A new integration method of IPQC as Zeta converter based DVR to improve the Power Quality in DG network

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***ABSTRACT-* A new proposal scheme in development of voltage control scheme for power quality improvement such as voltage sag, swell, harmonics, and transient conditions in DG connected micro grid/micro generation. Faults occurring in power distribution systems or amenities can inject the voltage sag or swell. This fault can damage or affect the power systems in transmission and distribution. For sensitive loads, the short duration of voltage sags also cause huge problems in the entire power system. DG will get the active power only and the series part of the IPQC injects / compensates the reactive and harmonic power in the grid. In order to reduce power fluctuations, this work proposes a IPQC as Zeta converter to improve the power quality. This proposed scheme can quickly access the voltage sag and swell under different transient conditions as well as improve the PQ in DG network.**

***Index Terms*—Improved power quality converter, Dynamic Voltage Restorer, Power Quality, Series Compensation, Voltage Sag/Swell, Zeta Converter, Distributed Generation (DG).**

I.INTRODUCTION

Power quality is "the provision of voltages and system design in such a way that the electric energy is utilized from the distribution side successfully without interference or interruption." Power quality is the most important concerned area of electric power system. The insufficient quality of power output sometimes leads to complete shutdown of the industries which provides a major economic loss to the industries and consumers [4,5,6]. The industries always demand the supplier or utility for high quality power. But the blame due to degraded quality depends not only upon the utility but also depends on the conditions that can disrupt process that are generated within the industry itself. Most of the industries use non-linear loads which cause transients and it can affect the quality of the power supply [8,9]. Some abnormal electrical conditions such as Voltage sags, swell, Phase outages, Voltage interruptions and Harmonics are generated both at utility and consumer end due to the presence of nonlinear loads [3,7,10].General scheme of a distributed generation(DG) unit connected to the grid is shown in Fig.1.

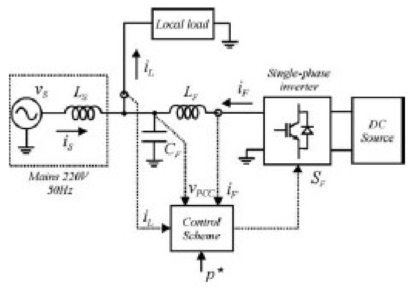

Fig.1.General scheme of a DG unit connected to the grid.

The distributed Generation (DG) concepts emerged as a way to integrate different power plants, increasing the DG owners' reliability and providing additional power quality benefits. In grid connected mode, the voltage at the point of common coupling is imposed by the grid; thus, the inverter must be current controlled. When operated in island mode, the inverters are voltage-controlled, generating the output voltage at a specified amplitude and frequency. All the commercial single phase inverters for DG systems inject only active power to the grid.

FACTS (Flexible AC Transmission Systems) and Custom power devices are the best examples for the utility and consumer end power quality solutions. Uninterruptible Power Supplies (UPS), Dynamic Voltage Restorers (DVR) and Active Power Filters (APF) are examples for commonly used custom power devices.

Among these three custom power devices, DVR is the most efficient and effective custom power device that is used to compensate voltage sag and swell conditions [1, 5, 11, 12]. DVR appeals reasonable cost, portable size and fast dynamic response to the disturbance. The basic operation of DVR is to inject a voltage of the required magnitude, phase angle and frequency in series with distribution feeder to maintain the desired amplitude and waveform for load voltage even when the source voltage is unbalanced or distorted [13–16].

There is a number of voltage sag/swell mitigating methods available, but the use of tradition power service is considered to be the most efficient method. This paper introduces a new concept of IPQC as Zeta converter based DVR (Dynamic Voltage Restorer) to compensate the reactive power in DG network. The performance of DVR depends on the efficiency of control technique of switching zeta converter. In this paper PI controller based control method is used to compensate voltage sag/swell. The proposed control technique is modeled based on MATLAB/ Simulink.Fig.2 Shows the converter based classification of improved power quality converters.

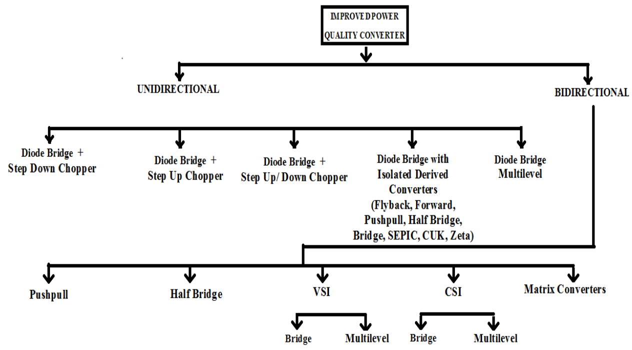

Fig.2. Converter based classification of improved power quality converters

II.DYNAMIC VOLTAGE RESTORER

DVR is a custom power device which acts as a harmonic isolator and prevents the harmonics in the source side. In addition it balances the voltages and provides voltage regulation. In order to regulate the load side voltage, DVR is a recently proposed scheme which is a series connected solid state device that injects voltage into the system.

The main function of DVR is to boost up the load side voltage in the place of disturbance in order to avoid any power disruption to the load. There are many control technique available to implement the DVR. The primary function of DVR is to compensate voltage sags and swells apart performing the tasks such as: harmonic compensation, reduction of transient in voltage and fault current limitation [17,18]. The proposed DVR system consists of an injection transformer, zeta converter, filter, voltage source converter and control & protection system. Fig.3 shows the schematic representation of proposed zeta converter based DVR control system.

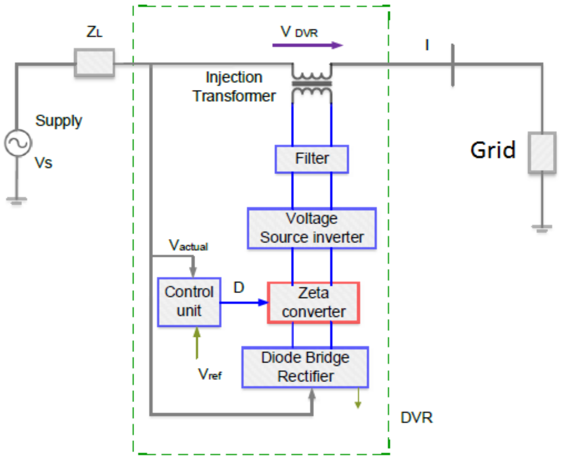

Fig.3 Schematic representation of zeta converter based DVR control system

A. ZETA CONVERTER

Different types of AC-DC converters have been introduced to fulfil the demanded power conversion such as sepic, cuk converters etc. From the available converters the zeta converters (Buck-Boost type) are incorporated in the proposed work. The zeta converter has advantages such as, safety, flexibility, isolation and output adjustment. Zeta converters usually have high transfer voltage gain and also produce high insulation on both sides. The gain of the Zeta converters always depends on the transformer's turn ratio N, which can be thousand times. The zeta converter is a transformer based converter with a low-pass filter. Its output voltage ripple value is small [19,20]. The circuit diagram of zeta converter is shown in Fig.4.

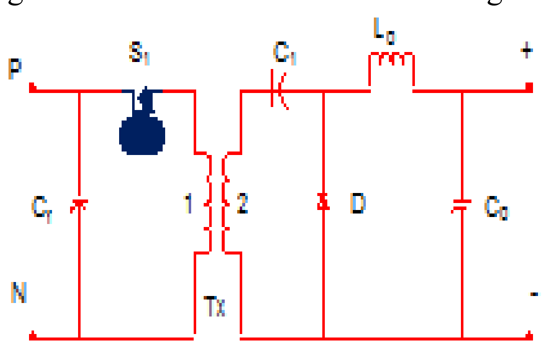

Fig.4. Circuit diagram of zeta converter

Where N is the turn ratio of transformer, and k is the conduction duty cycle k= t_{on} /T.

B. VOLTAGE SOURCE INVERTER

The function of the VSI is to convert the DC voltage into an AC voltage which is supplied by zeta converter. Step up voltage injection transformer is used in DVR power circuit, which enables VSI of low voltage rating to cope up the requirements [21].

C. INJECTION TRANSFORMER

In distribution line secondary side of the injection transformer is connected in series, while the primary side is connected to zeta converter based DVR. The function of the injection transformer is to inject the voltage supplied by the filtered zeta converter based VSI [21]. The injection transformer winding ratio will increase the primary side current, depending upon the performance of the zeta converter based VSI.

D. HARMONIC FILTER

The role of harmonic filter is to filter out the self-generated harmonics generated by DVR which is composed of power electronic devices. The main function of harmonic filter is to keep the harmonic voltage content to acceptable level which is generated by the zeta converter fed VSC.

E. CONTROL AND PROTECTION CIRCUIT

A controller is also used for the proper function of the DVR system. Load voltage from the DVR is sensed and passed through a sequence analyzer. The load voltage magnitude is compared with reference voltage. Duty cycle control technique is applied for zeta converter switching to generate a DC voltage equivalent to three phase quantity which is to be fed through voltage source inverter at the load terminals.

The input voltage of zeta converter is extracted from transmission line and fed through diode bridge rectifier. PI controller is used with zeta converter to maintain the voltage at the load terminals. The controller input is used as an actuating signal which is a measure of the difference between the V_{ref} (reference voltage) and V_{in} (actual voltage). An advantage of this proportional plus integral controller is to produce integral term which results in the steady-state error to become zero for a step input [22, 23].

III.COMPENSATION OF ZETA CONVERTER BASED DVR

Fig.5 shows the operation of the DVR that injects a controlled voltage generated by the zeta converter fed voltage source inverter in series to the system voltage by means of an injecting transformer. The zeta converter regulates the voltage by varying duty ratio control using PI controller. During normal operating condition the DVR injects very low voltage to compensate the voltage drop in the injection transformer and device losses and drop. When sag/swell occurs in the distribution system [24], the zeta converter based DVR system either injects/absorbs required control voltage to preserve output voltage to the load side. Switching pattern of the VSI can be inversed during sag/swell conditions. The DVR system is capable of generating or absorbing reactive power. In the proposed system the active power injection of the DVR must be provided by zeta converter which is connected to the same system. The response time of DVR is very small, and it is limited by the power electronics devices apart from the voltage sag/swell detection time.

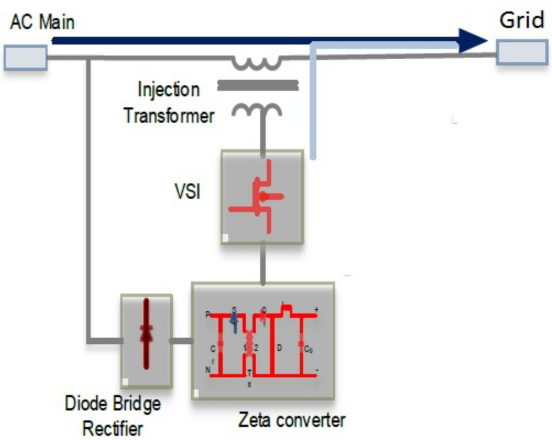

Fig.5. Compensation principle of zeta converter based DVR system

The injected voltage by DVR is mathematically expressed by the following equation

$$V_{inj(DVR)} = V_S + Z_L I_L - V_L$$

Where, V_L is the load voltage, V_S is supply voltage during sag and $V_{inj\,(DVR)}$ is the voltage injected by DVR. Under normal voltage conditions, the load current can be written using the following equation Where, I_L is the load current, P_L and Q_L are the active and reactive power taken by the load respectively during a sag/swell. When DVR inject voltage, the complex power is given by the following expression

$$S_L = (S_s + S_{inj})$$

And the load current can be expressed by the following equation

$$I_L = [(P_s - jQ_s) + (P_{inj} - jQ_{inj})] / V_L$$

IV.SIMULATION RESULTS

A 440V, 50Hz, power distribution system configuration is simulated using Math works Matlab/Simulink to study the effectiveness and response of suggested DVR control strategy under supply disturbances (Line-ground fault). Zeta converter based DVR is connected in series with line for compensation. Zeta converter is controlled by the PI controller by varying the duty ratio. Here DVR system is connected in series to the distribution system by using an injection transformer. The DVR operation is based on three phase voltage source inverter with LC output filter to remove high frequency voltage components. An inductive nature *R-L* load (*R*=1KΩ, *L* =1microh) is considered for evaluation of proposed system. Fig.6 and 7 shows the Simulink model of the proposed system and Zeta converter based DVR. The simulation results are presented to prove the possibility of the proposed system.

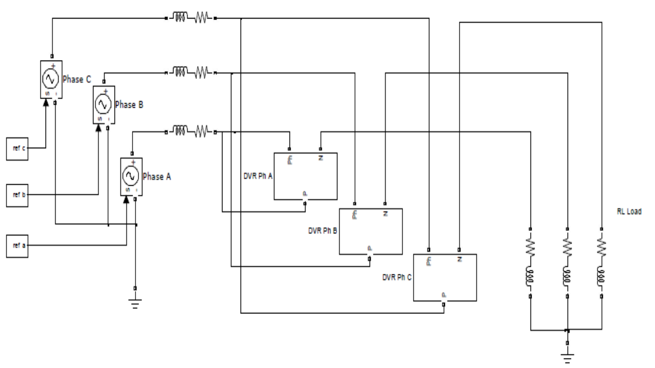

Fig.6. Overall Simulink model of Zeta converter based DVR control system for power quality improvement

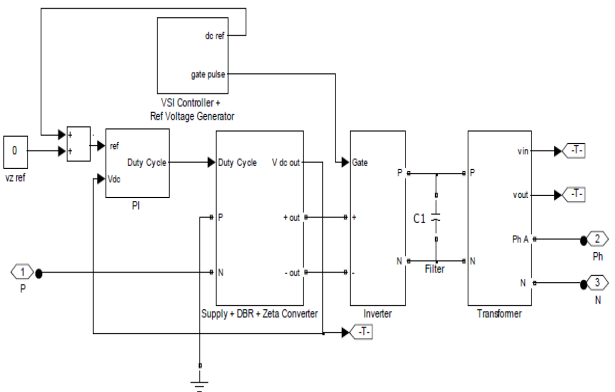

Fig.7. Simulink model of Zeta converter based DVR

A. RESULTS OF PROPOSED SYSTEM WITH VOLTAGE SAG

In this proposed system voltage sag is introduced in both the feeders for the duration of 1.4s to 1.5s using phase to ground fault. The output and results for the above system are shown below. Figs.8- 10 shows the input and output responses during sag the occurrence of condition in the test system. Fig.8 shows the source voltage with sag, load voltage after compensated by DVR and DVR output voltage., Fig.9 shows the reactive power compensated by DVR system and Fig.10 shows the DC reference voltage for converter during sag condition.

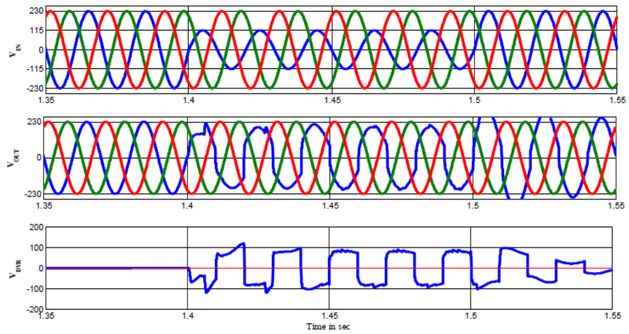

Fig.8. Simulated voltage response of proposed test system during sag condition Source voltage, Load voltage and Voltage injected by DVR

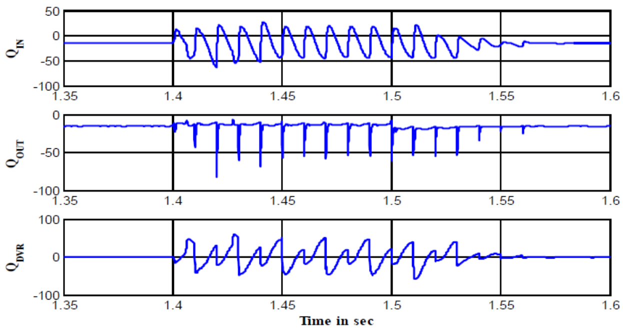

Fig.9. Reactive power compensation

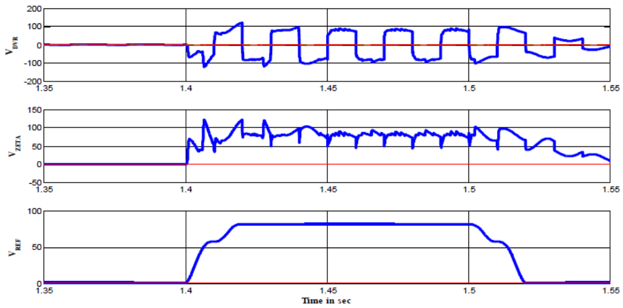

Fig.10. DC reference voltage and zeta converter voltage during sag condition

B. RESULTS OF PROPOSED SYSTEM WITH VOLTAGE SWELL

In this system voltage swell is introduced in both the feeders for the duration of 1.0s to 1.1s using phase to ground fault. The output results for the above system are shown below. Figs.11-14 shows the input and output responses during the occurrence of swell condition in the test system.

Fig.11 shows the source voltage with swell, load voltage after compensated by DVR and DVR output voltage. Fig.12 shows the real power injected by DVR system, Fig.13 shows the reactive power compensated by DVR system and Fig.14 shows the DC reference voltage and zeta converter voltage during swell condition.

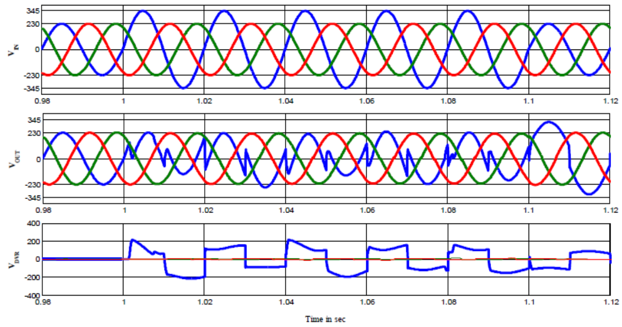

Fig.11. Simulated voltage response of proposed test system during swell condition Source voltage, Load voltage and Voltage injected by DVR.

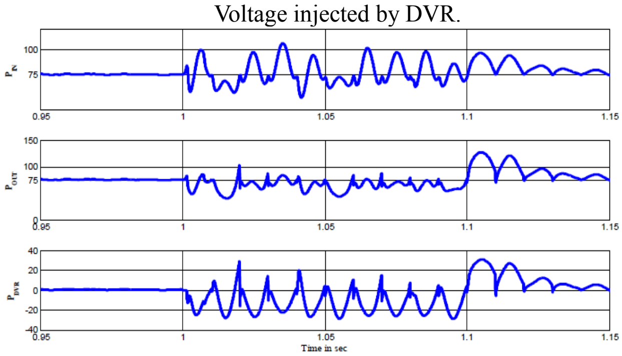

Fig.12. Simulated real power response of proposed test system Power at source end, Power at load end and Power injected by DVR

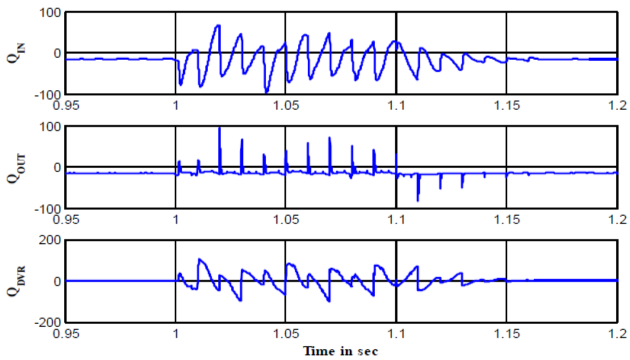

Fig.13. Reactive power compensated by DVR.

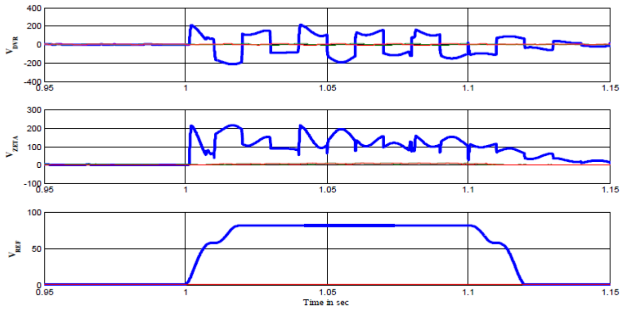

Fig.14. DC reference voltage and zeta converter voltage during swell condition

V. CONCLUSION

In this work deals with a single phase inverter for DG systems, acquiring power quality features as harmonic and reactive power compensation for grid connected operation. A fast response and cost effective based Dynamic Voltage Restorer (DVR) is proposed for compensating the problems of voltage sag and swell condition in distribution systems, the effectiveness of DVR using PI controller is established for nonlinear load. Also the inverter employed delivers active and reactive power to the load with a better power quality with low THD. Other kinds of controllers like fuzzy controller and adaptive PI fuzzy controller may be employed in the DVR compensation scheme in future.

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