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A Novel Technique to Improve Power Quality using Fuzzy Logic Controller with Transformer Less Dynamic Voltage Restorer

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Abstract

Power quality problems such as voltage sags are presently important issues in the industrial field. The dynamic voltage restorer (DVR) is a series compensation device that mitigates voltage sag problems. Due to the nonlinearity of the DVR dynamic characteristics, the compensating performance of the DVR is affected much by its control strategy. In this paper, fuzzy logic control is proposed to enhance the compensating performance of the transformer-less DVR. Recently new FL methods have been applied to Custom Power Devices, especially for active power filters. The operation of DVR is similar to that of active power filters in that both compensators must respond very fast on the request from abruptly changing reference signals. Simulation studies were conducted to show that the proposed fuzzy logic DVR control is very effective in damping the system oscillations and improving the compensating performances compared to the traditional PI control.

Keywords: Power Quality, Dynamic voltage Regulator, Fuzzy Logic

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I. INTRODUCTION

The impact of voltage sags is very significant in power systems. Voltage sags are voltage drops from 10% to 90% with 10ms to 2sec duration. When an industrial process is interrupted or shut down by voltage sags, it will take a long time to be recovered. Such events can result in a loss of multi-million dollars. Voltage sags not only cause power quality problems, but also affect the security operations of equipment. To overcome the above problems, the dynamic voltage restorer (DVR) is proposed to inject series voltage compensation into the system to compensate voltage sags. Normally, the injected voltage is introduced through an injection transformer for electrical isolation and voltage boost.

However, the transformer-less DVR is much more cost-effective for the low voltage load system. The DVR compensating performance will be much affected by the control strategy of the DVR inverter. Normally, an open-loop control is easily implemented in the practical design. However, due to the nonlinearity of the DVR dynamic characteristics, the open-loop control has poor dynamic performance and could lead to the system instability. A closed loop controller that consists of an inner current loop and an outer voltage loop has been incorporated into the DVR inverter to maintain the load voltage at a desired level.

An active cancellation technique is also proposed to overcome the limitation of the presence of the nonlinear element related to the magnetic energy of the filtering inductor. Stability is considered through analysis of the closed-loop poles of the system. Fuzzy logic methods have been applied to Custom Power Devices, especially for active power filters. The operation of DVR is similar to that of active power filters in that both compensators must respond very fast on the request from abruptly changing reference signals fuzzy logic control of DVR in the project. Fuzzy logic controllers evaluating 49 linguistic rules process these errors. The output voltage signal is sensed and compared with reference signal. The comparative result is send to fuzzy controller and it generates PWM inverter signals. In this study, a Fuzzy logic control is designed for the transformer-less DVR to enhance the closed-loop system stability and improve the compensating performance. In addition, simulation studies were conducted using a well-established MATLAB simulink. The simulation results show the comparisons study between compensating performances of PI controller and Fuzzy logic controller under different load condition.

Different solutions have been developed to protect sensitive loads against disturbances but the DVR is considered to be the most efficient and effective solution. Its appeal includes lower cost, smaller size and its dynamic response to the disturbance. This paper describes transformer-less DVR principles and voltage restoration methods for balanced and/or unbalanced voltage sags in a distribution system. Simulation results were presented to illustrate and understand the performances of DVR under voltage sags conditions.

II. DYNAMIC VOLTAGE RESTORER

A Dynamic Voltage Restorer (DVR) is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder. Its primary function is to rapidly boost up the load-side voltage in the event of a disturbance in order to avoid any power disruption to that load. Compared to the other Custom Power devices, the DVR clearly provides the best economic solution for its size and capabilities. For the most part DVR “does nothing” except monitoring the bus voltage, which means that it does not inject any voltage.

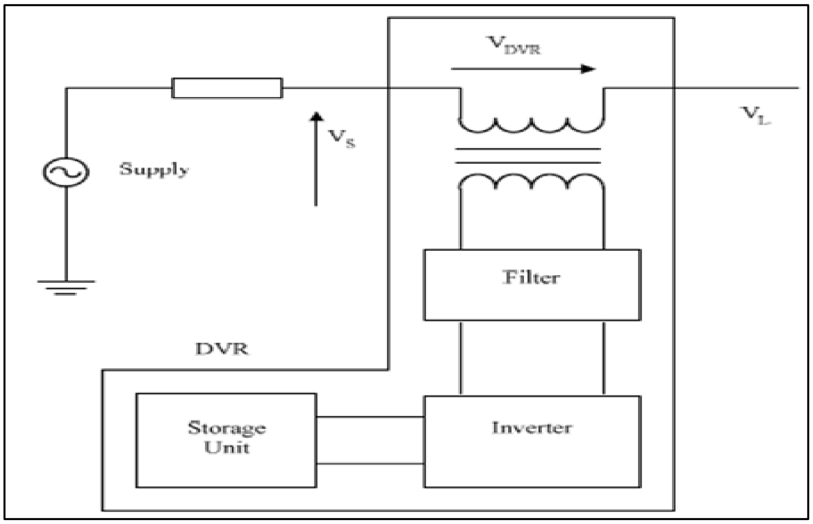

Fig: 1: DVR series connected Topology

($V_{inj}(t) = 0$) independent of the load current. Therefore, it recommends that the attention should be focused particularly on the losses of a DVR during normal operation. Two specific features addressing this loss issue have been implemented in its design, the transformer design including low impedance, and the semiconductor devices used for switching.

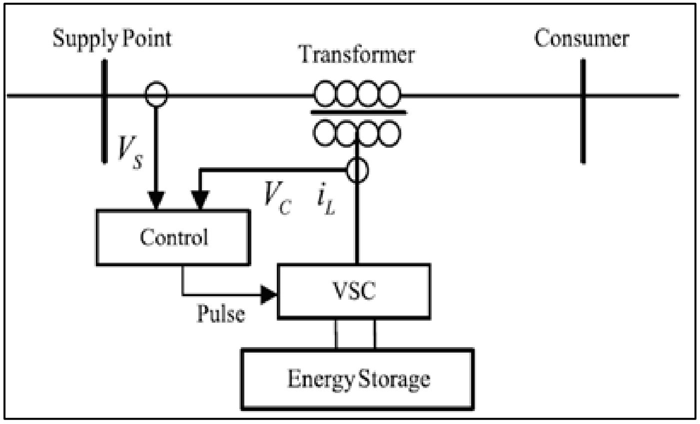

Fig. 2: Schematic Diagram of DVR system

An equivalent circuit diagram of the DVR and the principle of series injection for sag compensation are depicted in Fig. 2.

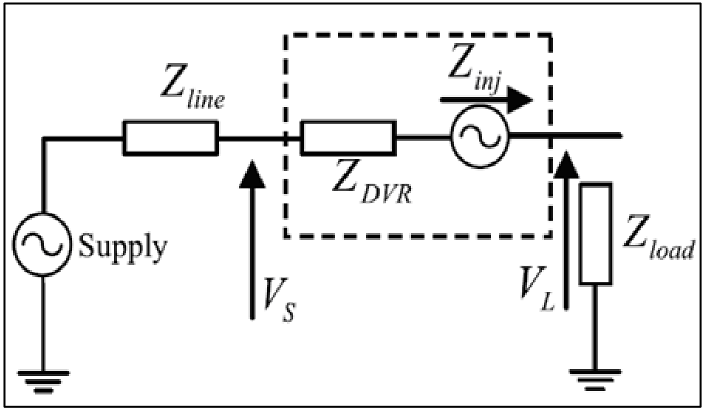

Fig. 3: Equivalent circuit of DVR

Mathematically expressed, the injection satisfies:

$$V_L(t) = V_s(t) + V_{inj}(t) \text{-------}(1)$$

Where $V_L(t)$ is the load voltage, $V_s(t)$ is sagged supply voltage and $V_{inj}(t)$ is the voltage injected by the mitigation device as shown in Fig. 3.

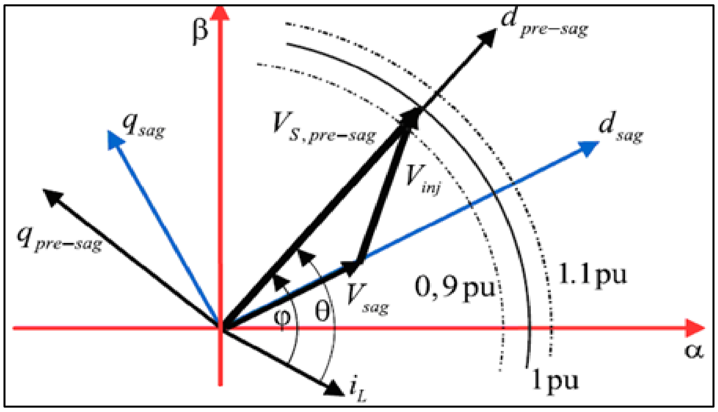

Fig. 4: Compensation strategy of DVR for voltage sag

Under nominal voltage conditions, the load power on each phase is given by (2)

$$S_L= V_L I_L= P_L\text{-}j\, Q_L\text{----------------} \qquad (2)$$

Where I_L is the load current, and P_L, and j Q_L are the active and reactive power taken by the load respectively during a sag/swell. When the mitigation device is active and restores the voltages back to normal, the following applies to each phase.

$$S_L= P_L\text{-}j\, Q_L\ = (P_s\text{-}j\, Q_s) + (P_{ing}\text{-}j\, Q_{ing})\text{----}(3)$$

III. CONTROL STRATEGY

For the identification of disturbance, we use the Park transformation technique (dq-frame). This work is primarily focused on closed-loop PWM control scheme. The closed-loop control introduced in this paper is made up of an inner current loop and an outer voltage loop to better satisfy different linear or nonlinear load disturbance. System level simulations of the whole inverter and control system will be performed based on MATLAB-Simulink. Proportional plus- integral (PI) controller will be used in this dual-loop control system to regulate output voltage of the PWM inverter.

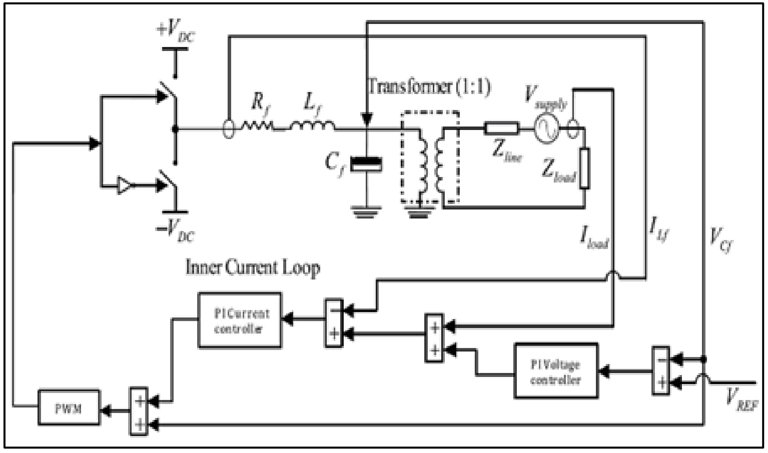

Fig. 5: Outer Voltage Loop

The current and voltage dual-loop control system for a single-phase PWM inverter can effectively reduce the output voltage distortion and achieve fast dynamic response. In this control scheme output voltage V_{cf} and inductor current I_{if} will form an outer loop and an inner loop each governed by a PI controller. In additional, load current I_{Load} and the output voltage V_{cf} will act as feedback compensation for the reduction of output disturbance even under rough load conditions.

The reference input will give the desired output voltage as a control reference. To determine K_p and K_i values of both regulators, we study every loop independent of each other. In the control loop all the components are represented by their respective transfer functions or gains. In particular, the controller represented by the typical proportional integral regulator structure, whose parameters K_p and K_i will be determined in the following. The output of the regulator represents the modulating signal that drives the pulse width modulator. This has been modeled as the cascade combination of two separate blocks: the first one is the modulator static gain, and the second is actually a first-order Pade approximation of its delay, considered equal to a half of the duration of the modulation period.

Considering the inverter and load models, we see that they based on the analysis which is presented as follows. Finally, to fully replicate a typical implementation, a transducer gain is taken into account. Additional filters, normally adopted to clean the transducer signal from residual switching noise, are not taken into account, in favor of a more essential presentation. Their transfer functions can be easily cascaded to the transducer block gain if needed.

IV. TRANSFORMER LESS DVR

A three-phase DVR consists of three independent single-phases. Charging thyristors, Thy3 and Thy4, will be controlled to limit charging currents during the device start-up as well as when the source voltage recovered after events. The thyristors will be OFF when there is any error happened at the dc bus. In addition, it will be fully ON once DC capacitors, C_1 and C_2, have been fully charged. At the normal operation, the source provides the power supply to the load through main thyristors Thy12. When voltage sags occur, the main thyristors, Thy12, will be off and the inverter consisting of IGBT1 and IGBT2 will output a high frequency pulse modulated voltage instantaneously.

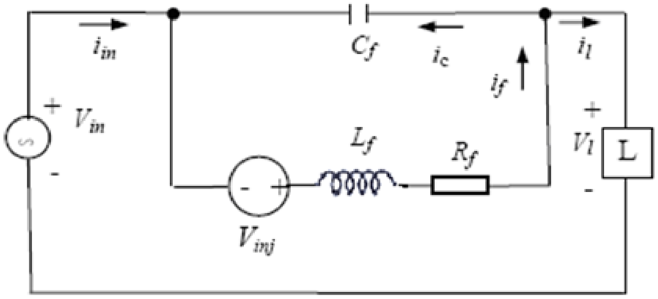

Fig. 6: DVR Equvalent diagram During compensation

The system model of the transformer-less DVR in figure 6 will be established in the following

$$C_f(V_t-V_{in})=i_f-i_l \quad \text{------------} \quad (4)$$

$$V_{in}+V_{inj}=L_f i_f+R_f i_f+V_l \quad \text{-------------} \quad (5)$$

where, C_f is the filter capacitance, R_f and L_f are resistance and inductance of the filter inductor respectively.V_1, V_{in} and V_{inj} are the load voltage, the input voltage and the injection voltage of the DVR respectively; i_l and i_f are the load and the filter inductor currents respectively. Assume that power loss is negligible in the filter inductor and IGBT switching, we have

$$C_1V_{dc1}V_{dc2}^{*}+C_2V_{dc2}V_{dc2}^{*}=V_{in}i_{in}-V_l i_l \text{--------}(6)$$

Where, V_{dc1} and V_{dc2} are dc voltages of dc capacitors C_1 and C_2 respectively, i_{in} is the load current. Let then $C_1=C_2=C_{dc}$ then i_f becomes

$$i_1=1/V_l(V_{in}i_{in}-C_1V_{dc1}V_{dc1}{*}\ C_2V_{dc2}V_{dc2}{*})- \quad (7)$$

Assuming R_f =0, and substituting it in the above equation then V_i and I_f is as follows

$$\left\{\begin{aligned} & V_l=\frac{1}{C_f}i_f-\frac{1}{C_fV_l}\left(V_{in}i_{in}-C_{dc}V_{dc1}V_{dc1}^{*}-C_{dc}V_{dc2}V_{dc2}^{*}\right)+V_{in} \\ & i_f=\frac{1}{L_f}V_{inj}-\frac{1}{L_f}V_l+\frac{1}{L_f}V_{in} \end{aligned}\right\} \quad (20)$$

Therefore, the nonlinear system model of the DVR shown in Fig.6 is established.

V. SIMULATION RESULTS

The MATLAB simulink diagram represents the system with an open loop control in a transformer-less DVR .

A sag of 50% voltage drop with 0.1 sec duration will be studied for the above control strategies. Waveforms of the input voltage and load voltage are shown correspondingly. Fig.7 and Fig.8 are simulation results under the resistive and inductive loads respectively with the open- loop PWM control strategy.

A. *Open Loop Control:*

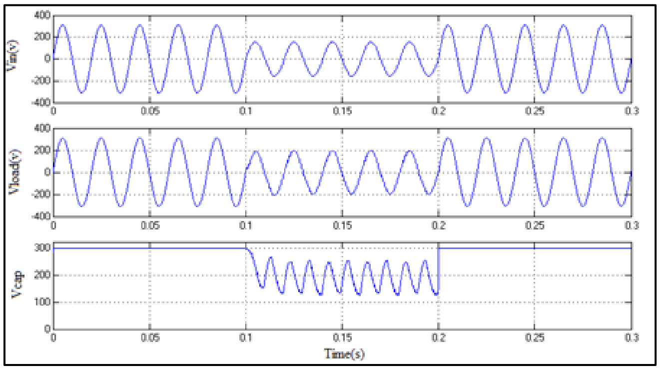

Fig. 7: A sag of 50% drop occurs under resistive loads with the open loop control

From Fig. 7, it shows that the DVR injects a corresponding voltage to the system when the sag occurs. Thus the load voltage will not be affected by the event. The DC capacitor voltages drop down quickly to 155V and then they are stable after 0.2s while the sag has not been cleared. This shows that the amount of DC capacitor design is not affected much by the sag duration and thus it is minimized. Therefore, the proposed DVR is cost-effective. During compensation, the load voltage waveform is quite smooth under resistive loads as shown in Fig. 8.

However, oscillations are observed obviously for the compensating voltage under inductive loads as shown in Fig. 8. This means that the system is lack of damping under inductive loads with theopen-loop control.

B. **PI Control:**

Using the same parameters from the above strategy we are going to see the PI controller in the transformer less DVR and its output obtained. Fig. 9 and Fig. 10 are simulation results under resistive and inductive loads respectively with the traditional PI control.

C. **Fuzzy Logic Control:**

Here the PI controller in the above section is replaced with a fuzzy logic controller and then system is analyzed Fig. 8 and Fig.9 are simulation results under resistive and inductive loads respectively with the proposed fuzzy logic DVR control strategy. The simulation results show that the proposed fuzzy logic DVR control can inject a smooth voltage to the load under both of resistive and inductive loads.

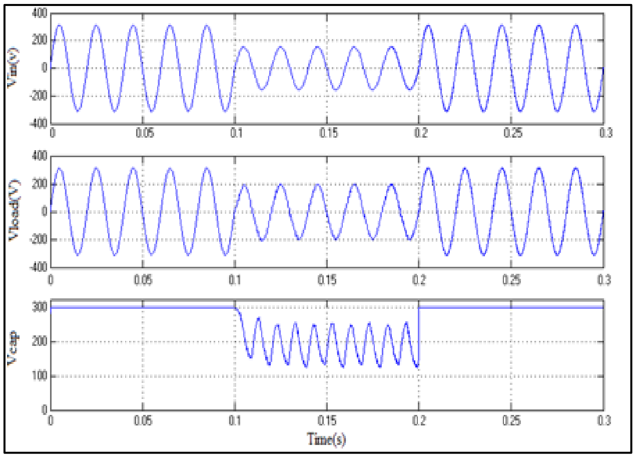

Fig. 8: A sag of 50% drop occurs under inductive loads with the open loop control.

It is obvious that the system oscillations are damped effectively under inductive loads with proposed fuzzy logic DVR control and the system is damped fast with the proposed fuzzy logic DVR control.

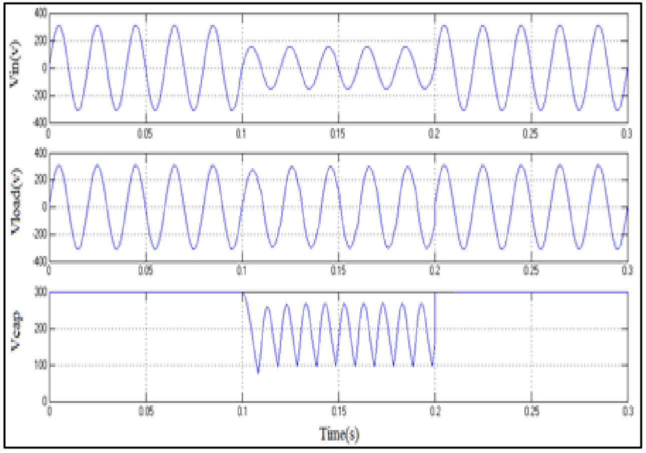

Fig. 9: A sag of 50% drop occurs under resistive with the fuzzy control

Thus, the proposed DVR can mitigate voltage sags effectively and the system stability is enhanced during compensation under resistive and inductive loads with the designed fuzzy logic control.

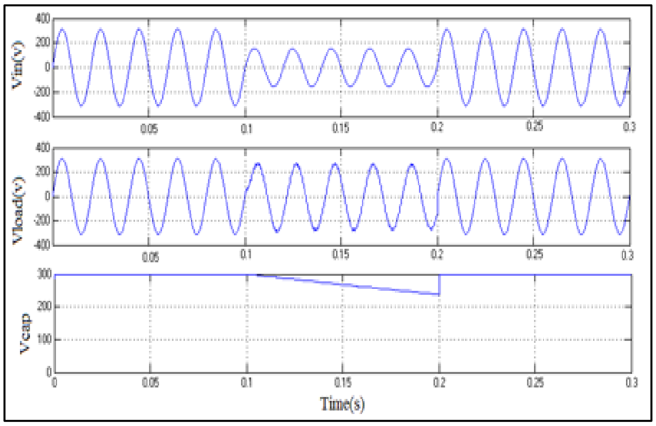

Fig. 10: A sag of 50% drop occurs under low inductive loads with the PI control

In the above simulation the value of resistance and inductance has been changed to 15 ohm and 10*10^-6 henry and the output results are shown in the figure 10.

VI. CONCLUSION

A cost-effective transformer-less DVR is proposed in this study to mitigate voltage sags by injecting compensating voltage directly into power systems. The amount of DC capacitor used for energy storage is minimized. DC capacitor charging currents are not only controlled at start-up of the device but also at the system voltage recovered after events. The fuzzy logic control has been introduced and designed for the DVR compensating strategy to damp oscillations under different load conditions. Simulation results show the proposed fuzzy logic DVR control is effective in mitigating voltage sags and improving the system stability. Compared to the traditional PI control, the system is damped faster with the proposed fuzzy logic DVR control.

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