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Simulation and Implementation of Interphase AC-AC topology for Voltage Sag Mitigation for Power Quality Improvisation

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ABSTRACT: The traditional voltage sag compensator, which isdynamic voltage restorer (DVR) has many disadvantages such as need of energy storage devices, having dc links and two stage power conversions. This increases its size, cost, power losses and control complexity. Also it is not adequate for compensating deep and long duration voltage sag. In this paper interphase AC AC topology is proposed for voltage sag compensation which suggeststhe idea of cross phase voltage injection. In this, sag supporter is connected in each phase which draws the power from remaining two phases. A single phase sag supporter is realized with two AC choppers and two transformers. The required injecting power is controlled by controlling the duty cycle of each chopper. It does not require any energy storage device hence the size, cost, and associated losses are decreased. Detail simulation along with results in MATLAB/Simulink for voltage sag due to single line to ground fault is presented in this paper.

KEYWORDS -Power quality, voltage sag, AC chopper

I. INTRODUCTION

The modern electrical power system is AC i.e. electricpower is generated, transmitted and distributed in the formof alternating current [1]. For reliable and uninterrupted flowof power systems, the generation plant must produce amplepower to meet consumer's demands, transmission system musttransport bulk power over long distances without overloadingsystem and distribution system must deliver electric powerto each consumers premises. Distribution system locates theend of power system and is connected to the consumerdirectly, so the power quality mainly depends on distributionsystem. Power quality is described as the variation of current,voltage and frequency in a power system [2], [3]. Among themthe voltage quality problem is very important and have thegreater percentage. It includes voltage sag, swell, interruptionand harmonics.

Voltage sag can be defined as a short duration reduction inRMS voltage at power frequency caused by faults and startingof large loads. Typical duration of voltage sag is 0.5 to 30cycles. Voltage sag is considered the most severe since thesensitive equipment's used in modern industrial plants suchas process controllers, programmable logic controllers (PLC),power robotics, adjustable speed drives are sensitive to voltagesags and causes serious economic loss due to malfunctionof the equipment's. Since it can occur even due to remotefaults in a power system, it is more often than interruptionand can occur 20-30 times per year with an average cost of50,000$ in each industry [4]. The main cause of voltage sagis any short duration type of faults which may be symmetricor unsymmetrical in nature, due to starting of induction motor,energization of transformer, operation of enclosures& circuitbreakers etc. Voltage sag is characterized by sag magnitude,duration, phase jump & three phase balance. Voltage sag withlow voltage sag magnitude is called deep sag while with highvoltage magnitude is called shallow sag. Fig.1 illustrates thesingle-phase model for voltage sag at the point of commoncoupling.

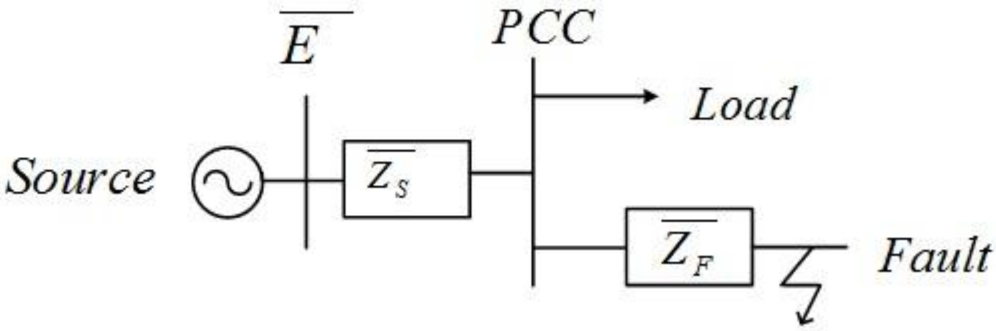

Fig.1. Single-phase model for voltage sag at the PCC

Studies show that voltage sag is accompanied with phase jump [5]. It occurs due to the difference in X/Rratio of the source($\overline{Zs}$) and feeder ($\overline{Zf}$) impendences.

II. EXISTING SYSTEMS

For mitigating voltage sags different FACTs controllers areused.
There are four types of FACTs controllers [6]
1) Series controllers
2) Shunt controllers
3) Combined series-series controller
4) Combined series-shunt controller

Dynamic voltage restorer (DVR) & Unified power qualityconditioner(UPQC) are examples of series controllers whileDistribution static synchronous compensator (DSTATCOM) &Distribution static voltage compensator (DSVC) are examplesof shunt controllers. Out of these the most currently useddevice is DVR i.e. Dynamic voltage restorer. Basically DVR ispower electronic based converter connected in series to injectthe appropriate voltage for. It consists of voltage source converter(VSI) which will provide injection voltage corresponding to sag magnitude, injection transformer, dc link and energy storage device. Although DVR is a definitive solution towards compensation of voltage sag it suffers number of disadvantages such as it is not adequate for compensating deep and long duration voltage sag, requirement of energy storage devices for providing compensating voltage, it has dc link and two stage power conversions which increases the compensator size, cost, power losses and control complexity.

III. PROPOSED SYSTEM

To eliminate all the disadvantages of conventional topologies for mitigating the voltage sag a new topology without dc link utilizing direct AC-AC converters are preferable. This paper implements interphase AC-AC topology for compensating the voltage sag. Interphase AC-AC topology [7] suggests the idea of cross phase voltage injection. When the voltage sag occurs in any phase remaining two phases are used to inject the compensating voltage.

The schematic diagram of the proposed topology with detailed phase-a sag supporter is shown in fig.2 It consist of three sag supporters connected in series with each phase. Each sag supporter consist of two AC choppers and two injection transformers. The main function of injection transformer is to isolate the chopper circuit from lines. When the voltage sag occurs at the point of common coupling (PCC) of any of the phase, the corresponding sag supporter injects appropriate voltage in series with the supply voltage to maintain the desired load voltage. The load voltage is the sum of respective phase voltage and injected voltage. The required injecting voltages are drawn from phase-b and phase-c with the help of individual AC choppers and connected to the primary of injection transformer. The injected voltage is vector sum oftwo AC choppers and injected in series with the line to compensate the voltage sag in phase-a. Similarly, for phase-b and phase-c sag supporters are realized.

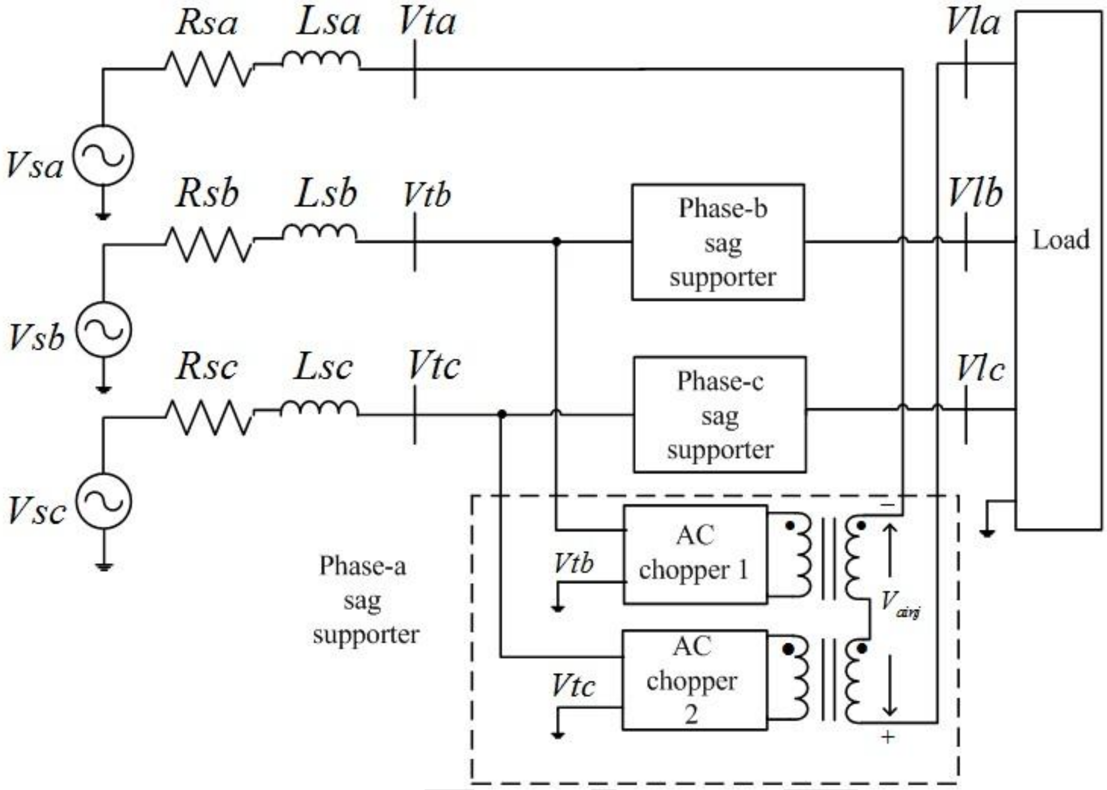

Fig.2. Interphase Ac-Ac converter topology

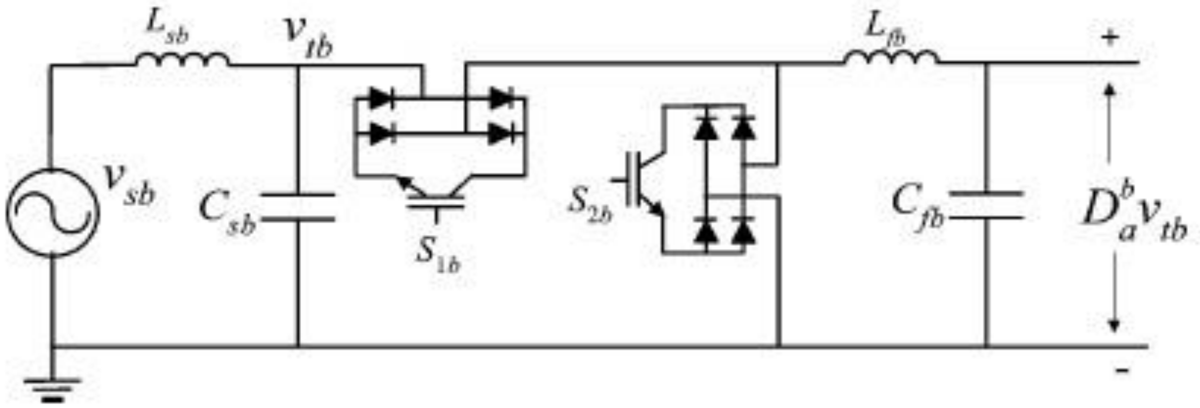

Fig.3. Ac-Ac chopper with input and output filters

Fig.3 shows the pulse width modulated (PWM) AC chopper with input and output filters placed across phase-b[4], [7], [8]. The chopper operates in buck mode. Each chopper consists of two switches. The bidirectional feature of switch is realized by using IGBT with Diode Bridge. The switching pulse T1 required to produce the desired output voltage is given to the series switch and the complementary switching pulse T1' is given to shunt switch for continuous flow of load current. Small LC filters are added at the input and output side to avoid propagation noise and to filter high-frequency components respectively. [9]

Let the phase voltage-b voltage be,[7]

$$v_{tb} = V_{tbm}\ cos(\omega t - 120° + \varphi_b) \tag{1}$$

where ω, φ_b and V_{tbm} are the angular frequency, phaseangle shift and peak value of the terminal voltage of phase-b respectively. When this voltage is chopped for constant duty cycle, the output voltage can be written as,

$$v_a^b = D_a^b V_{tbm}\ cos(\omega t - 120° + \varphi_b) + \sum_{k=1}^{\infty} \frac{V_{tbm}\ \sin k D_a^b\ \pi}{k\ \pi} \cos(k\omega_s t \pm\ \omega)t \tag{2}$$

Where ω_s is the angular switching frequency, v_a^b is the injectedphase-a voltage obtained from phase-b chopper, and D_a^b is theduty cycle of phase a sag supporter that is connected to chopthe phase-b terminal voltage. In equation (2), the first termrepresents the fundamental component while the second termrepresents the higher order switching frequency components,which are filtered out by output filters.

The output of AC chopper for phase-b is expressed as

$$v_a^b = D_a^b V_{tbm}\ cos(\omega t - 120° + \varphi_b) \tag{3}$$

A similar chopper circuit is used for chopping phase-c voltagefor the phase-a sag supporter. Its output voltage is expressed as,

$$v_a^c = D_a^c V_{tcm}\ cos(\omega t + 120° + \varphi_c) \tag{4}$$

The phase-a injected voltage (V_{ainj}) is the sum of voltages from phase-b and phase-c choppers. It is expressed as,

$$V_{ainj} = -(v_a^b + v_a^c) = -D_a^b V_{tbm}\ cos(\omega t - 120° + \varphi_b) - D_a^c V_{tcm}\ cos(\omega t + 120° + \varphi_c) \tag{5}$$

After arranging and expanding equation (5) we get,

$$V_{ainj} = \cos(\omega t)\left\{\frac{D_a^b V_{tbm}}{2}\cos(\varphi_b) + \frac{D_a^c V_{tcm}}{2}\cos(\varphi_c) - \sqrt{3}\frac{D_a^b V_{tbm}}{2}\sin(\varphi_b) + \sqrt{3}\frac{D_a^c V_{tcm}}{2}\sin(\varphi_c)\right\}$$
$$-\sin(\omega t)\left\{\frac{D_a^b V_{tbm}}{2}\sin(\varphi_b) + \frac{D_a^c V_{tcm}}{2}\sin(\varphi_c) + \sqrt{3}\frac{D_a^b V_{tbm}}{2}\cos - \sqrt{3}\frac{D_a^c V_{tcm}}{2}\cos(\varphi_c)\right\} \tag{6}$$

Equation (6) shows that it has two components in-phase and quadrature with respect to phase-a axis. If the quadrature component became zero then the resultant injected voltage lies on phase-a axis. This type of voltage injection is termed as in-phase voltage injection. With respect to value of quadrature component the resultant voltage leads/lags the phase-a axis. This type of method of voltage injection is termed as phase shifted voltage injection [7]. By controlling the duty cycle of each chopper in phase sag supporters, the magnitude and phase angle of the injected voltage can be realized. In this paper in phasevoltage injection method is used for compensating the voltage sag.

IV. SIMULATION CIRCUIT AND RESULTS

In this paper, the soundness of the proposed interphase AC AC topology is validated by simulation study conducted using MATLAB/Simulink.

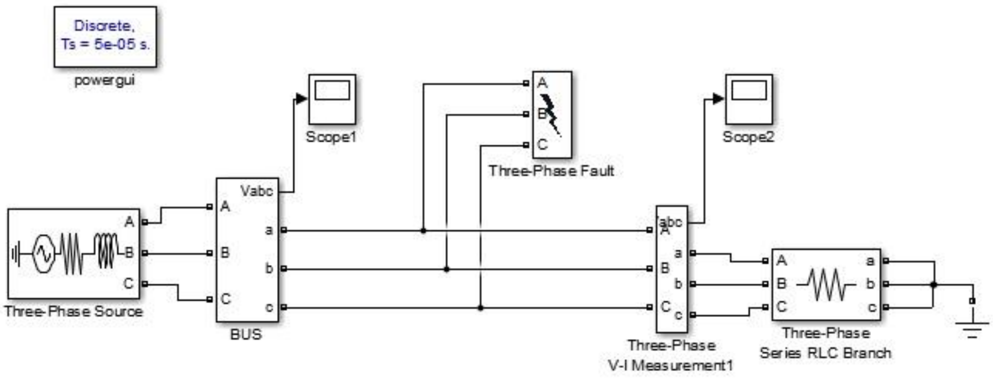

Fig.4. Simulation circuit for voltage sag without sag supporter

TABLE I

SYSTEM DETAILS

Parameters	Values	
Rated voltage and frequency	3-phase, 400 V, 50 Hz	
Load	100Ω	
Injection transformer	1:1, 500 V, 25MVA	
Sag duration	0.3 to 0.6 Sec	
AC chopper	Switching frequency	5 KHz
	Input inductance	0.9 mH
	Input capacitance	50 µF
	Filter inductance	0.25 mH
	Filter capacitance	180 µF

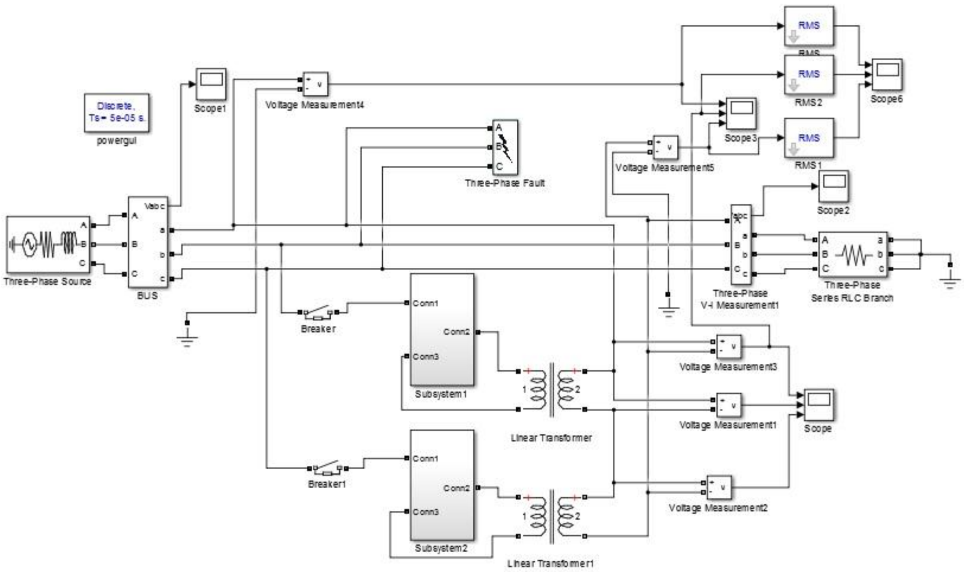

Fig.5. Simulation circuit for voltage sag with sag supporter

Simulation time for model is taken as 0.8 sec. In the begining simulation was done without creating any fault on the network. Fig.6 shows the load side voltage waveform without fault. X axis shows the simulation time and Y axis shows the voltage magnitude.

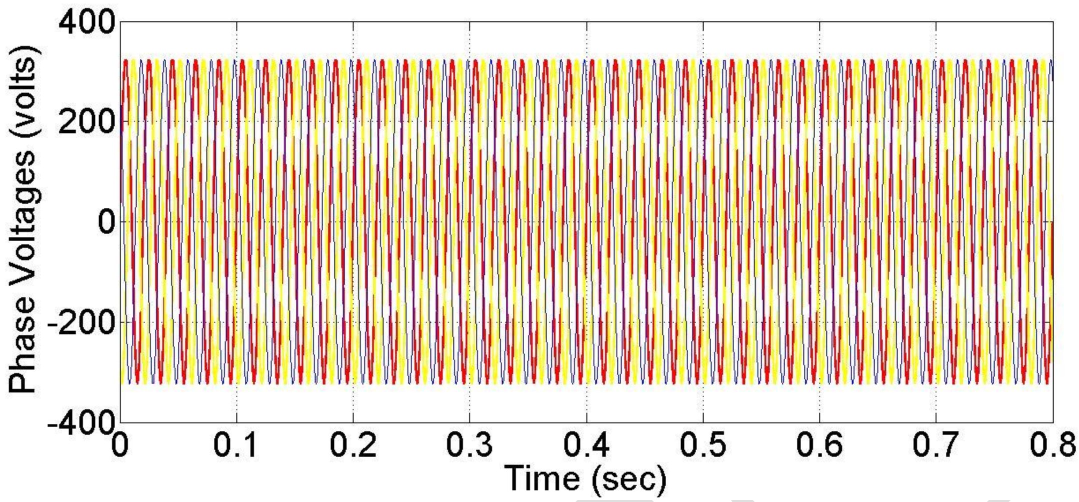

Fig.6. Load voltage without fault

Second simulation is done by creating single line to ground fault on the system with fault resistance of 0.1 Ω from 0.3 to 0.6 sec. The fault is created by using three phase shunt fault block from Simulink library. Fig.7 shows load voltage waveform during fault. From this waveform we can observelarge amount of voltage sag. Voltage drops to almost 90 %. This voltage drop is needed to be compensated by proposed topology.

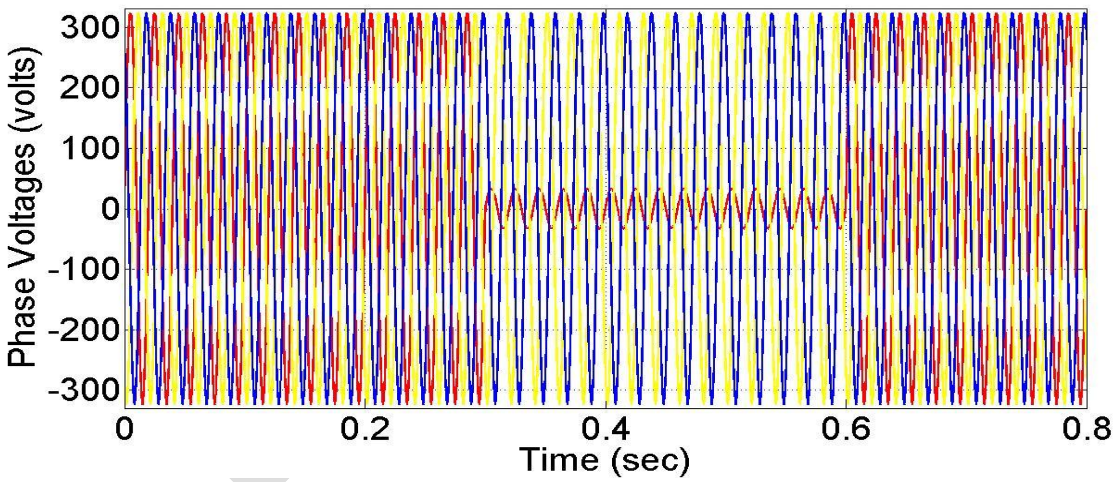

Fig.7. Load voltage during fault without sag supporter.

Third simulation is carried out by connecting sag supporter in phase-a for compensating the voltage sag occuring in the system mentioned above. Fig.7 and fig.8 shows the injected peak and RMS voltage respectively.

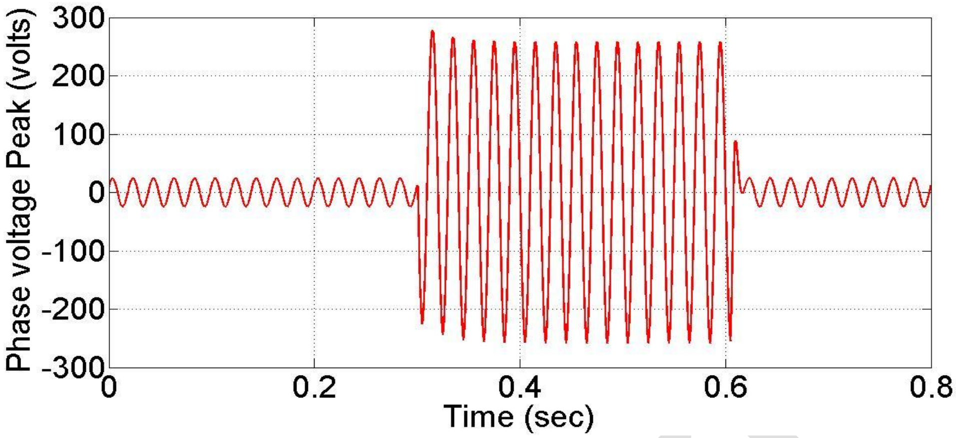

Fig.8. Injected peak voltage

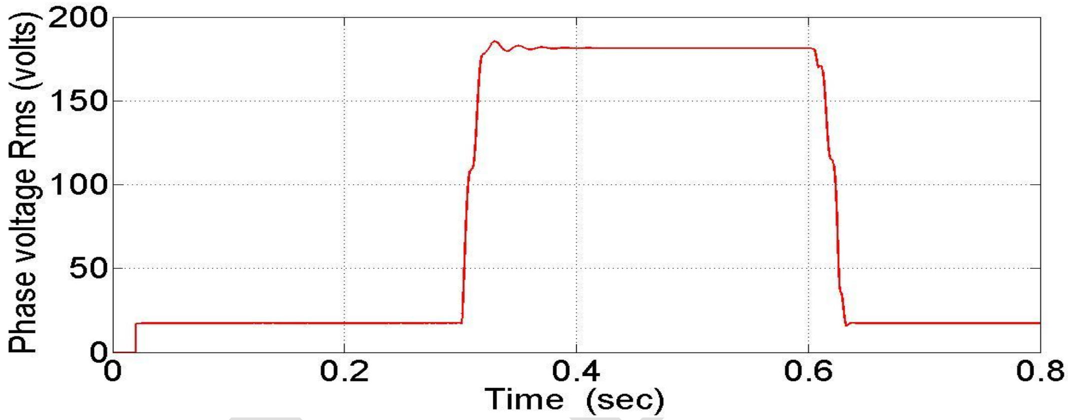

Fig.9. Injected RMS voltage.

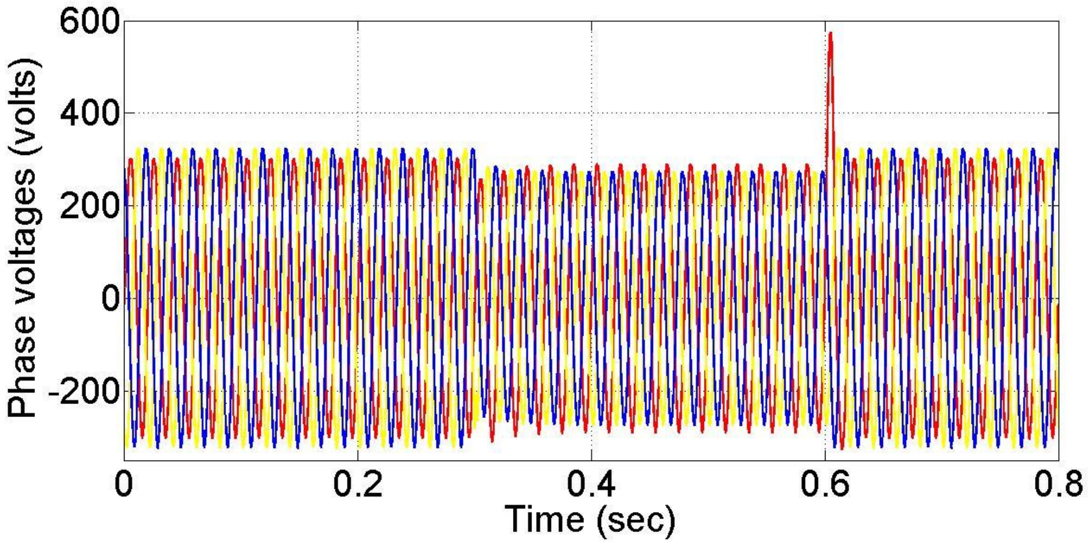

Fig.10. Load voltage with sag supporter

Fig.10 shows the load side waveform after connecting phase-a sag supporter for compensation. If we compare the waveform of load voltage with and without sag supporter we observed that when the sag supporter is in operation the voltage sag is compensated almost completely. From this waveform we can say that the proposed topology can compensate 96 to 98 % voltage sag magnitude. The sag supporter is designed to supply the sag voltage until fault isremoved from the system.

V. CONCLUSION

In this paper interphase AC-AC topology is used for voltage sag compensation. The proposed topology has number of advantages such as reduced size, cost and associated losses, no need of storage device, easy to implement. Control of compensation is achieved by providing proper duty cycle to AC choppers. From the detail analysis it can be seen that compensation achieved in case of single phase to ground fault is about 96 %.

VI. Acknowledgements

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