International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in

Vol.3., Issue.1, 2015

RESEARCH ARTICLE

ISSN: 2321-7758

VOLTAGE SAG AND SWELL COMPENSATION BY DVR

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Article Received: 19/01/2015 | Article Revised on: 31/01/2015 | Article Accepted on:05/02/2015

ABSTRACT

Power quality is the generally imperative prospect in the power system environment. Generally as often as possible occurring disturbances, pretending the quality of power are voltage sags and swells. Custom power device, Dynamic Voltage Restorer (DVR) associated in series with a goal to defend the loads from source side voltage disturbances. In this paper voltage type Impedance Source Inverter (ISI) is employed to correct deep voltage sags/swells under sudden load switching/removal respectively. The usefulness of DVR is studied under distinctive fault conditions, such as three phase and line to line faults. In this paper Unbalanced sags/swells are also adjusted by Dynamic Voltage Restorer. The potentiality of DVR is assured under source outage condition. DVR's employed as series compensators in Interline Power Flow Controller (IPFC) scheme to compensate voltage disturbances in individual feeders. Comparative study between PI and Fuzzy controllers is done. The undertaking is done by Simulink programming.

Keywords—Dynamic voltage restorer(DVR), Impedance source inverter(ISI), Interline power flow controller(IPFC)

INTRODUCTION

This paper deals with modeling and simulation technique of a Dynamic Voltage Restore (DVR).The DVR is a dynamic solution for protection of critical loads from voltage sags / swells. The DVR restores constant load voltage and voltage wave form by injecting appropriate voltage. Present novel structure improves the quality of power by compensating voltage sag and swells. Power quality is the most important aspect in the power system environment [1]. Most frequently occurring disturbances, affecting the quality of power are voltage sags and swells. Custom power device, Dynamic Voltage Restorer(DVR) connected in series with a goal to protect the loads from source side voltage disturbances[18]. In this paper voltage type Impedance Source Inverter(ISI) is employed to compensate deep voltage sags/swells under sudden load switching/removal conditions, respectively. The functionality of DVR is studied under different fault conditions, such as three phase and line to line faults. Unbalanced sags/swells are also compensated by DVR in this paper. The capability of DVR is checked under source outage condition. DVR's employed as series compensators in IPFC scheme to compensate voltage disturbances in individual feeders. Comparative study between PI and Fuzzy controllers is done.

Electric Power quality is a term which has captured increasing attention in power engineering in the modern years. The term power quality is to maintain a sinusoidal waveform of bus voltages at rated voltage and frequency[14]. The Power quality areas may be made according to the source of the problem such as converters, non linearity in magnetic circuit by the wave shape of the signal such as harmonics, flicker or by the frequency spectrum (radio frequency interference). The power quality is simply the interaction of electrical power with electrical equipment. It is the cause and the ability of the electrical equipment to function in the power quality environment is the effect. Power quality is used synonym with supply reliability service quality, current quality, quality of supply and quality of consumption.

Advanced mechanical methods containing voltage touchy gadgets, helpless against debasement in the nature of force supply. The force quality issues happens either on source side or burden side. Burden side issues are connected with change in present, shunt remuneration is needed. Yet in the event that heap surpasses past the source force rating reasons voltage vacillations at burden end. Thus source side issues are connected with change in voltage, arrangement pay is needed[2]. The deviation of voltage, current and recurrence which can be portrayed as a force quality issues. Voltage droop/swell, glimmer, music bending, drive homeless people and intrusions are the different force quality issues tended to in the circulation framework. Of the above force quality issues, a voltage hang/swell aggravation represents an arrangement danger to the businesses. It can happen more oftentimes than whatever other force quality phenomenon[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 cycles to one minute[4].Voltage fluctuations, often in the form of voltage sags/swells, can cause severe process disruptions and result in substantial economic loss. So cost-effective solutions which can help such sensitive loads ride through momentary power supply disturbances have attracted much research attention. Among recently developed custom power devices, the dynamic voltage restorer (DVR) for application in distribution systems is gaining acceptance.

Occurrence of three phase fault causes voltage dropped equally in all the three phases. Fault is to be cleared as early as possible, otherwise as in interconnected power system network, load side fault may be reflected as source side fault for another existing load. Due to sudden switching of extra loads beyond the source power rating causes voltage sag, sudden removal of existing loads causes voltage swell in the interconnected power system network[5]. 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. Due to switching On and Off of single phase loads of different power ratings causes unbalance between the three phases.DVR has to compensate unbalanced sags/swells also.

DYNAMIC VOLTAGE RESTORER

DVR stands for dynamic voltage restorer. DVR consists of major components like inverter bridge circuit, filter, energy source/energy storage device and injection transformers as shown in fig.1. The injected voltages generated by the inverter are introduced into the distribution system by means of using either a three phase injection transformer or three single phase individual transformers [10]. Filter is there to eliminate high frequency switching harmonics.

In Custom Power applications, the DVR is connected in series with the distribution feeder. By inserting voltages of controllable amplitude, phase angle and frequency (fundamental and harmonic) into the distribution feeder via a series insertion transformer, the DVR can “restore” the quality of voltage at its load-side terminals when the quality of the source-side terminal voltage is significantly out of specification for sensitive load equipment. The sum of the line voltage and the insertion voltage becomes the restored voltage seen by the critical load.

A. DVR OPERATION

DVR is a series controller which is used to compensate voltage sags and swells. DVR is used for short time faults only. DVR injects the voltage in

phase to the supply. So, that it can maintain a good power quality profile at the load [8]. DVR will operate in fault conditions only and in other conditions it will remains idle. It has the capability to absorb and supply the active and reactive power. DVR contains a Voltage Source Converter (VSC), an Energy Storage System, an Injection Transformer and a LC-Filter. In this VSC will convert the DC into AC and by this converting process [18] it will produce some harmonics. To reduce these harmonics we use an LC-Filter and it doesn't allow harmonics across it. Filter is connected in between the VSC and Injection Transformer. Injection Transformer will inject the voltage in series with the supply lines. Depending on the compensation the storage of energy will be stored and for energy storage capacitors and batteries are used. In this DVR we use fast switches, due to these fast switching operations we can get the desired output. By using fast switches the cost of the DVR will increases and the DVR cost will depends on the power rating and other equipments.

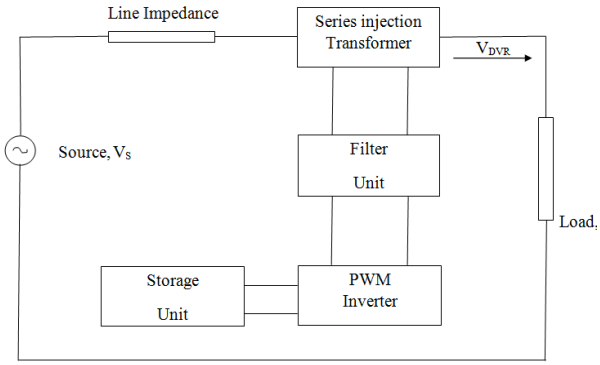

Fig 1: DVR Block Diagram

The DVR consists of two modes of operations. They are, Standby Mode and Boost Mode. DVR is associated in arrangement with the dissemination framework. As a rule a coupling transformer is set between the dissemination framework and the DVR for segregating the DVR from the appropriation framework. Moreover this gadget needs to be introduced as near to the delicate load as could be expected under the circumstances to amplify the repaying capacity. Being an arrangement joined gadget the DVR fundamentally infuses voltage into the framework. The part of DVR is particularly acknowledged if there should arise an occurrence of a feeble AC framework. The DVR is equipped for creating constantly variable inphase and stage resistance arrangement voltage pay at a level up to its most extreme MVA rating [12]. The DVR much of the time checks the line waveform regarding a reference air conditioning sign. It can likewise give the right measure of pay to diminish the measure of voltage variances.

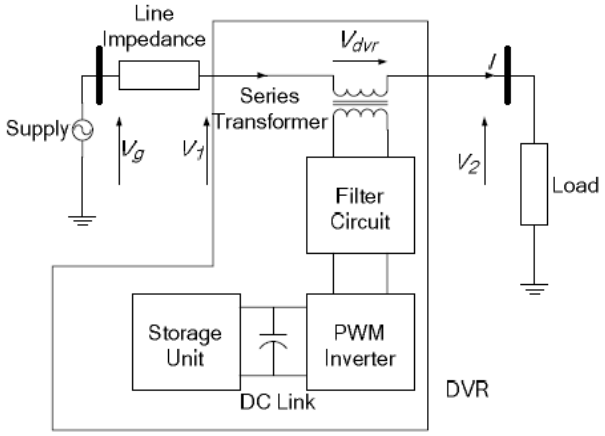

Fig 2: DVR general configuration

The DVR is a solid-state dc to ac switching power converter that injects a set of three-phase ac output voltages in series and synchronism with the distribution feeder voltages. DVR employs IGBT solid state power electronic switching devices in a pulse width modulated (PWM) inverter structure. It is capable of generating or absorbing independently controllable real and reactive power at its ac output terminal. The amplitude and phase angle of the injected voltages are variable thereby allowing control of the real and reactive power exchange between the DVR and the distribution system. Real power exchanged at the DVR ac terminals must be provided by dc voltage source of appropriate capacity connected at the DVR dc terminals[16]. The reactive power exchanged between the DVR and the distribution system is internally generated by the DVR without any ac passive reactive components such as reactors or capacitors.

DVR has to inject the three phase voltage, in-phase for sag compensation, phase opposition for swell compensation. That can be seen by dq to abc transformation employed in control circuit. DVR compensation capability purely depends up on the rating of dc voltage source, connected to the input terminals of inverter bridge circuit. Source outage condition is the special aspect, DVR has to supply total power to the load. The load demand satisfied only when the dc voltage source is capable, under source outage condition.

CONTROL CIRCUIT

In general, FACTS Controllers can be divided into four categories as Series controllers**,** Shunt controllers**,** Combined series-series controllers**,** Combined series-shunt controllers. Phase locked loop employed to generate output signal, whose phase is same as that of the input signal. Keeping input and output phases in lock implies keeping input and output frequencies the same. The voltage sag/swell can be identified by measuring the error between the reference source voltage and actual source voltage [17]. Error is positive, while voltage sag occurs and negative for swell occurrence. Before going to compare, the actual and reference source voltages are transformed to dq frame from abc. This transformation facilitates the individual control of active and reactive powers by controlling the dq components. Actual dq components are compared with reference dq components and error is given to PI/Fuzzy controller.

The output of PI/Fuzzy controller is again transformed back to abc to recover the actual three phase ac results and then fed to PWM generator. DVR has to inject the three phase voltage, in-phase for sag compensation, phase opposition for swell compensation. That can be seen by inverse parks transformation.PWM generator generates gating signals for the inverter bridge circuit operation.

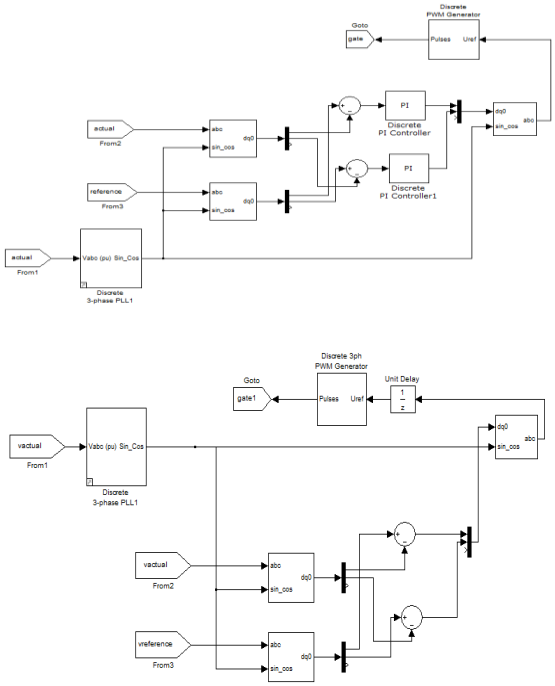

Fig 3: Control circuit

FUZZY CONTROLLER

Fuzzy logic is all about the relative importance of precision: use as Fuzzy Logic Toolbox software with MATLAB technical computing software as a tool for solving problems with fuzzy logic. Fuzzy logic is a fascinating area of research because it does a good job of trading off between significance and precision something that humans have been managing for a very long time [13-14]. Unlike conventional controllers, fuzzy logic controller does not require mathematical model of the system process being controlled. But, an understanding of the system process and the control requirements are necessary. The fuzzy controller designs must define what information data flows into the system (control input variable), how the information data is processed (control strategy and decision) and what information data flows out of the system (solution output variables).

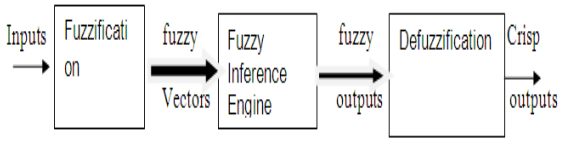

Fig 4: Fuzzy interface system

In this study, a fuzzy logic based feedback controller is employed for controlling the voltage injection of the proposed dynamic voltage restorer (DVR). Fuzzy logic controller is preferred over the conventional PI and PID controller because of its robustness to system parameter variations during operation and its simplicity of implementation. The proposed FLC scheme exploits the simplicity of the mamdani type fuzzy systems that are used in the design of the controller and adaptation mechanism.

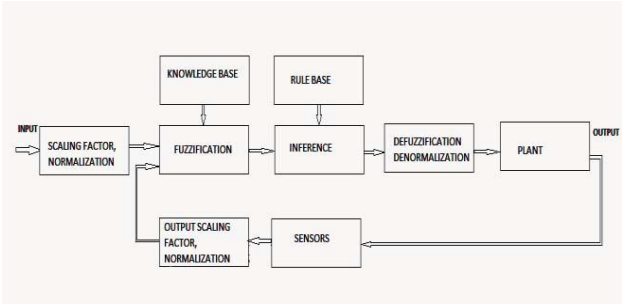

Fig 5: Fuzzy logic controller

The fuzzy logic control scheme can be divided as knowledge base, fuzzification, inference

mechanism and defuzzification. The knowledge base is composed of database and rule base. The rule base consists of a set of linguistic rules relating the fuzzified input variables to the desired control actions. Data base consists of input and output membership functions and provides information for appropriate fuzzification and defuzzification operations. Fuzzification converts a crisp input voltage signals, error voltage signal (e) and change in error voltage signal (ce) into fuzzified signals that can be identified by level of memberships in the fuzzy sets. The inference mechanism uses the linguistic rules to convert the input conditions of fuzzified outputs to crisp control conditions using the output membership functions. The set of fuzzy control linguistic rules is given in table. The inference mechanism in fuzzy logic controller utilizes these rules to generate the required output.

'e' / 'ce'	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table 1: Rule base for fuzzy logic controller

IMPEDANCE SOURCE INVERTER

The inverter topology used in conventional DVR is both VSI and CSI. The VSI topology based DVR has buck type output voltage characteristics thereby limiting the maximum voltage that can be attained. In CSI topology an additional dc–dc buck (or boost) converter is needed[18]. The additional power conversion stage increases system cost and lower efficiency and startup difficult.

Z-source inverter is a efficient, low-cost and reliable inverter for traction drives of solar cell. To reduce the cost and to increase the system reliability, Z-source as a single-stage transformer-less inverter topology is proposed. By utilizing the unique x-shaped LC impedance network, a shoot-through zero state can be added inplace of the traditional zero state of the inverter to achieve the output voltage boost function.

Z-source inverter is less affected by the EMI noise, compared to VSI and CSI. 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. A 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 supress voltage and current ripples [11]. The inductor and capacitor requirement should be smaller compared to the traditional inverters. When inductors are small and approaches to zero, it becomes a traditional voltage source. If capacitors are small and approaches to zero, it acts like traditional current source.

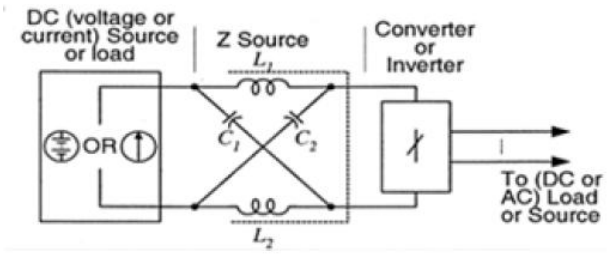

Fig 6: Impedance source inverter(ZSI/ISI)

MODELLING OF DVR

The performance of the DVR with proposed controller is evaluated using MATLAB/SIMULINK platform. The proposed DVR is connected at the load side of the distribution system.

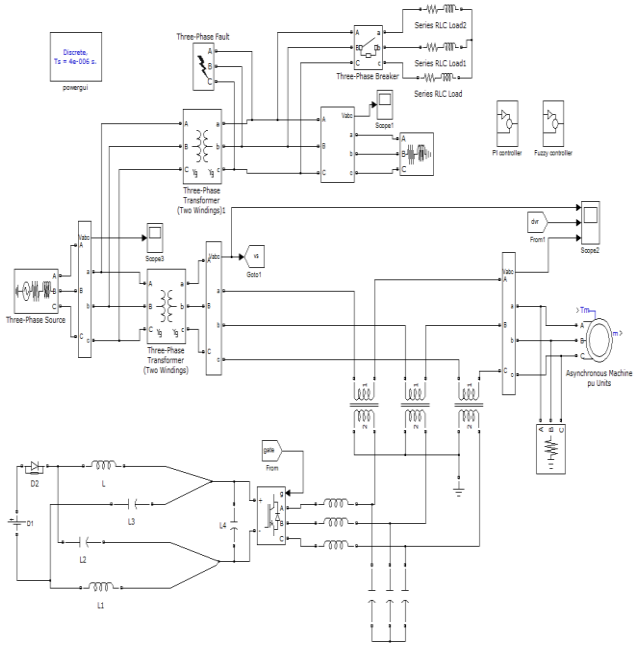

Fig 7: Simulation circuit of Dynamic Voltage Restorer

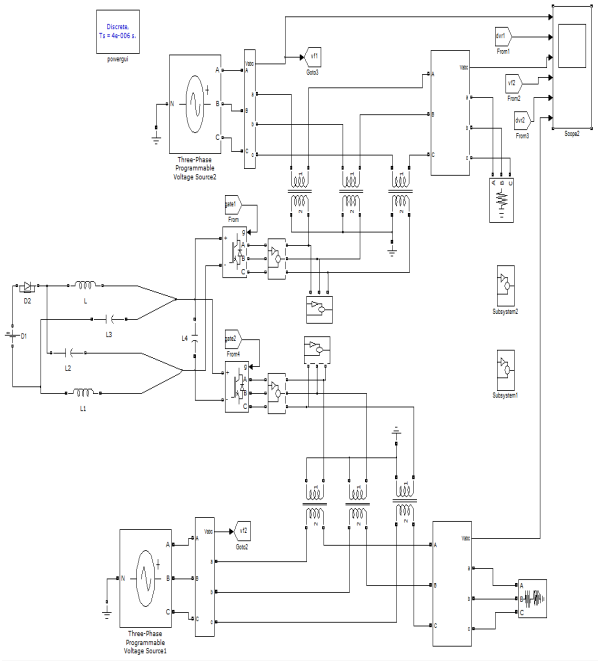

Fig 8: Simulation circuit of DVR's employed as IPFC scheme

SIMULATION RESULTS

Occurrence of three phase fault causes voltage dropped equally in all the three phases. A sudden three phase to ground fault generated in the system results in decrease in voltage. The above problem can be avoided by using load side compensation of DVR using Z – source inverter. Figure shows the three phase voltage of source, DVR injected and load respectively, during three phase fault without compensation and with compensation. For simplicity it is carried out in PU system.

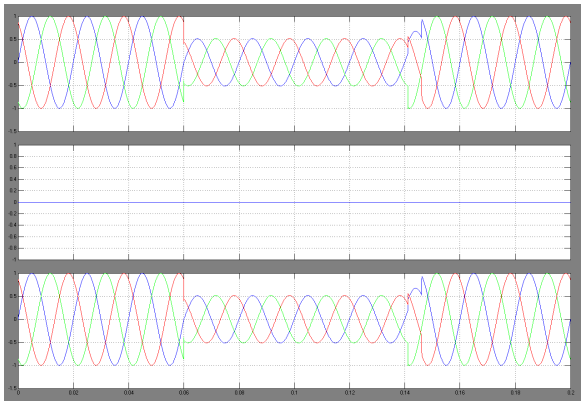

Fig9: Source, DVR injected and load voltages during three phase fault without compensation

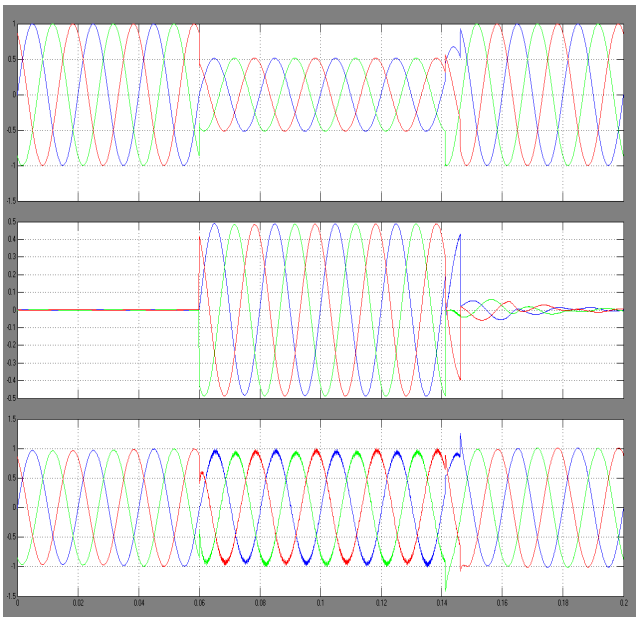

Fig. 10: Source, DVR injected and load voltages during three phase fault with compensation

Due to sudden removal of existing inductive loads beyond the source power rating causes voltage swell, or sudden switching On of capacitive load causes voltage swell as shown in the following figure.

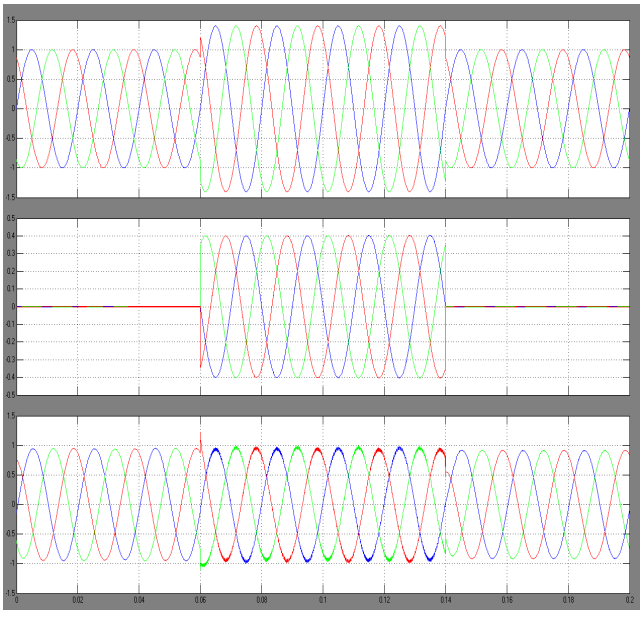

Fig11: Source, DVR injected and load voltages during voltage swell with compensation.

The three phase control circuit adopted so far is not worked out for single phase, two phase, three phase unbalanced sags/swells. So we need to adopt three individual single phase control circuits and inverters.

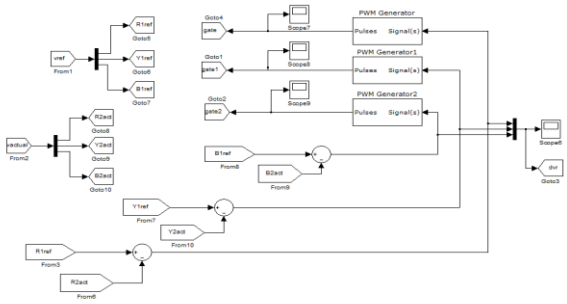

Fig 12: Control circuit of three individual phases

Due to sudden switching On and Off of single phase loads of different power ratings, beyond the source power rating causes unbalance between the three phases.DVR compensated unbalanced sags/swells as shown in the following two figures respectively.

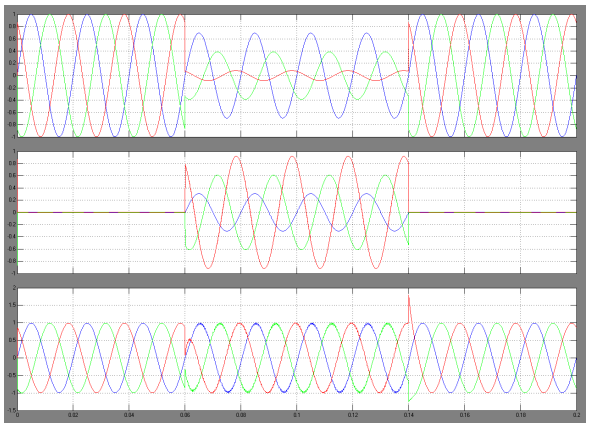

Fig 13: Source, DVR injected and load voltages during unbalanced sag between the phases with compensation

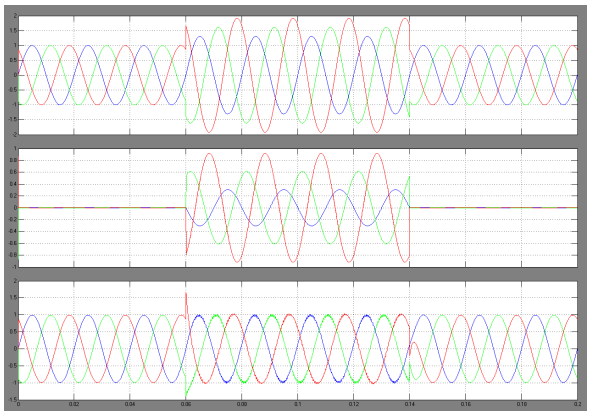

Fig 14: Source, DVR injected and load voltages during unbalanced swell between the phases with compensation.

DVR responds for LG and line to line faults as shown in the following two figures respectively.

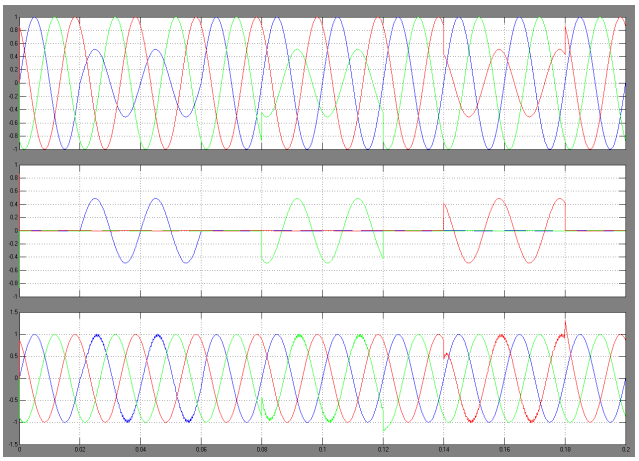

Fig 15: Source, DVR injected and load voltages during LG fault with compensation.

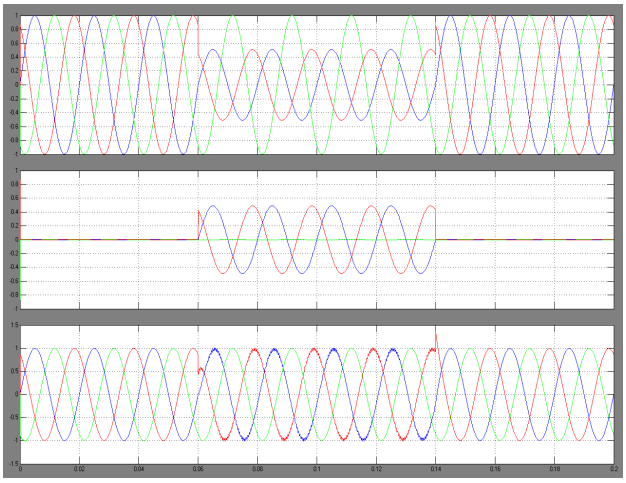

Fig 16: Source, DVR injected and load voltages during LL fault with compensation.

DVR performance is investigated under two more conditions as shown below.

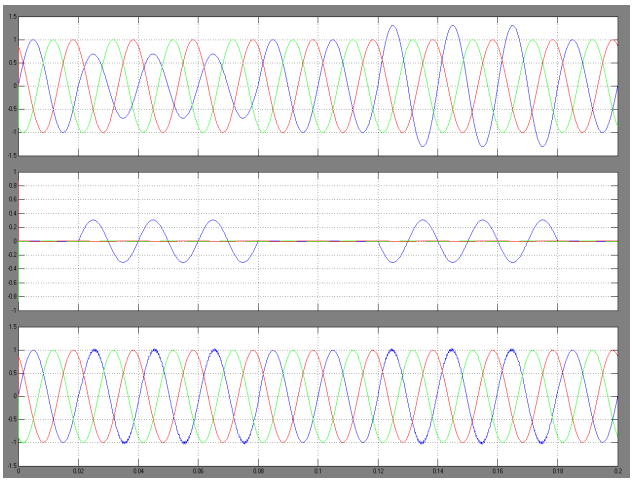

Fig 17: Source, DVR injected and load voltages with compensation.

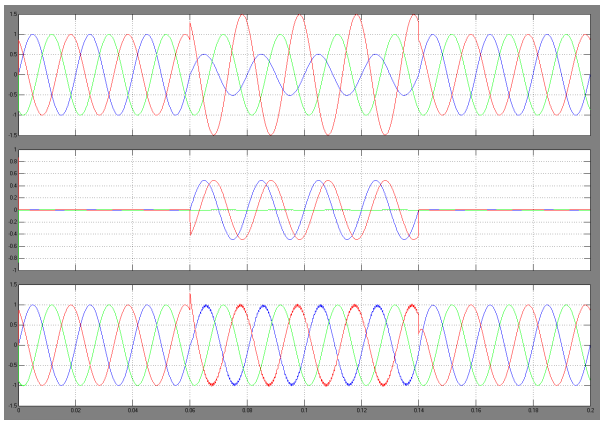

Fig 18: Source, DVR injected and load voltages with compensation.

DVR's employed as series compensators in Interline Power Flow Controller. Two DVR's connected to common dc link. Voltage sag and swell created in feeder 1 and 2 respectively by means of programmable voltage source. Following figure shows the source, DVR injected, load voltages of feeder 1 and 2 respectively.

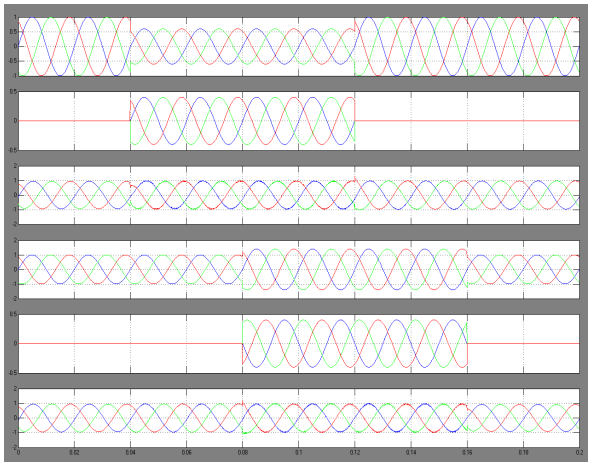

Fig 19: Source, DVR injected and load voltages of feeder 1 and 2 respectively

CONCLUSION

Dynamic Voltage Restorer is an effectual tradition power device, compensates voltage sags/swells in the distribution system. The load voltage is to be asserted constant, nothing but at its craved value by means of using the principle operation of DVR. DVR along with fuzzy controller compensates sags/swells efficaciously as equated to PI controller. PI controller can also accomplish commanded control strategy, if it is tuned precisely. Using fixed gains, the PI controller may not furnish expected control strategy, when there is variation in the system parameters and operating conditions. Regardless of the causes of happening of voltage disturbances, DVR compensates both balanced as well as unbalanced sags/swells. DVR's employed in interline power flow controller (IPFC) are efficaciously compensates sags/swells fell out in individual feeders.

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