Power Quality Improvement using Three Leg VSC Based DVR

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***Abstract* — The dynamic voltage restorer (DVR) is one of the modern devices utilized in distribution systems to protect consumers against sudden changes in voltage amplitude. The instantaneous reactive power theory (IRPT) control algorithm for three leg VSC based DVR is implemented. Power quality is of immense importance in all modern environments where electricity is involved. It may be primarily influenced by vital issue like quality service. The proposed DVR is employed to mitigate power quality problems like voltage sag, swell, harmonics and unbalance within the supply voltage. The gating signals for three leg VSC based DVR are extracted from the reference load voltages. The simulation results are validated using MATLAB / SIMULINK.**

***Index Terms*— Power Quality, Dynamic Voltage Restorer, IRPT, voltage source converter.**

I. INTRODUCTION

Power quality is acts as a very important source for common in both the industrial sectors and domestic environment. So both electrical utilities and end users are becoming concerned regarding the quality of electric power. As the primary demand of any power distribution system is to boost power quality, the improvement of power quality in the distribution system has many benefits like elimination of harmonics, maximum load capability, most utilization of equipment etc. The power electronic converters such as AC voltage controller, voltage source converter, switched mode power supplies, uninterruptible power supplies has increased in domestic and industrial instrumentation etc. The power electronic converters not only pollute power distribution system but also enhance power quality. These power electronic equipments draw harmonics from supply and are responsible for voltage dip at the load end.

Custom power devices are based on power electronic current, harmonics and the reactive power loading from AC supply. DVR is one of the series connected custom power device to mitigate voltage connected problems at point of common coupling (PCC). Many power quality standards are used in the design of power system with non linear loads such as IEEE519 IEEE1159 IEEE241 IEC 61642.In a three leg VSC based DVR, the power supplied/absorbed is zero in the steady state. There are various control algorithms such as instantaneous symmetrical components theory for DVR, Artificial Neural Network (ANN), based control algorithm for shunt active filter sliding mode and fuzzy logic controller for static series compensator. In this paper, a simple IRPT control algorithm is implemented for three-leg VSC based DVR for mitigation of voltage sag, swell, harmonics and unbalance in supply voltage. The computer based simulation results of IRPT based DVR are validated using MATLAB / SIMULINK.

II. PRINCIPLE AND OPERATION OF DVR

The schematic diagram of three-leg VSC based DVR is depicted in Fig.1.The three phase sources(v_{sa}, v_{sb}, v_{sc}), three phase source series impedance consists of resistance (R_s) and inductance (L_s).The DVR uses a three phase transformer to inject voltage in series with supply voltage and to maintain load voltage at a rated value. A three-leg VSC along with a dc capacitor (C_{dc}) is used in DVR.

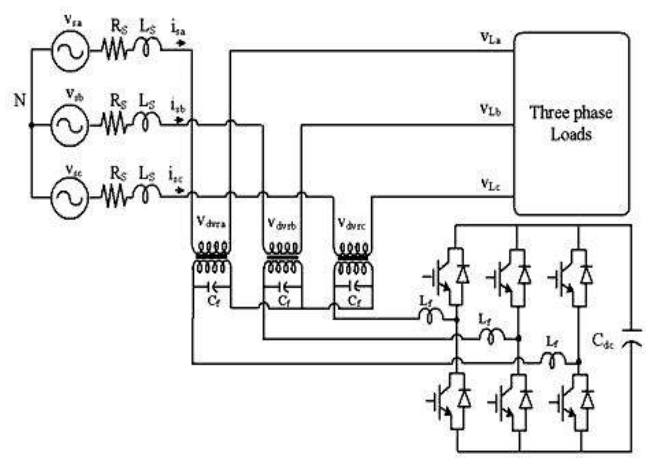

Fig.1.Schematic Diagram of three-leg VSC based DVR

The different compensation techniques of DVR are:

1 .Pre-sag/dip compensation method:

The pre-sag technique tracks the supply voltage endlessly and if it detects any disturbances in supply voltage it will inject the difference voltage between the sag or voltage at PCC and pre-fault condition, so the load voltage will be restored back to the pre-fault condition. Compensation of voltage sags in the both phase angle and amplitude sensitive loads would be achieved by pre-sag compensation technique. in this technique the injected active power cannot be controlled and it's determined by external conditions like the type of faults and load conditions.

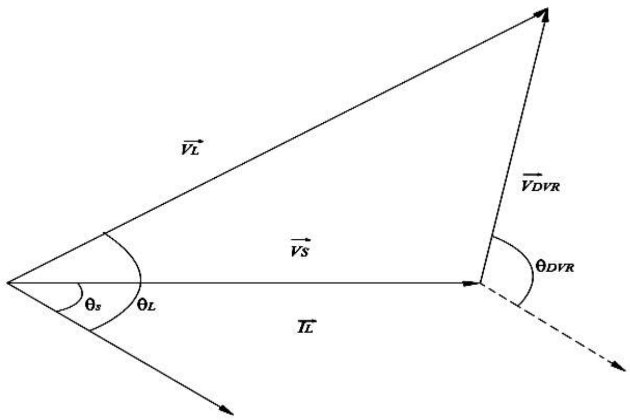

Fig.2. Pre-sag compensation method

2. In-phase compensation method:

This is the most straight forward technique. In this technique the injected voltage is in phase with the supply side voltage regardless of the load current and pre-fault voltage. The phase angles of the pre-sag and load voltage are totally different but the most important criteria for power quality that's the constant magnitude of load voltage are satisfied. One of the benefits of this technique is that the amplitude of the DVR injection voltage is minimum for certain voltage sag when compared with the alternative method.

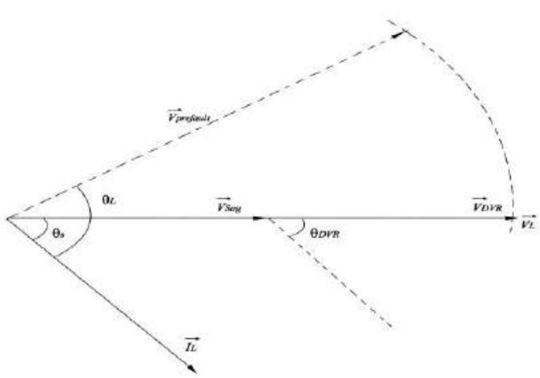

Fig.3. In-phase compensation method

3. Voltage tolerance method with minimum energy injection:

A small drop in voltage and small jump in phase angle will be tolerated by the load itself. If the voltage magnitude lies between 90-110% of nominal voltage and 5-10% of nominal state which will not disturb the operation characteristics of loads. Both magnitude and phase are the control parameter for this technique which may be achieved by small energy injection.

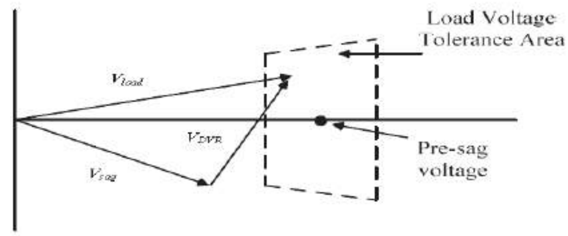

Fig.4. Voltage tolerance method with minimum energy injection

III. PROPOSED IRPT CONTROL ALGORITHM

The proposed IRPT control algorithm is to estimate reference load voltages for three leg VSC based DVR. Fig.5. shows IRPT control algorithm for three leg VSC based DVR for generation of gating pulses. The three phase source voltages (i_{sa}, i_{sb}, i_{sc}) and source currents (v_{sa}, v_{sb}, v_{sc}) are converted in to α-β frame using Clarke's transformation is represented as

$$\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \quad (2)$$

These two axis components of source voltages and source currents are used for calculating the instantaneous active and reactive powers. This instantaneous power consists of ac and dc components. It can be represented as

$$p_s=v_{sa}i_{sa}+v_{sb}i_{sb}+v_{sc}i_{sc}=v_{s\alpha}i_{s\alpha}+v_{s\beta}i_{s\beta}=p_{sdc}+p_{sac} \quad (3)$$

$$q_s=\left\{\frac{1}{\sqrt{3}}\right\}\{i_{sa}(v_{sa}-v_{sb})+i_{sb}(v_{sb}-v_{sc})+i_{sc}(v_{sc}-v_{sa})\} \quad (4)$$

$$=v_{s\alpha}i_{s\beta}-v_{s\beta}i_{s\alpha}=q_{sdc}+q_{sac} \quad (5)$$

Two low pass filters (LPF) are used to extract dc component of active power (p_{sdc}) and reactive power (q_{sdc}) from instantaneous active and reactive powers.

The error in dcbus voltage of VSC($v_{edc(k)}$) at k^{th} sampling instant is given as

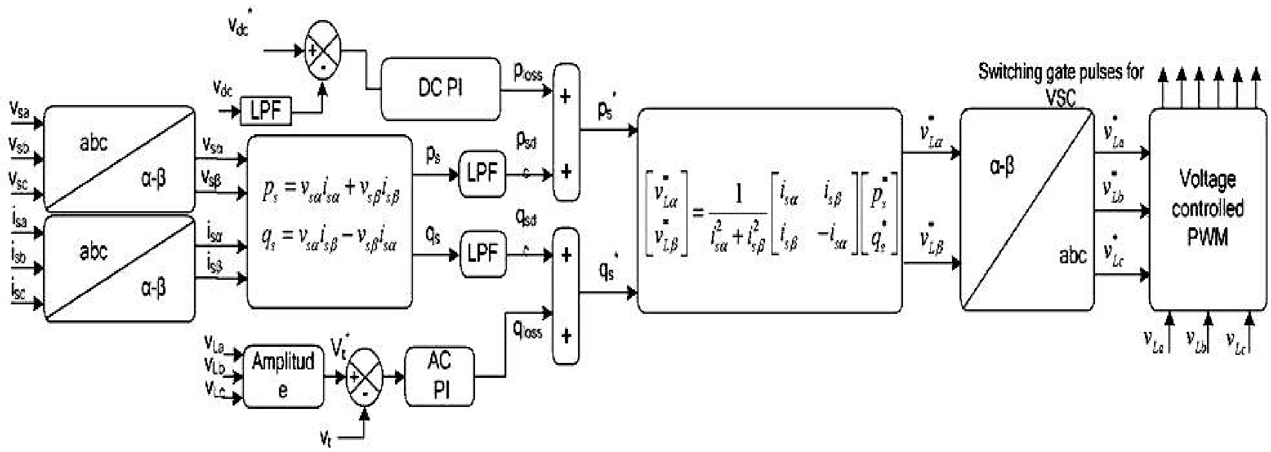

Fig.5.IRPT Control Algorithm for three-leg VSC based DVR

$$v_{edc(k)} = v^*_{dc(k)} - v_{dc(k)}$$
(6)

where $v_{dc(k)}^*$ is reference dc bus voltage and $v_{dc(k)}$ is the sensed bus voltage of the VSC.

The output of the DC PI controller is used to maintain constant dc bus voltage of VSC at kth sampling instant is given as

$$p_{loss(k)} = p_{loss(k-1)} + k_{p1}\{v_{edc(k)} - v_{edc(k-1)}\} + k_{q1}v_{edc(k)} \quad (7)$$

Where k_{p1} and k_{q1} are the dc bus proportional and integral gain of VSC. $P_{loss(k)}$ is active power component of the VSC.

This active power loss (p_{loss})in the VSC is added to the dc active power component p_{sdc} to obtain fundamental component of active power p_s^*

$$p_s^* = p_{sdc} + p_{loss} \quad (8)$$

This p_s^* is considered as reference active power component drawn from the load.

Similarly AC PI controller is used to maintain constant terminal voltage ($v_{er(k)}$) at kth sampling instant is given as

$$v_{er(k)} = v^*_{t(k)} - v_{t(k)} \quad (9)$$

where $v^*_{t(k)}$ is reference terminal voltage and $v_{t(k)}$ is the sensed ac bus terminal voltage at kth sampling instant. The sensed ac load terminal voltage (v_t) which is given as

$$v_t = \{(2/3)(v_{La}^2 + v_{Lb}^2 + v_{Lc}^2)\}^{1/2} \quad (10)$$

The output of the AC PI controller is used to maintain constant Ac bus terminal voltage at kth sampling instant is given as

$$q_{loss(k)} = q_{loss(k-1)} + k_{p2}\{v_{er(k)} - v_{er(k-1)}\} + k_{q2}v_{er(k)}$$

(11)

Where k_{p2} and k_{q2} are the ac bus proportional and integral gain of VSC. $q_{loss(k)}$ is reactive power component loss of the VSC.

This reactive power loss (p_{loss})in the VSC is added to the ac reactive power component q_{sdc} to obtain fundamental component of reactive power q_s^*

$$q_s^* = q_{sdc} + q_{loss} \quad (12)$$

These fundamental components of active power(p_s^*) and reactive power(q_s^*) are used to obtain reference load voltages in α-β frame as given by

$$\begin{bmatrix} v^*_{L\alpha} \\ v^*_{L\beta} \end{bmatrix} = \frac{1}{i_{s\alpha}^2 + i_{s\beta}^2} \begin{bmatrix} i_{s\alpha} & i_{s\beta} \\ i_{s\beta} & -i_{s\alpha} \end{bmatrix} \begin{bmatrix} p_s^* \\ q_s^* \end{bmatrix} \quad (13)$$

These reference load voltages in α-β frame are transformed into three-phase reference load voltages in three phase a-b-c system using inverse Clarke's transformation as given by

$$\begin{bmatrix} v^*_{La} \\ v^*_{Lb} \\ v^*_{Lc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v^*_{L\alpha} \\ v^*_{L\beta} \end{bmatrix} \quad (14)$$

These reference load voltages ($v_{La}^*, v_{Lb}^*, v_{Lc}^*$) are compared with the sensed load voltages(v_{La}, v_{Lb}, v_{Lc}) in the voltage controller for generation of gating signals.

IV. RESULTS AND DISCUSSION

The performance of IRPT Control Algorithm for three-leg VSC based DVR under various power quality disturbances are studied. The proposed IRPT Control Algorithm for three-leg VSC based DVR is tested for various power quality disturbances like voltage sag is depicted in Fig.6, voltage swell is depicted in Fig.7. and harmonic spectrum of IRPT Control Algorithm based DVR for non-linear load condition is shown in Fig.8. and Fig.9.

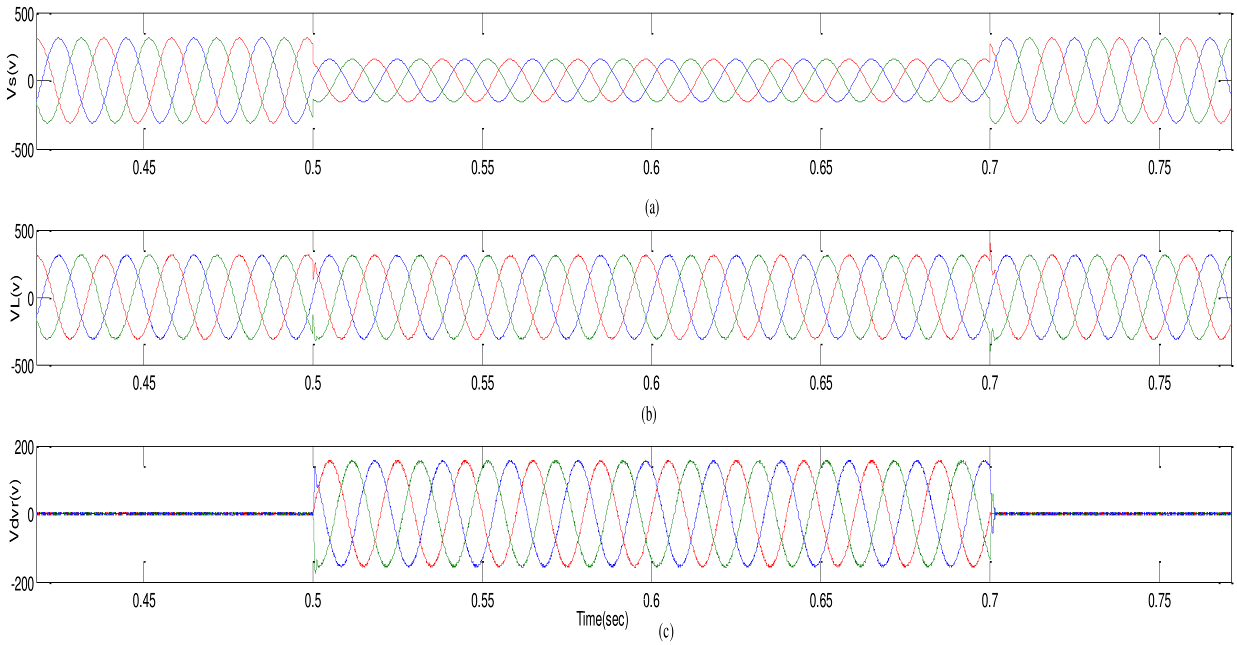

Fig.6.Compensation of voltage sag using IRPT Control Algorithm based DVR

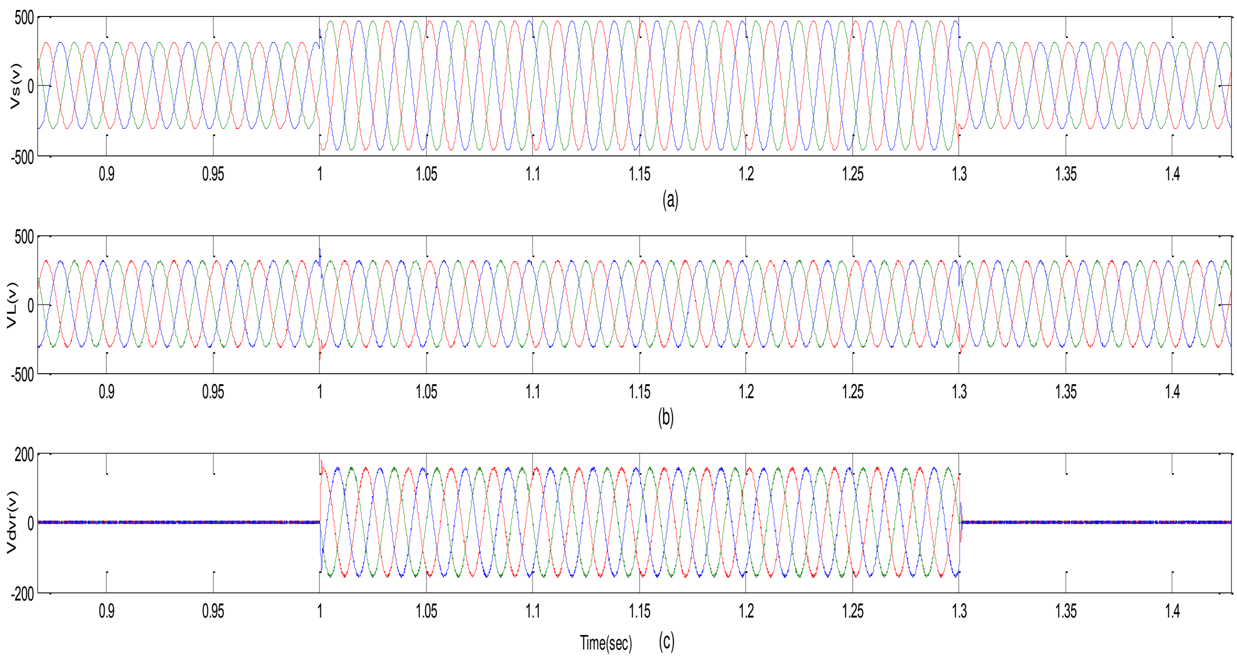

Fig.7.Compensation of voltage swell using IRPT Control Algorithm based DVR

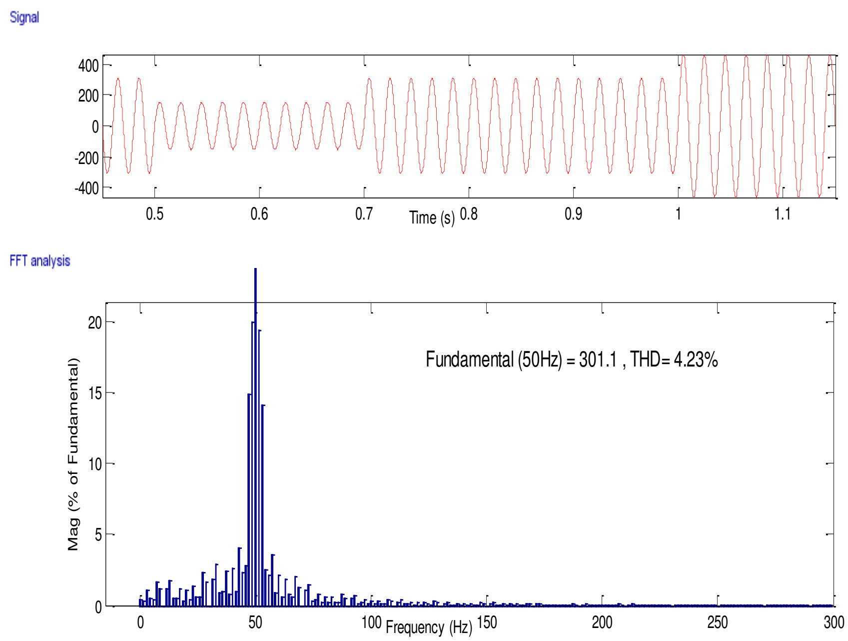

Fig.8.Harmonic spectrum of source voltage under compensation of harmonics

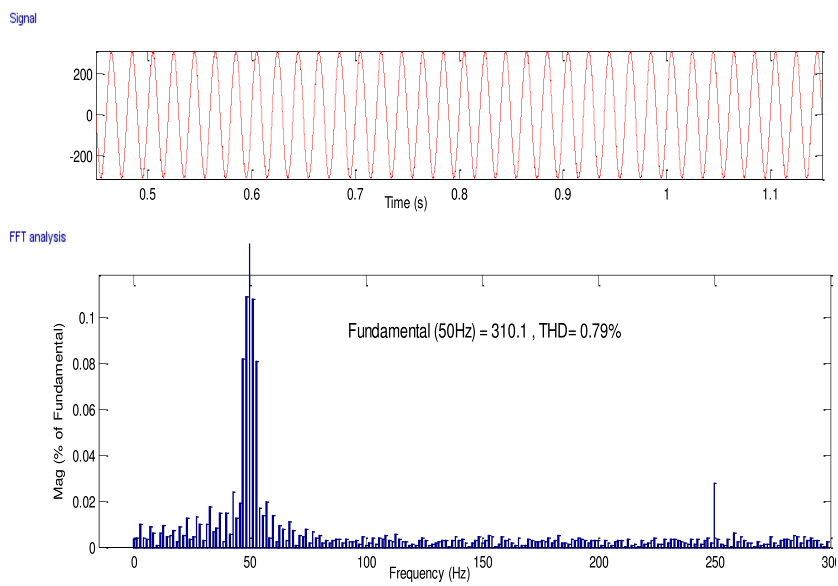

Fig.9.Harmonic spectrum of load voltage under compensation of harmonics

A. Performance of IRPT Control Algorithm based DVR during voltage sag condition:

To demonstrate dynamic performance of IRPT Control Algorithm based DVR, voltage sag of 30% in supply voltage is introduced during t=0.5 to 0.7seconds which is depicted in Fig.6. in which fig.(a) shows voltage sag before compensation and fig.(b) shows voltage sag after compensation and fig.(c) shows voltage injected voltage. During this period of t=0.5 to 0.7seconds it was observed that IRPT Control Algorithm based DVR injects compensating voltage (v_{dvr}) in series with supply voltage (v_s) to maintain at rated load voltage (v_L).

B. Performance of IRPT Control Algorithm based DVR during voltage swell condition:

To demonstrate dynamic performance of IRPT Control Algorithm based DVR, voltage swell of 30% in supply voltage is introduced during t=1.0 to 1.3 seconds which is depicted in Fig.7.in which fig.(a) shows voltage sag before compensation and fig.(b) shows voltage sag after compensation and fig.(c) shows voltage injected voltage. During this period of t= 1.0 to 1.3 seconds, it was observed that IRPT Control Algorithm based DVR injects compensating voltage (v_{dvr}) in series with supply voltage (v_s) to maintain at rated load voltage(v_L).

TABLE

S.No	VOLTAGE	THD (%)
1	Without Compensation	4.23%
2	With Compensation	0.79%

V. CONCLUSION

The dynamic performance of IRPT control algorithm based DVR shows satisfactory results for mitigation of voltage sag, voltage swell, unbalanced source voltages and compensation of voltage harmonics. The results show that IRPT control algorithm based DVR is simple and robust to mitigate power quality problems related voltage. The proposed IRPT control algorithm based DVR during harmonic compensation the load voltage (v_L) has a THD of 0.79 %, source voltage (v_s) has a THD of 4.23%,which are well within IEEE-519 standard.

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