# Performance Investigation of DVR & IPFC under different fault and operating conditions

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***Abstract*: Power quality is the most important aspect in the power system environment. 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. 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/swellsare 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.**

***Keywords*: Dynamic voltage restorer(DVR), Impedancesource inverter(ISI),Interline power flow controller(IPFC)**

## I. INTRODUCTION

Modern industrial processes containing voltage sensitive devices, vulnerable to degradation in the quality of power supply. The power quality problems occurs either on source side or load side. Load side problems are associated with change in current, shunt compensation is required. 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, series compensation is required. The deviation of voltage, current and frequency which can be described asa power quality problems. Voltage sag/swell, flicker, harmonics distortion, impulse transients and interruptions are the various power quality problems addressed in the distribution system. Of the above power quality problems, a voltage sag/swell disturbance poses a series threat to theindustries. It can occur more frequently than any other power 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 maybe 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. Irrespective of the causes of occurrence of voltage disturbances, DVR has to protectthe critical loads by maintaining the load voltage at its desired level. Due to switching On and Off of singlephase loads of different power ratings causes unbalance between the three phases.DVR has to compensate unbalanced sags/swells also.

## II. DYNAMIC VOLTAGE RESTORER

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 terminalvoltage 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 thecritical load[5-8].

DVR consists of major components like inverterbridge 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. Filter is there to eliminate high frequency switching harmonics.

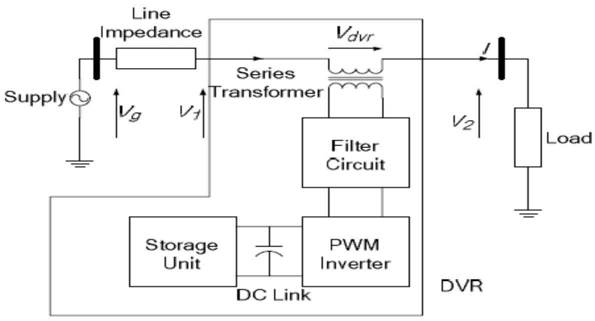

Fig.1: DVR general configuration

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 therebyallowing control of the real and reactive power exchange between the DVR and the distribution system. Real powerexchanged at the DVR ac terminals must be provided by dc voltage source of appropriate capacity connected at theDVR dc terminals. The reactive power exchanged between the DVR and the distribution system is internallygenerated 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. DVRcompensation 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.

## II.CONTROL CIRCUIT

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. Error is positive, while voltage sag occurs and negative for swell occurrence. Before going to compare, the actual and reference source voltages are transformedto 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.

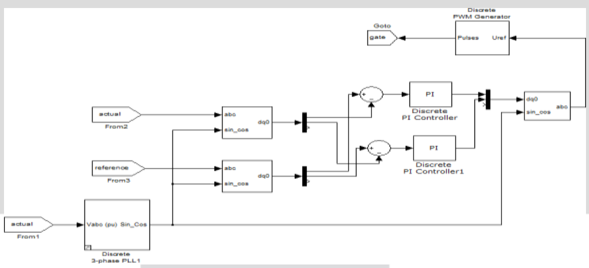

Fig.2: Control circuit

## III.FUZZY CONTROLLER

Unlike conventional controllers, fuzzy logiccontroller does not require mathematical model of thesystem process being controlled. But, an understanding ofthe 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). In this study,a fuzzy logic based feedback controller is employed for controlling the voltage injection of the proposed dynamic voltage restorer (DVR).

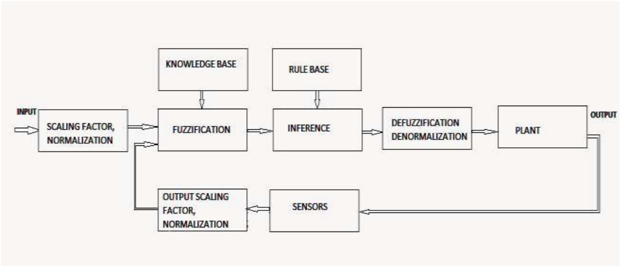


Fig.3: Fuzzy logic controller

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 ofthe controller and adaptation mechanism[9-10].

| '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 |
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| 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

The fuzzy logic control scheme can be divided asknowledge base, fuzzification, inference mechanism and defuzzification. The rule base consists of a set oflinguistic rules relating the fuzzified input variables to thedesired control actions. Data base consists of input andoutput membership functions and provides information for appropriate fuzzification and defuzzification operations. Fuzzification converts a crisp input voltagesignals, error voltage signal (e) and change in errorvoltage signal (ce) into fuzzified signals that can beidentified by level of memberships in the fuzzy sets. Theinference mechanism uses the linguistic rules to convertthe input conditions of fuzzified outputs to crisp controlconditions using the output membership functions. The set of fuzzy control linguistic rules is given in table. Theinference mechanism in fuzzy logic controller utilizes these rules to generate the required output.

## IV.MPEDANCE SOURCE INVERTER

The inverter topology used in conventional DVRis 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. 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 reducethe 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 impedancenetwork, a shoot-through zero state can be added inplace of the traditional zero state of the inverter to achieve the output voltage boost function[11-14].

Z-source inverter is less affected by the EMInoise, 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 currentflow.

The impedance source inverter facilitates the second order filter, so as to supress voltage and current ripples. 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.

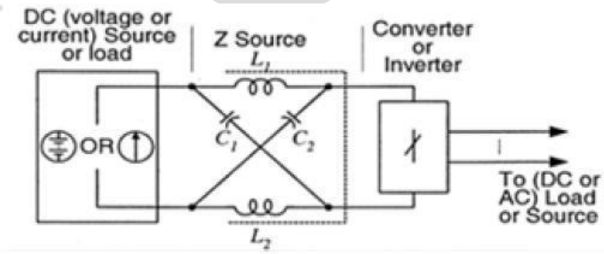


Fig.4: Impedance source inverter(ZSI/ISI)

## V.MODELLING OF DVR

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

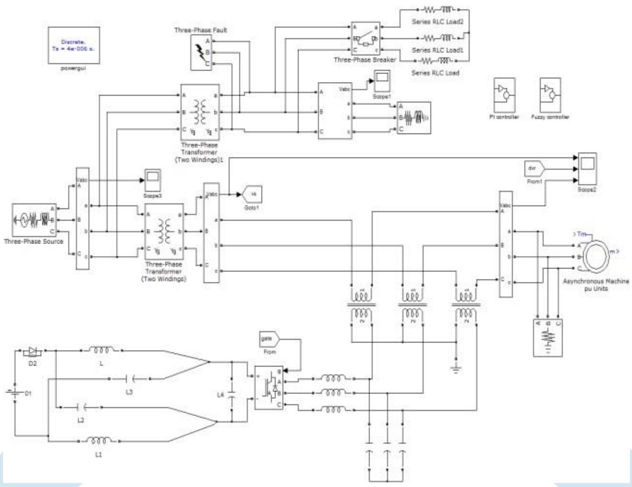

Fig.5: Simulation circuit of Dynamic Voltage Restorer

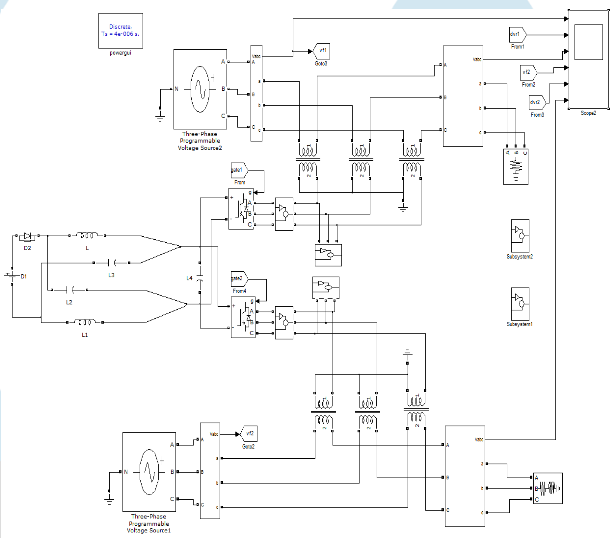

Fig.6: Simulation circuit of DVR's employed as IPFC scheme

## VI.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 – sourceinverter. 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. Without compensation, load voltage is same as that of the source voltage. Results with fuzzy controller are shown.

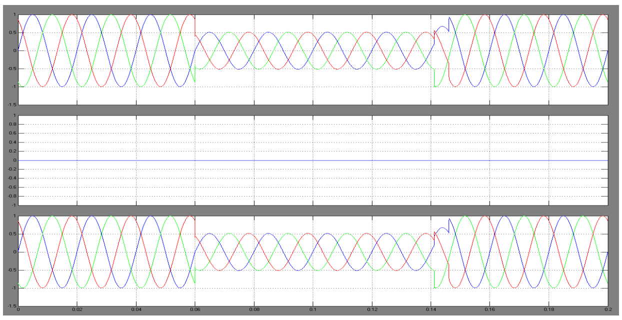

Fig.7: Source, DVR injected and load voltages during threephase fault without compensation.

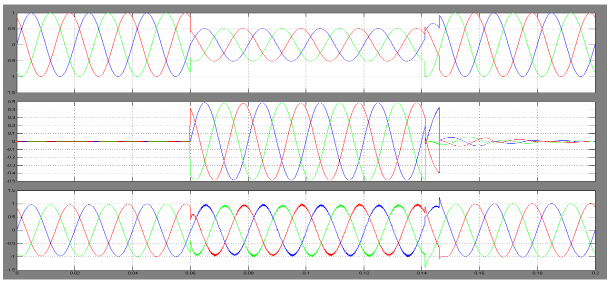

Fig.8: Source, DVR injected and load voltages during threephase fault with compensation.

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.

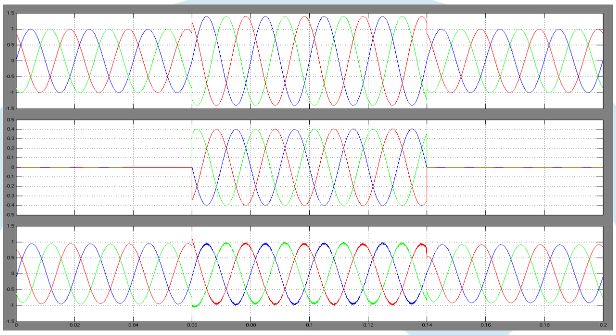

Fig.9: Source, DVR injected and load voltages during voltage swell with compensation.

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.

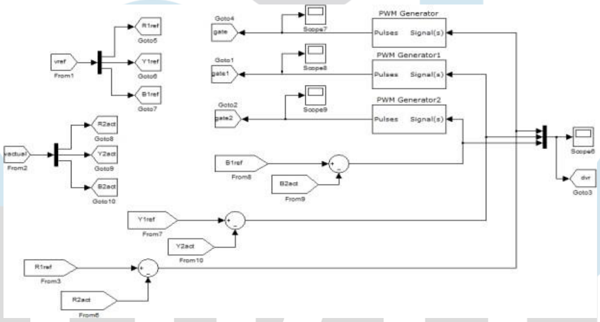

Fig.10: Control circuit of three individual phase

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.

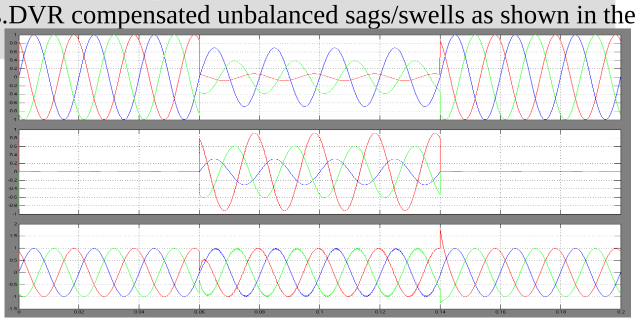

Fig.11: Source, DVR injected and load voltages duringunbalanced sag between the phases with compensation.

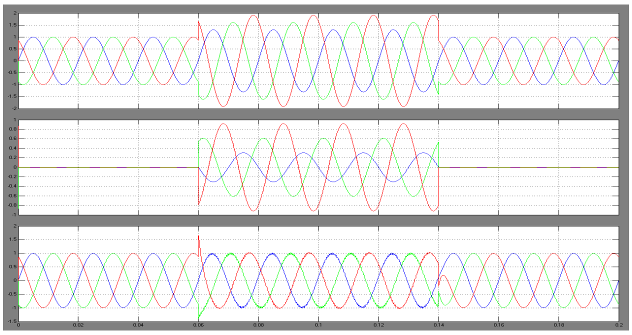

Fig.12: Source, DVR injected and load voltages duringunbalanced swell between the phases with compensation.

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

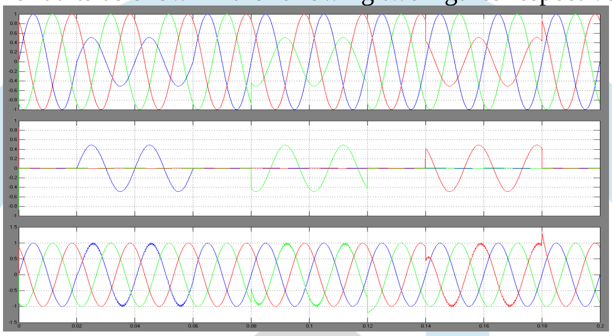

Fig.13: Source, DVR injected and load voltages during LG faultwith compensation.

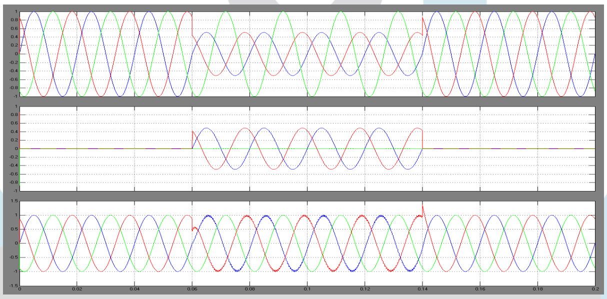

Fig.14: Source, DVR injected and load voltages during LL fault with compensation

DVR performance is investigated under twomore conditions as shown below.

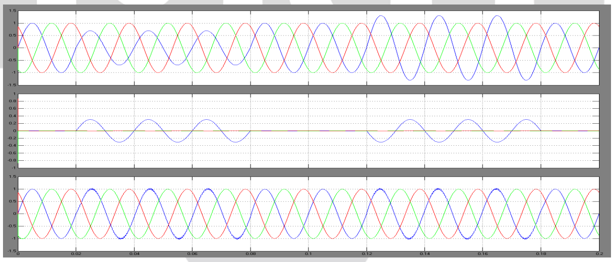

Fig.15: Source, DVR injected and load voltages with compensation.

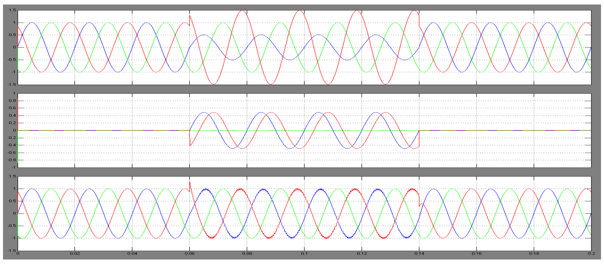

Fig.16: Source, DVR injected and load voltages with compensation.

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 feeder1 and 2 respectively by means of programmable voltage source. Following figure shows the source, DVR injected,load voltages of feeder 1 and 2 respectively.

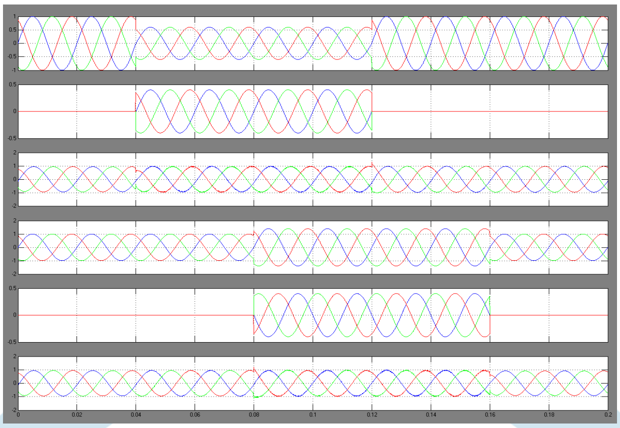

Fig.17: Source, DVR injected and load voltages of feeder 1 and2 respectively

## VII.CONCLUSION

DVR is an effective custom power device, compensates voltage sags/swells in the distribution system. The load voltage is to be maintained constant, nothing but at its desired value by means of using the principle operation of DVR. DVR along with fuzzy controller compensates sags/swells effectively as compared to PI controller. PI controller can also achieve required control strategy, if it is tuned exactly. Usingfixed gains, the PI controller may not provide required control strategy, when there is variation in the system parameters and operating conditions. Irrespective of the causes of occurrence of voltage disturbances, DVR compensates both balanced as well as unbalanced sags/swells. DVR's employed in interline power flow controller(IPFC) are effectively compensates sags/swells occurred in individual feeders.

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