Performance Analysis of DVR with Hysteresis and Double Loop Controller

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***Abstract*-With the wide applications of the nonlinear and electronically switched devices in distribution Systems, the problems such as voltage sag/swell, flicker, harmonics and asymmetries of voltages have become increasingly serious. To tackle these situations, custom power apparatuses are utilized. Dynamic Voltage restorer (DVR) is a modified power apparatus that is utilized to enhance voltage stability i.e. to minimize the power quality problems in electrical power system network. The important parts of the dvr comprise of voltage source inverter (VSI), booster transformers, filter and a dc energy source. The principle of the dvr is utilized to inject the voltage in series and in synchronism with the standard voltages with a goal to compensate voltage influences. There are various control techniques used for the operation of dynamic voltage restorer. This paper compare the hysteresis voltage control technique and double loop control technique for generation of switching pulses for inverter of dynamic voltage restorer. The two control techniques along with dvr test system are designed in mat lab software.**

1. INTRODUCTION

Nowadays, modern industrial devices are mostly based on electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics and voltage imbalances. Voltage dips are considered to be one of the most severe disturbances to the industrial equipments.

Voltage sags can occur at any instant of time, with amplitudes ranging from 10 – 90% and a duration lasting for half a cycle to one minute [3]**.** Voltage swell, on the other hand, is defined as a *swell* is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min. typical magnitudes are between 1.1 and 1.8 up. Swell magnitude is also is also described by its remaining voltage, in this case, always greater than 1.0. [2, 3, 4].

Harmonics are produced by nonlinear equipment, such as electric arc furnaces, variable speed drives, and large concentrations of arc discharge lamps, and loads which use power electronics. Harmonic currents generated by a nonlinear device or created as a result of existing harmonic voltages will exacerbate copper and iron losses in electrical equipment. In rotating machinery, they will produce pulsating torques and overheating [6].

Voltage imbalances are normally brought about by unbalanced loads or unbalanced short-circuit faults, thus producing overheating in synchronous machines and, in some extreme cases, leading to load shutdowns and equipment failure.

There are many different methods to mitigate voltage sags and swells, but the use of a custom Power device is considered to be the most efficient method. Switching off a large inductive load or Energizing a large capacitor bank is a typical system event that causes swells.

This paper compares the performance analysis of hysteresis controller based dvr and double loop controller based dvr. Hysteresis controller based dvr for compensating voltage sag and swell but the double loop controller for compensating the voltage-quality disturbances such as, voltage sags, harmonic voltages, and voltage imbalances. Double loop controller was originally applied to eliminate speed fluctuations in electric motors but it has since been adopted in a wide range of power-electronics applications.

2. BASIC STRUCTURE OF DVR

Dynamic voltage restorer is overall suited to secure susceptible or delicate load from short span voltage dips and swells. Whenever a short circuit happens in a power system network, a sudden voltage dip will show on nearby feeders. With a DVR introduced on a load feeder, the line voltage is restored to its normal level within the reaction time of a few milliseconds. Hence power interruption is avoided.

The DVR is essentially a voltage-source converter connected in series with the ac network via an interfacing transformer, which was originally conceived to ameliorate voltage sags [7].However, as shown in this paper; its range of applicability can be extended very considerably when provided with a suitable control scheme.

The basic operating principle behind the DVR is the injection of an in phase series voltage with the incoming supply to the load, sufficient enough to reestablish the

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voltage to its pre sag state. Its rate of success in combating voltage sags in actual installations is well documented [8], this being one of the reasons why it continues to attract a great deal of interest in industry and in academic circles.

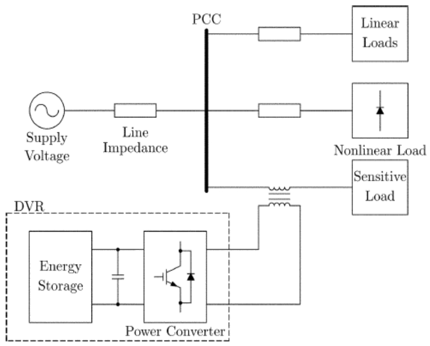

Fig. 1. System configuration with a DVR.

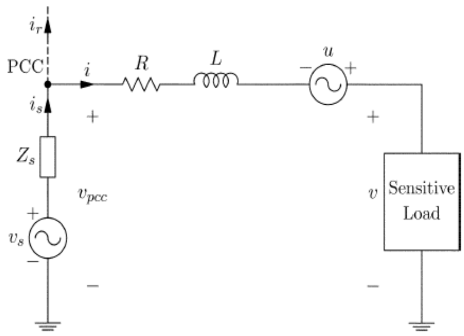

Fig. 2 DVR equivalent circuit diagram

3. HYSTERESIS VOLTAGE CONTROL TECHNIQUE

The control of dynamic voltage restorer is relates with the detection of voltage sag/dip, voltage swell, and the generation of the reference voltages for injection purpose. The sag, swell detection technique is very important task for the appropriate working of dynamic voltage restorer. There are various techniques for the detection of voltage sag, swell. Some are given below [6].

- Measuring peak values of input supply.
- Measuring of voltage components in dq frame in a vector controller.
- Applying phase locked loop to each phase.
- Applying the Fourier transform to every phase.
- Applying the wavelet transform to every phase.

Structure of DVR by using Hysteresis Voltage Control Technique:

Following figure explains the main control diagram of dynamic voltage restorer with hysteresis voltage controller. It mainly consists of three phase IGBT inverter, Energy storage, booster transformer and the hysteresis voltage controller. The hysteresis controller mainly requires two voltage signals, one is from supply side voltage signal and another is from booster transformer which is voltage injected by dynamic voltage restorer. The controller compares these two signals and according to these signals switching pattern is established. The hysteresis switching method is well explained in fig.6 also the design of hysteresis voltage controller in MATLAB software is given in fig. 7. [14]

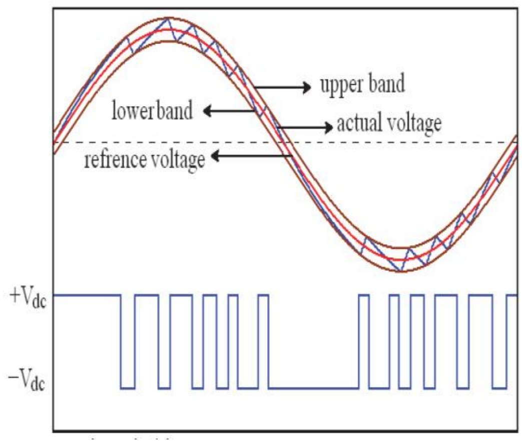

Fig. 3. Hysteresis switching pattern

The control technique applied in this paper is based on voltage error and is non linear control method. It consists of a comparison between the output voltage and the tolerance limits (V_H, V_L)around the reference voltage, While the output voltage is between upper limit and lower limit , no switching occurs and when the output voltage increases to the upper limit (lower band) the output voltage is decreased (increased).

4.0. DESIGN OF THE DOUBLE LOOP CONTROLLER

The aim of the control system is to regulate the load voltage in the presence of various kinds of disturbances. The control structure proposed in this paper is based on the use of a feed forward term of the voltage at the PCC to obtain a fast transient response, and a feedback term of the load voltage to ensure zero error in steady state.

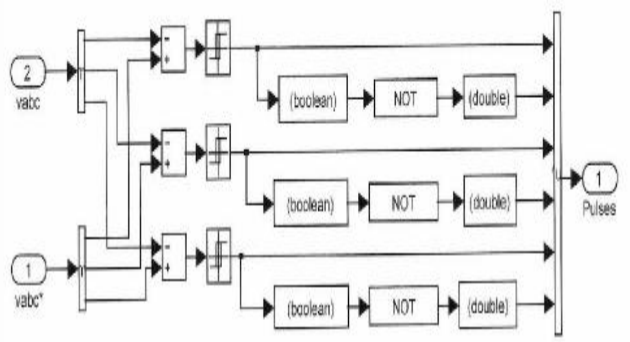

Fig. 4. Hysteresis voltage controller in MATLAB.

The continuous time of the whole control system is depicted in Fig. 5 where **C(S)** represents the controller. If the switching frequency is high enough, the DVR can be modeled as a linear amplifier with a pure delay $P_1(s)=e^{-t_0 s}$ [20]. This delay is the sum of one-sample-period plus the time delay of the inverter due to PWM switching. The former applies in cases of microprocessor-based implementations [27] and the latter can be taken to be half the switching period [20]. The transfer function $P_1(s)$ is equal to L_s+R*(s) is the reference voltage for the load*(s) is the control output, where as U(s) is the output voltage of the DVR and V(s) is the load voltage. The inputs V_{pcc}(s)

and I(s) stand for the grid voltage and the current through the load, respectively.
The load voltage is

$$V(s) = F(s)V^*(s) + F_w(s)V_{\mathrm{pcc}}(s) + F_i(s)I(s)$$

$$F_i(s) = -\frac{P_2(s)}{1 + C(s)P_1(s)},$$

$$F_w(s) = \frac{1 - P_1(s)}{1 + C(s)P_1(s)}$$

whe $F_i(s) = -\frac{P_2(s)}{1 + C(s)P_1(s)},$

$$C(s) = \frac{M(s)}{1 - e^{-\frac{2\pi}{w_1}s}}$$

Where M(s) is a transfer function chosen so that the closed-loop stability is always fulfilled and w1 is the fundamental frequency at the mains.
The modified controller is proposed as

$$C(s) = \frac{Q(s)e^{-(T-\hat{t}_0)s}}{1 - Q(s)e^{-Ts}}$$

Where Q(s) is the transfer function of a low-pass filter, t_0 is the estimated value for the DVR delay, with , $T = \frac{2\pi}{\omega} - \beta$ and β is a design parameter which is smaller than the period of the grid voltage ($\beta < \frac{2\pi}{\omega}$)
Double loop controller is a contemporary control technique that may be used to cancel out, simultaneously, voltage sags, voltage harmonics, and voltage imbalances, characteristics rarely achieved with other control techniques, such as PI controllers.

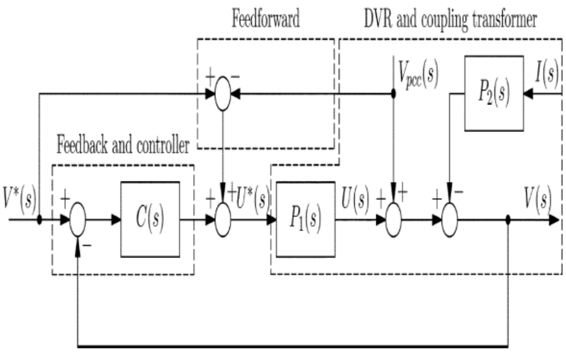

Fig.5. Closed Loop Controller System

5. SIMULATION RESULTS

5.1 HYSTERISIS CONTROLLER

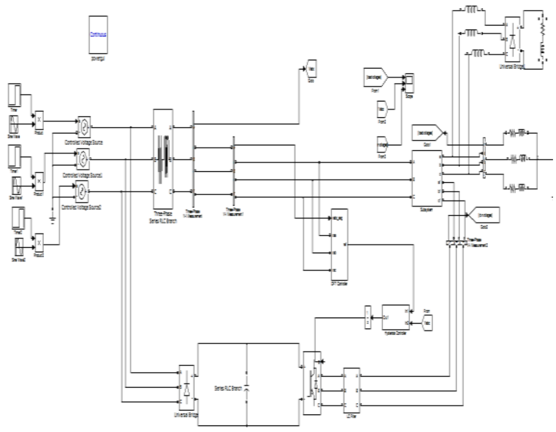

Fig 6.Simulink model for hysteresis control based dvr with linear and non linear load

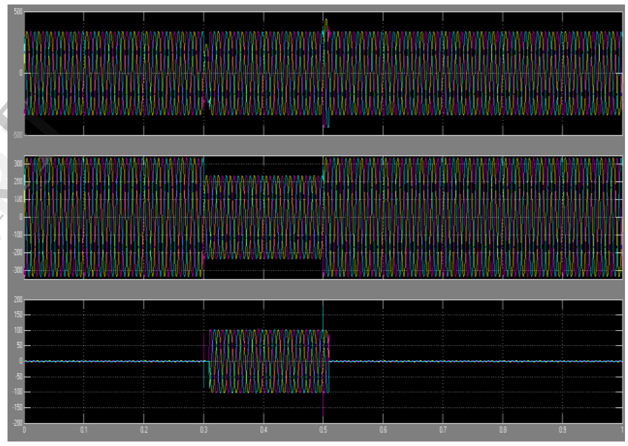

Fig 7.load voltage, source voltage and dvr voltages for linear loads

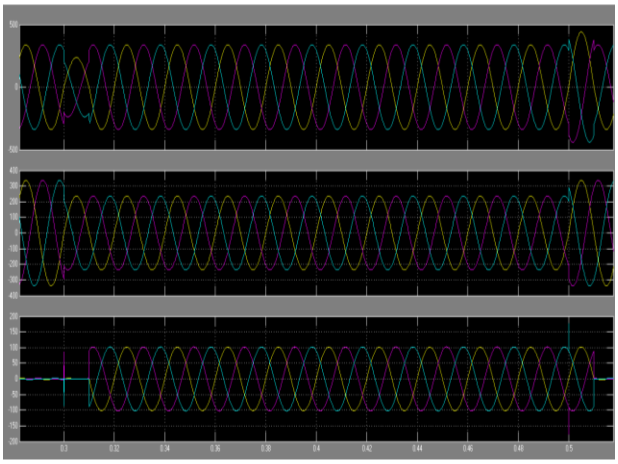

Fig 8. load voltage, source voltage and dvr voltages for linear loads (zoomed)

From these figures we can easily say that hysteresis controller based dvr best for voltage sag and swell problems. When non linear load is connected with hysteresis controller based dvr it compensates the sag and swell problems but the harmonics injected by the non linear load cannot compensate.

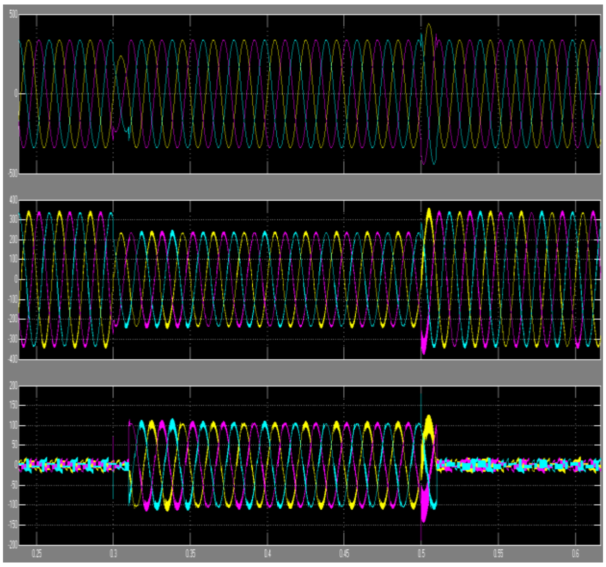

Fig 9. load voltage, source voltage and dvr voltages for non linear loads

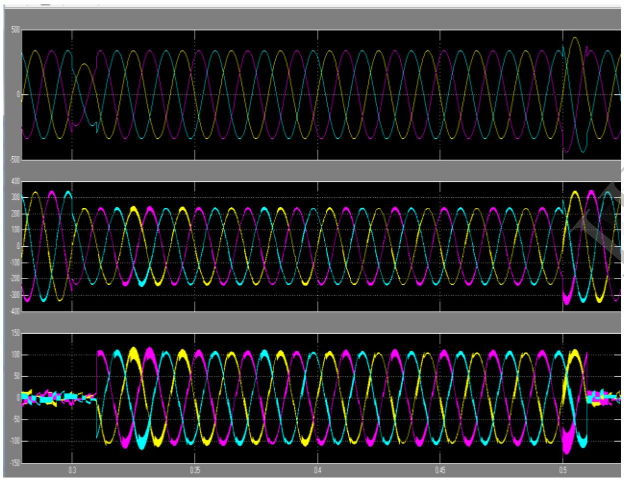

Fig 10. load voltage, source voltage and dvr voltages for linear loads (zoomed)

5.2 DOUBLE LOOP CONTROLLER

The developed model consists of a 400 V 50 Hz source which feeds three different loads: 1) A squirrel –cage induction machine 2) A non-linear load which consists of an uncontrolled three phase rectifier with an inductive-resistive load and 3) A three phase sensitive load which consists of a star made up of a resistance connected in series with an inductance in each phase.

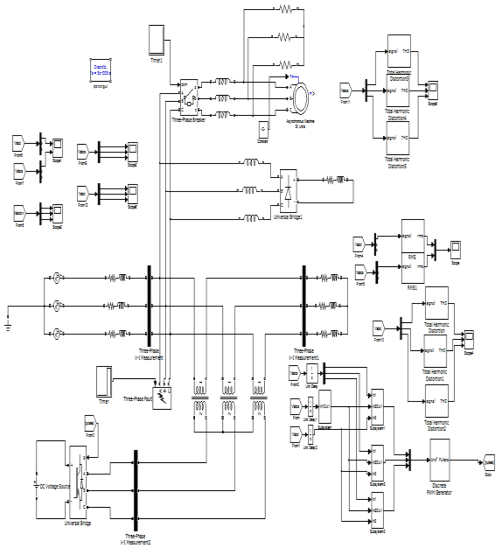

Fig.11. Simulink model for double loop controller based dvr with linear and non linear loads

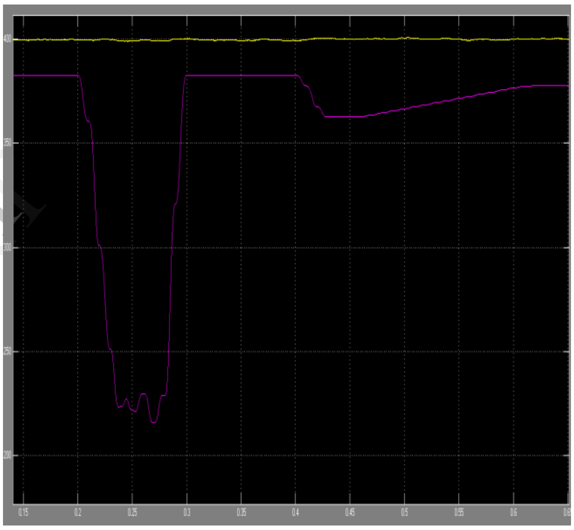

Fig.12. Rms voltage signal of source voltage and load voltage

Fig 12 shows the RMS voltage for the sensitive load and at PCC for the interval of 0.8 seconds. A non-linear load and DVR are connected at t=0 secs. A two phase short circuit fault is applied at PCC from t=0.2 s to t=0.28 s. The induction machine is connected at t=0.4 s to t=0.65 s. The non-linear load is disconnected at t=0.65 s. The total simulation time is 0.8 s.

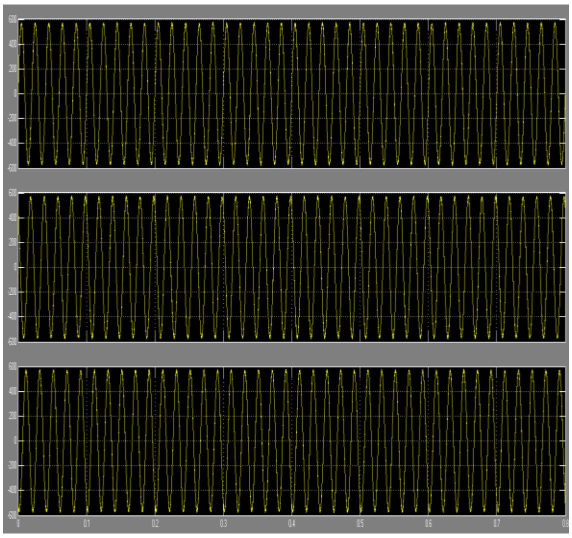

Fig.13. Three phase load voltages

Fig 13 shows that Line to Line Voltages at PCC in the Interval 0 to 0.8 even we applied short circuit fault and non linear load voltage at sensitive load is constant with pure sinusoidal.

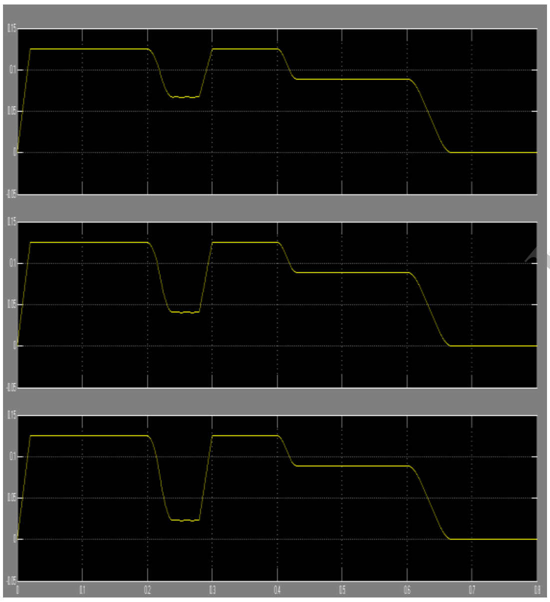

Fig.14. THD of source voltage

Fig.14 shows that the total harmonic distortion injected by the non linear load is completely compensated by the dvr with double loop control. The thd in the source voltage is 0.3% which is within the IEEE standard.

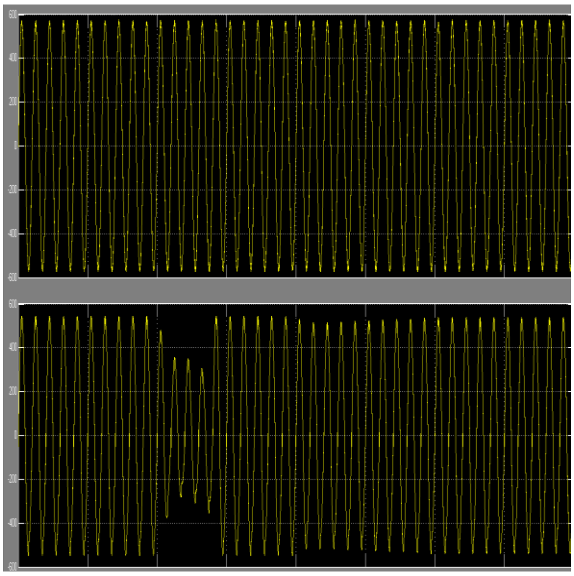

Fig.15. load voltage and source voltage

Fig.15 shows that the single phase load voltage and source voltage which are lightly affected by the harmonics injected by the non linear load.

CONCLUSION

This paper provides a better solution for power quality problems among the various controlling technique for DVR. Many industries will have large number of power electronics devices and energy resourceful apparatus these are more easily influenced to the unbalance in the input supply voltage. To solve power quality problems like sag, swell unbalancing and harmonics custom power device Dynamic Voltage Restorer (DVR) is used to mitigate these power quality problems. Simulation results shows that the hysteresis voltage control technique is very good technique for voltage sag and swell problems and it is not suitable for unbalanced voltages and harmonics injected by non linear loads. Double loop controller based dynamic voltage restorer is effectively solves mitigation of voltage sag, voltage swell, harmonics and voltage unbalancing conditions.

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