalent resistance *R*con , the equivalent capacitance *C* can effectively smooth the voltage drop across *Ra* and *vd* is the overall voltage drop across R_a. As a function of the charge double layer, the PEMFC bears eminent dynamic characteristics.

DYNAMIC VOLTAGE RESTORER

DVR is static series compensator used to protect the sensitive load customers from voltage dips and swells. So it is also called as custom power device. It is a power-electronic converter-based device that has been designed to protect critical loads. It is connected in series with a distribution feeder and is capable of generating or absorbing real and reactive power at its ac terminals. The basic principle of a DVR is inserting a voltage of required magnitude and frequency, the DVR can restore the load-side voltage to the desired amplitude and waveform even when the source voltage is unbalanced or distorted through the series insertion transformer. The sum of the line voltage and the insertion voltage becomes the restored voltage seen by the critical load.DVR consists of major components like inverter bridge circuit, the modulation unit, the control unit, the filter, the injection transformer, the energy source/energy storage device and the bypass switch as shown in Fig.2. Filter is there to eliminate high frequency switching harmonics.

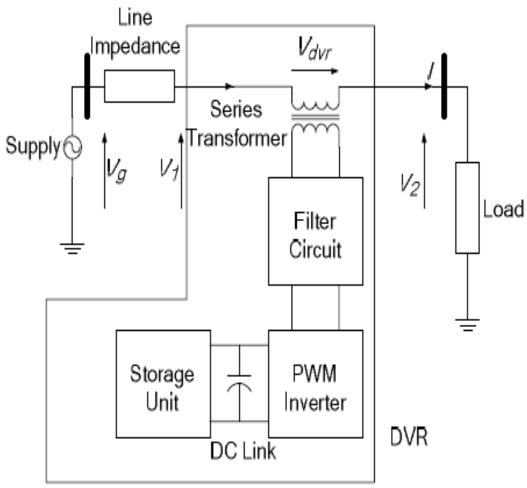

***Fig.2:** DVR general configuration*

The DVR consists of a VSC, IGBT switching devices in a pulse width modulated (PWM) inverter structure, a DC energy storage device and a coupling transformer that in this case, is connected in series with the AC system, as illustrated in Fig 2. The DVR injects a set of three-phase AC voltages in series and synchronized with the distribution feeder voltages of the AC system. The amplitude and phase angle of the injected voltages are variable thereby allowing control of the active and reactive power exchanges between the DVR and the AC system within predetermined positive (power supply), and negative (power absorption) limits [6-8].

CONTROL CIRCUIT

The control circuit is shown in figure 3, which generates the gate pulses using PWM generator whenever there is a sag/swell in the source voltage. The voltage sag/swell can be identified by measuring the error between the reference source voltage and actual source voltage. Error is positive while voltage sag occurs and negative for swell occurrence. The resultant error signal is given as input to Discrete PWM generator which provides gating pulses to the inverter bridge circuit. The main objective of this compensation is to control the amount of active power as well as reactive power drawn. Hence it is necessary to design a control structure to manage active and reactive powers simultaneously. Also the suitable control is presented to regulate the input fuel flow in order to meet a desirable output active power demand and to prevent transient conditions in fuel cell stack. Three individual single phase control circuits and inverters are employed for all types of sags/swells compensation.

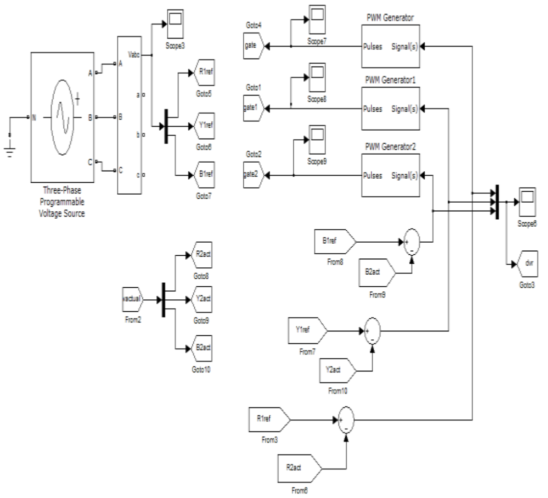

Fig.3: *Control circuit*

IMPEDANCE SOURCE INVERTER

Z-Source Inverter is a cost effective and reliable single-stage transformer-less inverter topology, having x-shaped LC impedance network. In this paper, voltage type Z-source inverter based topology is proposed where the storage device can be utilized during the process of load compensation along with the use of boost functionality of the inverter. Figure 4 shows Impedance source inverter (ZSI/ISI), in this series diode is connected between the source and impedance network, which is required to protect the source from a possible current flow. The impedance source inverter facilitates the second order filter, so as to suppress voltage and current ripples [9-12].

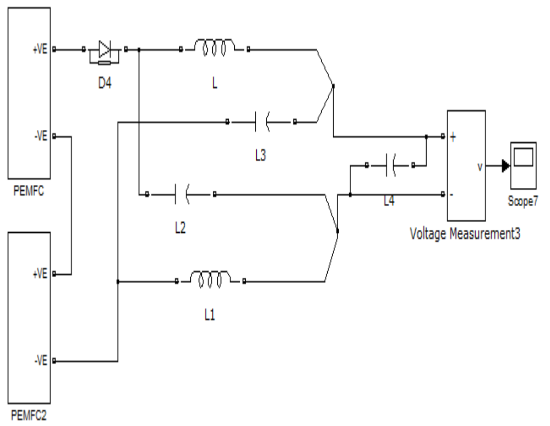

Fig.4: *Impedance source inverter (ZSI/ISI)*

MODELLING OF DVR

The performance of the PEM fuel cell incorporated DVR is evaluated using MATLAB/SIMULINK platform. Figure 5 shows the block diagram of PEMFC incorporated DVR. The proposed PEM fuel cell incorporated DVR is connected at the load side of the distribution system.

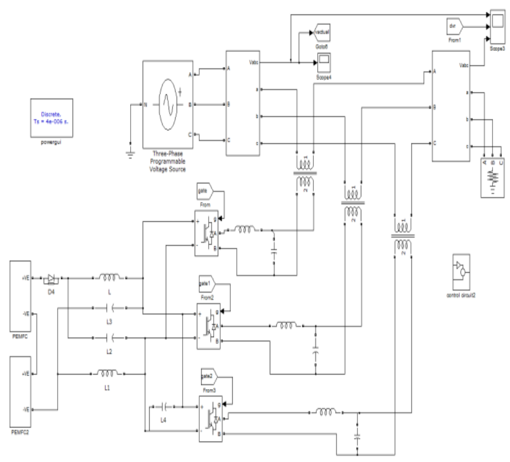

Fig.5: *PEMFC incorporated DVR*

SIMULATION RESULTS

For simplicity it is carried out in PU system. Without compensation, load voltage is same as that of the source voltage. The results for various types of faults with compensation are shown below. A ramp type amplitude variation from 0.1sec to 0.2 sec, is considered and the results are shown in Figure 6 with compensation. From 0.05 to 0.1sec sag is created and from 0.15 to 0.2sec swell is created in all the three phases, DVR injects in phase voltage for sag compensation and out of phase injection for swell compensation which is shown in Figure 7. Figure 8 and figure 9 shows the DVR injection voltage for voltage sag and swell with different disturbances.

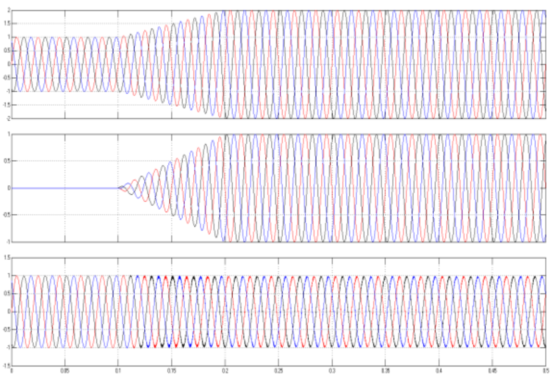

Fig.6: *Source, DVR injected and load voltages with compensation.*

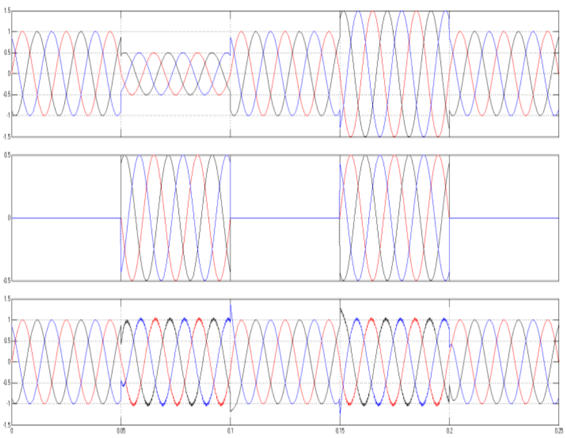

Fig.7:*Source, DVR injected and load voltages during balanced sag and swell with compensation.*

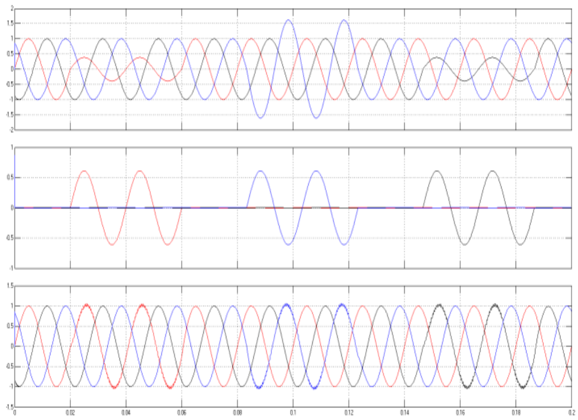

Fig.8: Source, DVR injected and load voltages with compensation.

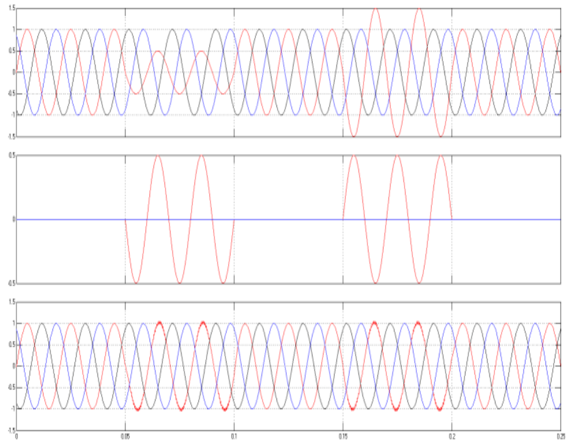

Fig.9: *Source, DVR injected and load voltages with compensation.*

The active and Reactive power analysis during Voltage sag/swell conditions at Source, DVR and load with compensation are shown in below fig.10 and fig.11

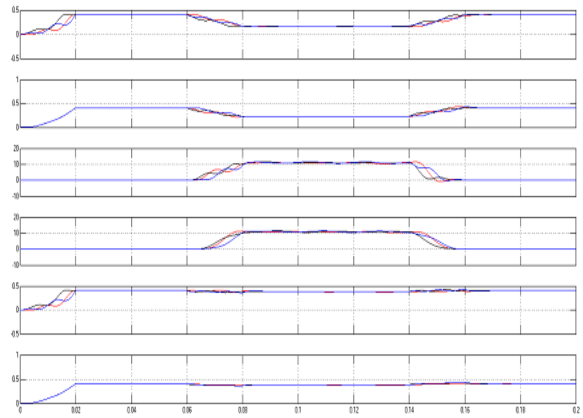

Fig.10: *Source, DVR injected and load active, reactive powers during voltageSag with compensation.*

The active and reactive power compensation at Source, DVR injected and a load voltage during voltage Sag/swell with compensation is observed.

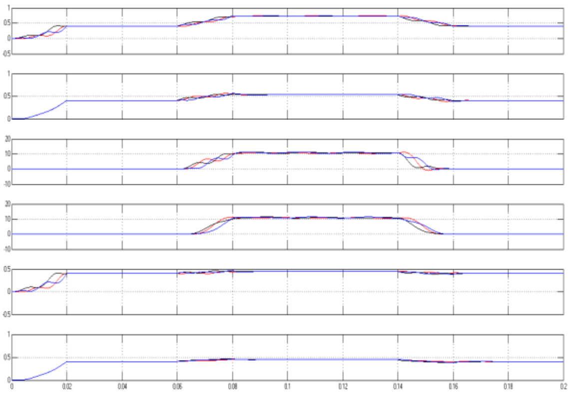

Fig.11: *Source, DVR injected and load active, reactive powers during voltage Swell with compensation.*

CONCLUSION

DVR is one of best custom power device. Voltage sags/swells in the distribution system are effectively compensated by using DVR. In this paper PEMFC based DVR is used to mitigate the voltage sags and swells. The results indicate that PEMFC Incorporated DVR effectively compensates the sags/swells occurred in distribution system for all types of voltage disturbances. It is also observed that PEMFC Incorporated DVR effectively controls the active and reactive power flow in the system.

REFERENCES

1. M.Balamurugan, T.S. Sivakumaran, M. Aishwariya Devi, "Voltage Sag/Swell Compensation Using Z-Source Inverter DVR based on FUZZY Controller" 978-1-4673-5036-5/13, 2013 IEEE.
2. Hingeroni, N.G, "Introducing custom power devices" IEEE Spectrum, 1995, pp. 41-48.
3. N.H.Woodley, L.Morgan, and A.Sundaram, "Experience with an inverter-based dynamic voltage restorer" IEEE Trans. Power delivery, vol.14, pp. 1181-1186, July 1999.
4. Math H. J. Bollen, "Understanding Power Quality Problems" a volume in the IEEE Press Series on Power Engineering, 2000.
5. JiaJ., Y. Wang, Q. Li, Y.T. Cham, and M. Han."Modeling and Dynamic CharacteristicSimulation of a Proton Exchange MembraneFuel Cell", IEEE Transactions on EnergyConversion, Volume.24, no.1, March 2009.
6. F.A.L.Jowder, "Design and analysis of dynamic voltage restorer for deep voltage sag and harmonic compensation" IET Gener,Transm,Distib. 2009, vol.3, Iss.6, pp.547-560.
7. Woodley.N.H,Morgan.L,Sundaram.A, "Experience with an inverter based dynamic voltage restorer' IEEE Trans. Power Deliv., 1999, 14, (3), pp. 549-557.
8. C.E.Thenmozhi, C.Gopinath, R.Ramesh, "A Novel Method for Voltage Sag/Swell Compensation using Dynamic Voltage Restorer"IEEE Trans., 978-81-909042-2-3,March 2012.
9. S.Torabzad, E.Badaei, M.Kalantari "Z–source Inverter based dynamic voltage restorer" 1st Power elecronics& Drive systems & Technologies Conference IEEE 2010
10. P.C.Loh, D.M.Vilathgamuwa, Y.S.Lai, G.T.Chua, and Y.Li, "voltage sag compensation with Z-Source inverter based dynamic voltage restorer" in industrial applications, volume-5, October 2006.
11. B.Justus Rabi &R.Arumugam" Harmonics study & comparison of ZSI with traditional inverters" IEEE Industrial Electronics Society Conference.
12. F. Z. Peng, "Z-source Inverter" IEEE Trans. Industry Applications, Vol.39, pp.504-510,2003