Indonesian Journal of Electrical Engineering and Computer Science
Vol. 1, No. 3, March 2016, pp. 501 ~ 511
DOI: 10.11591/ijeecs.v1.i3.pp501-511

Analysis of AC-AC Converter Based Dynamic Voltage Restorer for Maintaining Power Quality in the Transmission Line

Tamilvanan G*, Mahendran S
Department of EEE, K.S. Rangasamy College of Technology, Tiruchengode -637215,
Tamil Nadu, India
e-mail: vrgtamilvanan@gmail.com

Abstract

In the power system the major issue is to maintain the power quality. The term of power quality is to maintain the disturbance less voltage to the power system. The voltage disturbance mainly caused by voltage sag, voltage swell and harmonics presented in the system. If the system voltage is going below to the nominal voltage, then it is called as voltage sag. These power quality (PQ) events typically last for less than one second. If the system voltage is going above the nominal voltage, there it is called as voltage swell. The AC-AC converter based DVR is proposed. It can properly compensate for unlimited time duration, balanced, and as well as unbalanced voltage sag by observing the power from the grid. The pulse width modulation technique is used to triggering the switches. Only by the simple Bidirectional switches were used for generate the compensation voltage.

Keywords: *voltage sag, voltage swell, AC-AC converters*

1. Introduction

Power quality is an issue that is becoming gradually important to electricity consumers at entire levels of usage. Power electronic equipment and non-linear loads are very sensitive and these are widely used in industrial, commercial and domestic applications leading to distortion in voltage and current waveforms. In modern fully automated electrical power systems, electricity is produced at generating stations, transmitted through a high voltage station, and finally it can distributed to consumers. The rapidly increasing power demand is also leads increase the electric power systems. It has developed extensively during the 20th century.Since voltage sag can happen even due to a remote fault in a system, it is more often than an interruption and can occur 20–each in an industry [17]. 30 times per year with a typical cost of U.S.$ 50 000 Therefore, voltage sag is a serious power-quality (PQ) problem to be addressed. Voltage disturbances like voltage sag and swell are the most common power quality (PQ) problem in industrial distribution systems and harmonics, unbalances, and flickers [11] also the major consideration while maintaining the power Quality. These disturbances can cause the breakdown of voltage-sensitive loads in factories, buildings, and hospitals [6] and sever process disruptions resulting in considerable commercial and/or data losses [7]. Voltage sag is a temporary decrease in the RMS AC voltage (1pu–9pu of the nominal voltage) at the power frequency of duration from 0.5 cycles to a few seconds [8]. The INFLUX of digital electronics for calculating and control Applications has prepared quality power an inevitable requirement. A major data centre reports that a interruption can cost about U.S.$ 600 000 [17]. Now a days the voltage maintained by using by the axillary energy support connected with power electronics switches the device are named as Dynamic Voltage Restorer (DVR) The A dynamic voltage restorer (DVR) is connected with the sires to the custom power device to mitigate voltage sags. The injected voltage is generated either by a voltage-source inverter sustained by energy storage or conventionally by an AC-DC-AC converter. The resent years the mitigation of voltage level can archived by direct converter it can eliminating the set of dc link. Energy storage makes the DVR unit larger in size and very costlier. Also, the dc link imposes a limit on compensation capability of the DVR in terms of magnitude and duration of compensation (4) Preliminary research on the new family of DVRs that eliminates the dc link dates back to 1996 [9]. Only sparse developments in the topology are reported in the literature [10]–[12], until progresses in semiconductor technology. The growth of bidirectional switches, in

Received November 27, 2015; Revised February 14, 2016; Accepted February 24, 2016

turn, augmented the growth of a new range of direct converters, such as matrix converters and Z-source converters. The matrix converter has particularly found applications in the DVR topologies [13]. In [13], a combination of a matrix converter and a flywheel to forming the energy storage, is active to mitigate sag with bidirectional power flow, but the incidence of the flywheel again limits the compensation capability. Vector based switching converters (VeSCs) [14], based on matrix switching, are used to inject the required positive- and negative-sequence components to compensate for balanced and unbalanced voltage sags. Though the control looks easy, it includes 10 transformers and 18 bidirectional switches.in [15-20] the AC chopper is used to produce the controlled AC voltage and it is again increased by transformer then that voltage is added with system voltage for the sag compensation. When comparing conventional DVR with AC-AC converter based DVR it requires less components for getting voltage from the sag. The conventional DVR requires three stages of conversion like AC-DC-AC so that these type of DVR requires both rectifier and inverter set and it also need a DC link, and in AC-AC converter based compensator can eliminate the all above the problems.

1.1. Power Quality Disturbances

There is a wide variety of power quality disturbances compensated which affect the performance of customer equipment. The most common of these are briefly described in this section of the chapter.

1.1.1. Voltage Sag

A voltage sag or voltage dip is a short duration reduction in RMS voltage which can be produced by a short circuit, overload or starting of electric motors. A voltage sag happens when the RMS voltage reduces between 10 and 90 percent of ratted voltage for one-half cycle to one minute.

1.1.2. Interruption

Interruption is defined as a reduction of 0.9 pu in voltage magnitude for a period less than one minute. An interruption is considered by the duration as the magnitude is more or less constant. An interruption might follow voltage sag if the sag is produced by a fault on the source system. During the time required for the protection system to operate, the system sees the effect of the fault as sag. Following circuit breaker operation, the system gets isolated and interruption occurs.

1.1.3. Transient over Voltages, Swells

Overvoltage is an increase of Root Mean Square (RMS) voltage magnitude for longer than one minute. Typically the voltage magnitude is 1-1.2 pu and is caused by switching off a large load from the system, energizing a capacitor bank, poor tap settings on the transformer and inadequate voltage regulation. Over voltages can cause equipment harm Power Quality A swell is typically of a magnitude between 1.1 and 1.8 pu and is usually associated with single line to ground faults where voltages of non-faulted phases rise.

1.1.4. Voltage Imbalance

This type of power quality disturbance is caused by unequal distribution of loads amongst the three phases. At three-phase distribution level, unsymmetrical loads at industrial units and transposed lines can result in voltage imbalance. Voltage imbalance is of extreme importance for three-phase equipment such as transformers, motors and rectifiers, for which it results in overheating due to a high negative sequence current flowing into the equipment. The asymmetry can also have an adverse effect on the performance of converters, as it results in the production of harmonic.

1.1.5. Causes of Voltage Sag and Voltage Swell

Voltage sag is caused by switch on the higher ratting of loads and it also caused by when the short circuit fault accrues in the system. On that situation the taken from the power system is three or more times of normal current. So that the corresponding voltage will be going to drop at small interval of time this term is called as voltage sag or voltage dip. The voltage sag is one of the significant problems in power system. Voltage swells and over voltages are most often caused by a sudden decrease in load on a circuit with a poor or a damaged voltage regulator, though they may also be a result of a damaged or a loose neutral connection. It leads to unnecessary power losses, lowering of the power factor of the supply and reducing efficiency. Moreover, these fluctuations may significantly impact the power quality as well as the reliability of voltage controlling devices.

1.1.6. Effects of Voltage Sag and Swell

Due to voltage sag and swell, various expensive electrical equipment is insufferable to such fluctuations may get substantially damaged. At the distribution level, the voltage sags occur when a short circuit fault takes place on a parallel feeder and swell is occur when switch on the capacitive load. In addition, the sag depth depends on the distance from the fault location and impedance profile of the system**,** Among these, two power quality problems such as voltage sag and voltage swell have been identified a major concern to the customers. The voltage sag/swell has major influence on the performance of the microprocessor based loads as well as the sensitive loads. So that faults should be avoid to maintaining the power quality. The dynamic voltage restorer is one of most reliable device to control the problem of voltage sag.

1.1.7. Dynamic Voltage Restorer

The Dynamic Voltage Restorers (DVR) and Uninterrupted Power Supply systems (UPS) have been developed during last two decades and they are capable to compensate voltage harmonics, sags and swells maintaining a clean regulated voltage at critical loads during enough period of time. Nevertheless, they depend on devices to store energy, like large capacitors or batteries bank. The rated power operation is a function of the size and capacity of these devices; if the power is increased, the size of these devices will increase. The dynamic voltage restorer is used to compensate voltage in the transmission line. The DVR is used to supply or suppress voltage to transmission line for compensation.

DVRs can be classified into two major groups with respect to the source of energy employed for compensation. The conventional DVR with AC/DC/AC converter or DC/AC converter, which requires energy storage elements, such as battery or capacitor banks. These DVRs suffer from disadvantages, such as limited time of compensation, high cost, and large energy storage devices. The second group of DVRs is realized without a DC link using direct AC/AC converters. In a direct converter-based DVR with a boosting transformer ratio of 1:1 was presented in which, five bidirectional switches are used along with the series transformer.

2. Proposed AC-AC Converter Based New DVR Topology

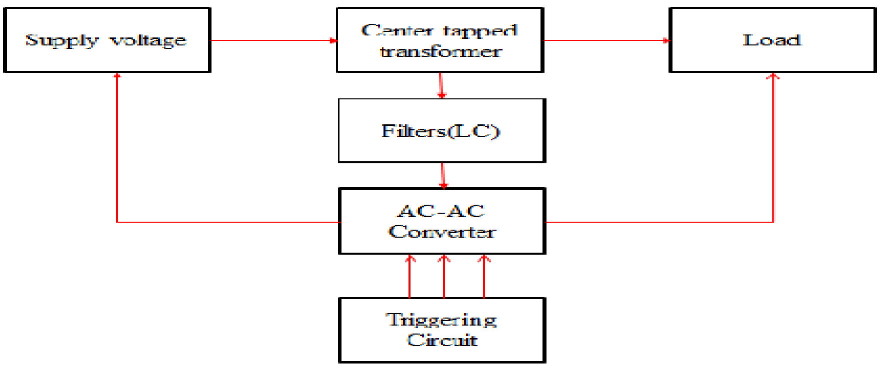

Figure 1. Block diagram of AC-AC converter based DVR

In the new proposed DVR topology mainly consists of direct converter coupled with center tapped transformer. The center-tapped series transformer is connected between the grid and AC-AC converter (Figure 1). The turns ratio of center-tapped transformer is 1:1. So that the induced voltage at the secondary exactly equal to primary. LC filter is used to reduce the harmonics to the system. The direct converter takes the power required for compensation from the grid. The switching pulses of the converter are given by ordinary pulse width modulation techniques. Each one of the phase is have three AC–AC converters and that AC-AC converter formed by the bidirectional switches. The secondary of +series transformer produce the two different levels of voltages

3. Sag and Swell Compensation

The left side end winding output voltage will be in phase with the grid voltage and the right end winding output voltage will be out of phase with the grid voltage for the reason of get proper injecting voltage to the source. In the proposed topology, Sa1 is the switch connected in one terminal of the center-tapped series transformer for phase ‘R’. When switch Sa1 is closed, the output voltage of the center tapped series transformer will be in phase with the phase ‘R’ voltage. Sa2 is the switch connected in the other terminal of the center-tapped series transformer.

Hence, when the switch Sa2 is closed, the output voltage of the center-tapped series Transformer will be out of phase with the phase ‘R’ voltage. Sa3 is the switch connected across the center-tapped series transformer. When the phase ‘R’ voltage is at the balanced condition, switch Sa3 is in closed condition to shorten the primary side of the series transformer. If phase ‘R’ has sag, then the switches Sa1’ and Sg3 are alternatively switched to generate the compensating voltage till the voltage getting balance which is in phase with the grid voltage, as shown in Figures 2 and 3.

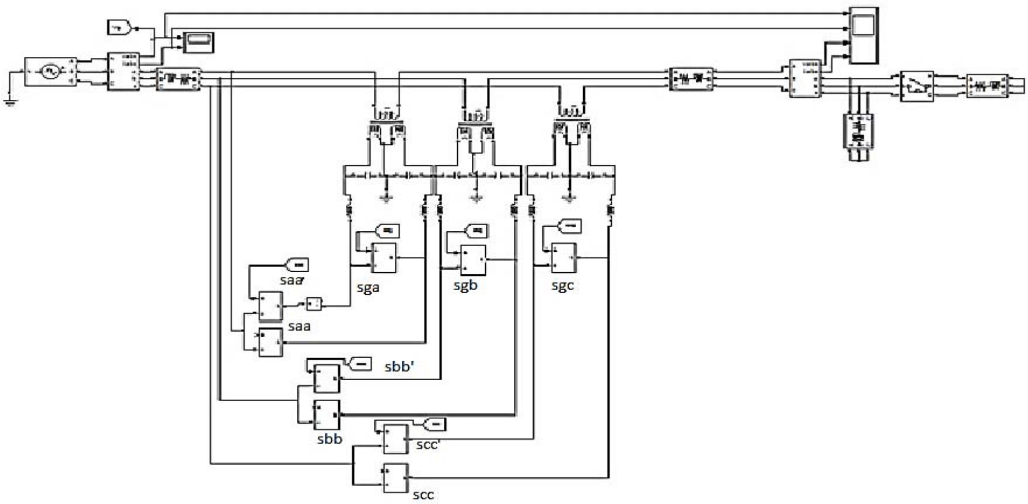

Figure 2. Sag compensation

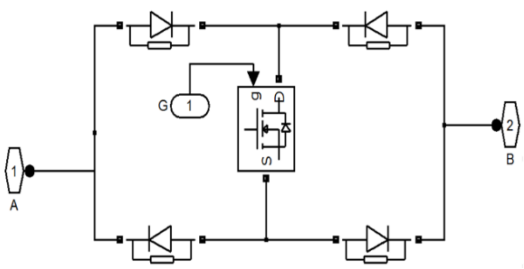

Figure 3. Direct converter model

$$V_{l\,r} = V_{gr} + V_{con\,r}$$
$$V_{ly} = V_{gy} + V_{com\,y} \quad (1)$$

$V_{lb} = V_{gb} + V_{com\ b}$

In equation (1, 2, 3), l, g, and con subscripts are used for the load, grid, and compensating measures, respectively. The second subscript refers to the corresponding phases. Assuming sinusoidal waveforms and considering on phase ‘a’, the voltages can be expressed as follows:

$$V_{lr} = V_{lr} Sin\ \omega t$$
$$V_{gr_l} = V_{gr_l} Sin\ \omega t \text{ and} \quad (2)$$
$$V_{con\ r} = V_{con\ r}\ Sin\ \omega t + \emptyset$$

In the equations the peak values of load, grid, and injected voltages are given, the value of Ø is 0 for sag compensation.

If swell is found, then switches Sa2 and Sa3 are alternatively switched to balancing voltage is added or reduced to the grid through the center tapped series transformer according to the voltage oscillation produced in the transmission line by the different type of miss behavior in the line.

The each of the converter has single MOSFET and four diodes. The switches are controlled by a pulse width modulation (PWM) technique. Considering Figure 1, the following equation can be obtained:

vr = vG r + vGr comp
vy = vGy+ vGy comp (3)
vb = vGb + Vb comp

In the three equation, Vr, Vy, Vb are the output load voltages for the three phases VGr, VGy, VGb are the grid voltage of each phases and Vr comp, Vy comp, Vb comp compensating quantities. All the voltages are only referred as a sinusoidal quantities. So the above equation is written like below; peak value of the Load voltages expressed as;

vr = v r sin(ωt)
vy = vy sin(ωt) (4)
vb = vb sin(ωt)

The peak value of the grid voltage can be expressed as

vLr = VLr sin(ωt)
vLy = VLy sin(ωt) (5)
vLb = VLb sin(ωt)

And the peak value of the compensating voltage can be expressed as

vr comp = Vr comp sin(ωt + ∅)
vy comp =vy comp sin(ωt + ∅) (6)
Vb comp= vy comp sin(ωt + ∅)

∅ is the phase angle of the injected voltage and ∅ is minimum value for sag and the maximum value for swell.

4. Control Procedure

Single-phase d-q theory is used to quantify the voltage sag and swell in each phase. The grid voltage is measured by using a potential transformer. This measured grid voltage is given as input to the analog to digital converter (ADC) of the microcontroller. The ADC output is expressed in two forms. One form is the true output as in normal. The other output is delayed by 5ms (or 90°), as shown in Figure 4.

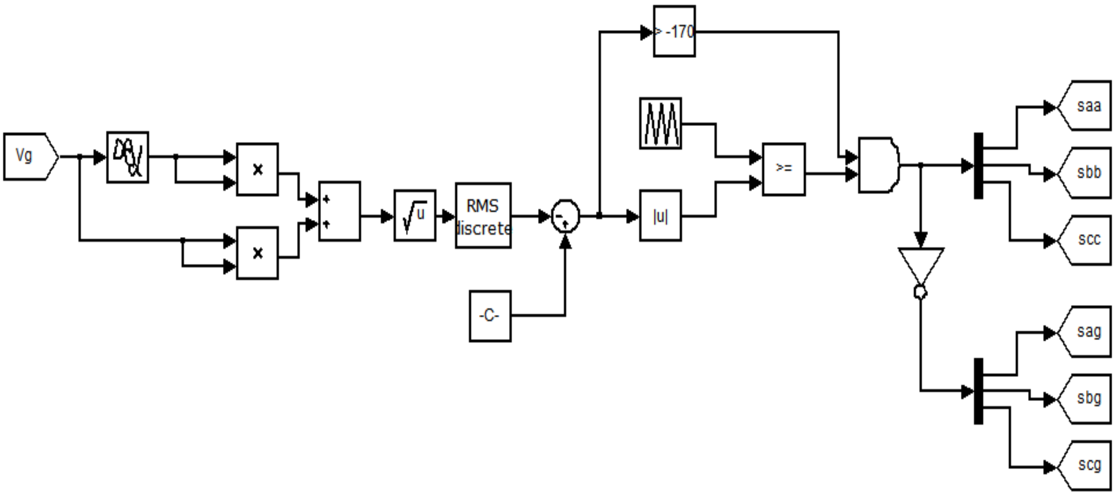

Figure 4. Firing circuit

4.1. Voltage Sag and Swell Mitigation

In order to mitigate the voltage sag, it is necessary to inject voltage in phase with the grid voltage. The two different polarity voltages are taken from center- tapped transformer. Such that one will be in phase and the other end output of the transformer will be out of phase with the grid voltage. Therefore, the switches that correspond to synthesis voltage in phase with the grid voltage are chosen. Hence, if voltage sag occurred in phase 'a' then the bidirectional switches Saa' and Sga will be alternatively modulated to mitigate the sag.

A detailed block diagram for switching pulse generation to mitigate voltage sag is shown in Figure. The peak value of grid voltage Ugmax is already computed from single-phase d-q transform. U reference is the peak value of the rated voltage, which is a user specified constant value set in the microcontroller program. The difference between the reference voltage U reference and peak value of the grid voltage Ugmax provides the amount of voltage sag or swell in the grid.

5. Simulation of Proposed AC – AC Converter Based DVR

The MATLAB/SIMULINK software was used for simulation. Three phase RL load were connected to the lines. The desired terminal voltage was set at 70 V rms (1 p.u), 50 Hz. The LC filter is used reduce harmonics produced in the system. The L value is fixed at 1.732 mile Henry and the capacitor value is fixed as 15 mile Farad. The ability of the DVR to mitigate balanced voltage sag of 50% in all the phases. It can also compensate the voltage swell at unlimited quantity.

5.1. Unbalanced Voltage (Voltage Sag) and their Corresponding Current

The unbalanced voltage sag and their corresponding current is shown in Figure 5. From the above figure the sag is produced from 0.1 sec. and the corresponding current also shown. In the X axis the time is noted and in the axis voltage and current is noted. The voltage sag is produced due to any kind of short circuit or switching on the motor loads. In above figure the voltage level is reducing into 0.8 pu value of the normal system voltage.

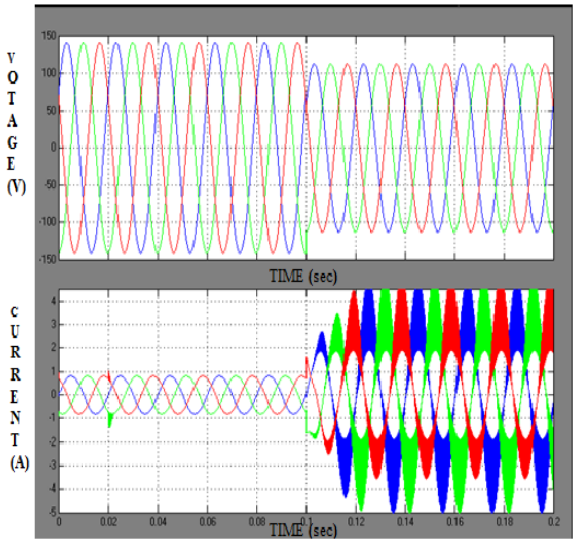

Figure 5. Unbalanced voltages (voltage sag) and their corresponding current

5.2. Compensating Voltage of DVR While Producing Sag

The figure 6 shows the DVR injecting voltage while the producing sag in the transmission line. In the time of voltage sag the voltage reduced from the nominal voltage. So the voltage injected from the DVR is in phase with the system voltage.

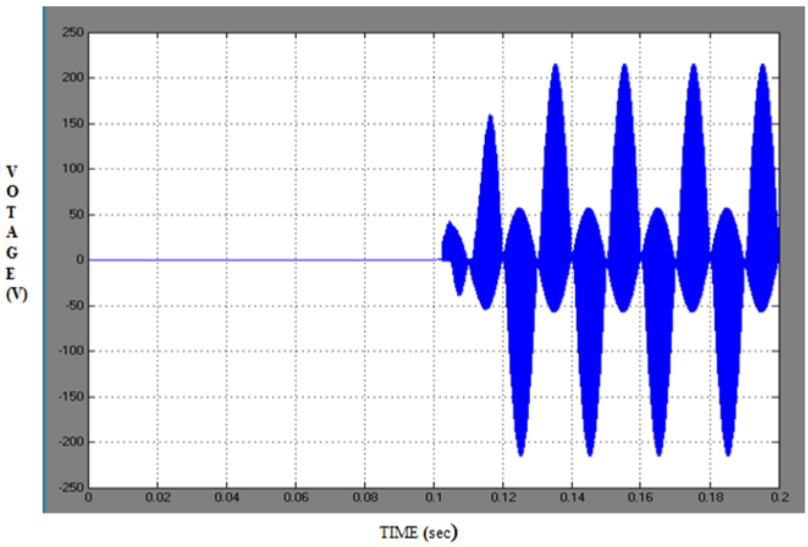

Figure 6. Compensating voltage of DVR while producing sag

At normal time he injecting voltage of the DVR is zero at faulted condition the AC-AC converter is triggered by the control circuit then it is going to conduct until the voltage gets compensated. Compensating voltage of DVR while producing sag is shown in Figure 6.

5.3. Compensated Voltage

The compensated voltage, after producing sag is shown in Figure 7. After the time of 0.1sec compensating voltage is produced by the DVR. Then that in phase voltage is added with uncompensated voltage so that the voltage level can get regulated. The regulated voltage is continuously produced until the compensated level is reached. From the proposed DVR can mitigate the 50% of swell.

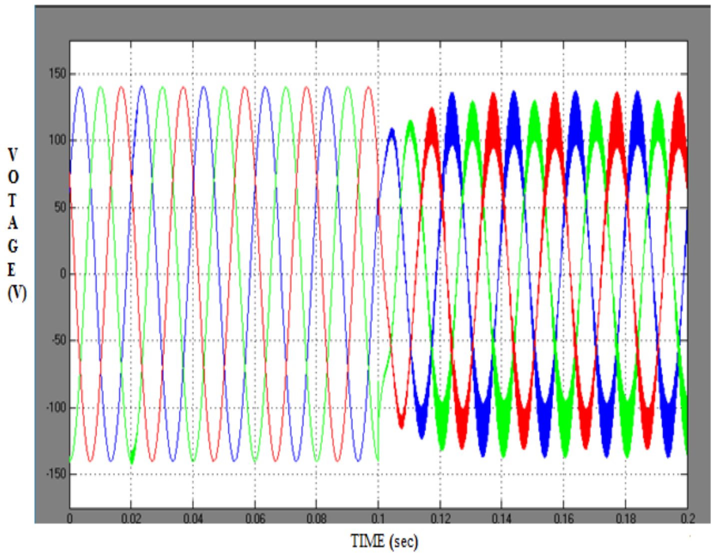

Figure 7. Compensated voltages

5.4. Comparison of Balanced and Unbalanced Voltages

The comparison of uncompensated voltage with the compensated voltage is shown in Figure 8. From that figure the input side the sag is appeared until 0.1 sec and the sag is continued as unlimited time period. The next waveform shows the compensated voltage. The sag can be eliminated completely from 0.12 sec.

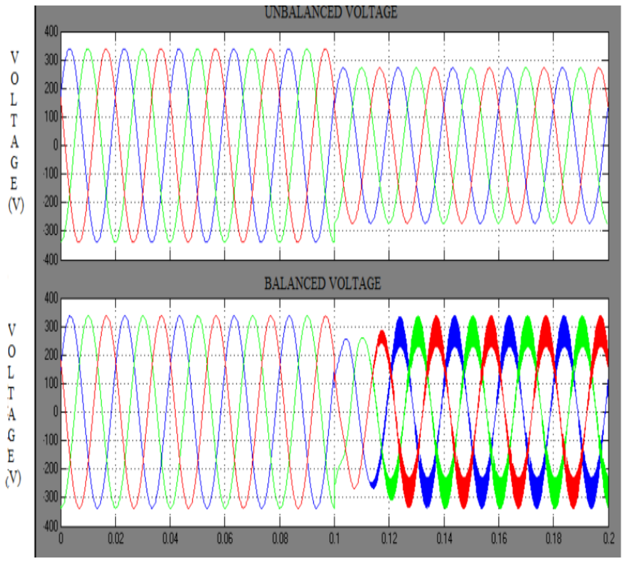

Figure 8. Comparisons of balanced and unbalanced voltages

5.5. Unbalanced Voltage (Voltage Swell) and their Corresponding Current

The figure 9 shows the unbalanced voltage source. The voltage swell is produced due to any kind of sudden open circuit and also due to disconnect the higher ratted loads. From the above figure the sag is produced from 0.1 sec. and the corresponding current also shown. In the X axis the time is noted and in Y the axis voltage and current is noted. The voltage swell is produced due to disconnect the load suddenly or switching on the capacitor banks. The voltage level is raising into 1.2 pu value of the normal system voltage is shown in Figure 6.5.

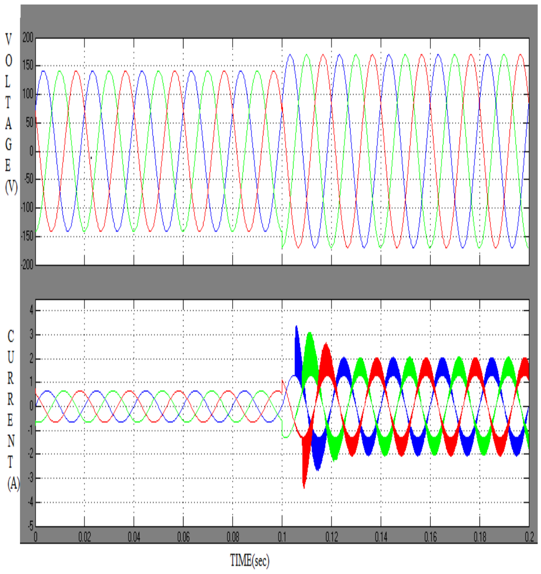

Figure 9. Unbalanced voltage (voltage swell) and corresponding current

5.6 Compensating Voltage of DVR While Producing Swell

The Compensating voltage of DVR while the time of producing swell is shown in Figure 10. That time the DVR produces the voltage in the out of phase to the system voltage. It will be subtracted to the source voltage. The DVR produces compensating voltage until the swell is compensated. At normal time the injecting voltage of the DVR is zero at faulted condition the AC-AC converter is triggered by the control circuit then it is going to conduct until the voltage gets compensated.

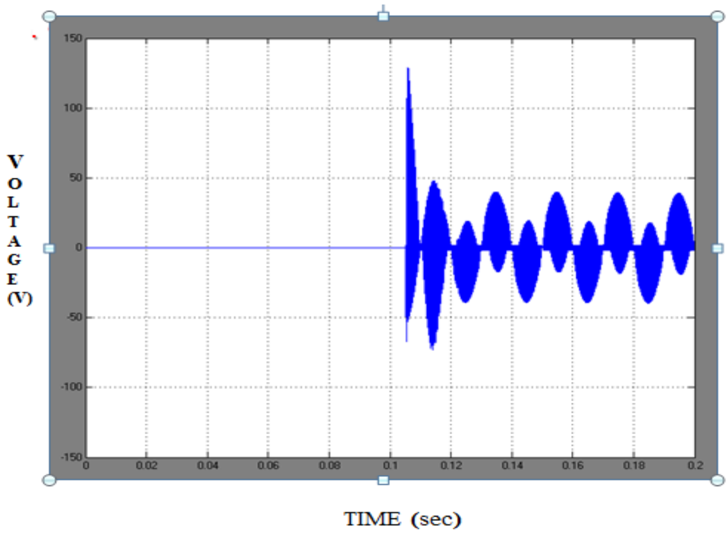

Figure 10. Compensating voltage of DVR while producing swell

5.7. Compensated Voltage

The compensated voltage, after producing swells is shown in Figure 11. After the time of 0.1sec compensating voltage is produced by the DVR.

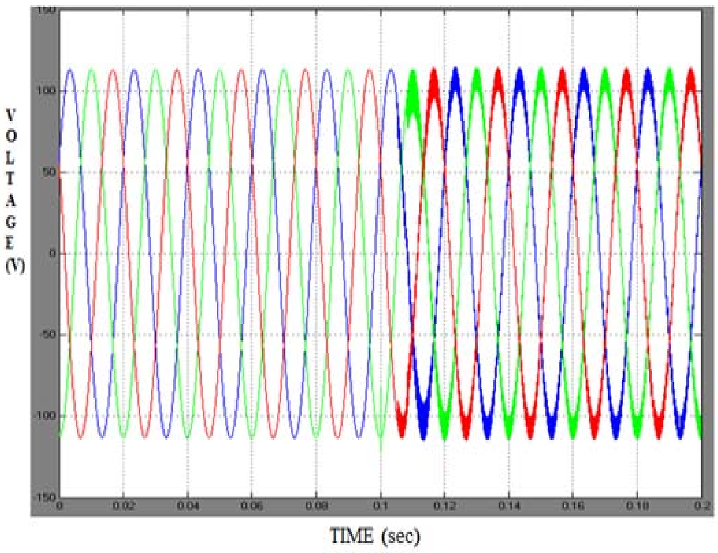

Figure 11. Compensated voltages

Then that phase shifted voltage is added with uncompensated voltage, so that the voltage level can get regulated. The regulated voltage is continuously produced until the compensated level is reached. From the proposed DVR can mitigate the unlimited quantity of swell. The regulated voltage is continuously produced until the compensated level is reached. From the proposed DVR can mitigate the unlimited quantity of swell.

5.8. Comparison of Balanced and Unbalanced Voltages

The comparison of uncompensated voltage with the compensated voltage is shown in Figure 12. From the proposed DVR the input side the swell is appeared from 0.1 sec and the swell is continued as unlimited time period. The next waveform shows the compensated voltage.

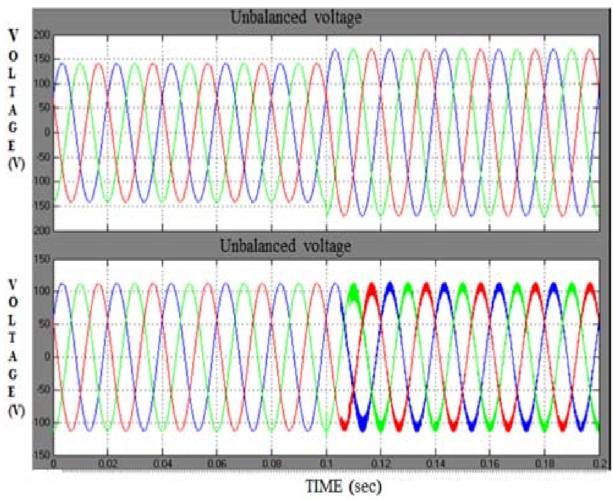

Figure 12. Comparisons of balanced and unbalanced voltages

The swell can be eliminated completely from 0.12 sec. And the voltage is continued as the normal ratted voltage without appearing of any disturbance. The regulated voltage is continuously produced until the compensated level is reached. From the proposed DVR can mitigate the unlimited quantity of swell.

6. Conclusion

The performance of proposed AC-AC converter based voltage compensator is proposed. It can eliminate the sag and swell without need of any kind of storage elements like capacitor and battery, and it does not need DC link like another DVR. This proposed DVR can compensate the voltage within a required range without need inverter and rectifier set. This DVR can compensate the voltage sag and swell by 50% of normal voltage. The requirement of bidirectional switch is only three per phase. The simulation results are taken by MATLAB 2011.

References

[1] Elnady A, Salama A. Mitigation of voltage disturbances using adaptive perceptron- based control algorithm. *IEEE Transection power Delivery*. 2005; 20(1): 309–318.
[2] Wang B, Venkataramanan G. Dynamic voltage restorer utilizing a matrix converter and flywheel energy storage. *IEEE Transection on Industrial Application*.2009; 45(1): 222–231.
[3] Babaei M, Kangarlu F, Sabahi M. Mitigation of voltage disturbances using dynamic voltage restorer based on direct converters. *IEEE Transection power Delivery.* 2010; 25(4): 2676–2683.
[4] Aeloíza C, Enjeti N, Morán A, Hernandez M, Kim S. Analysis and design of a new voltage sag compensator for critical loads in electrical power distribution systems. *IEEE Transection on Industrial Application.* 2003; 39 (4): 1143–1150.
[5] Gobinath K, Mahendran S, Gnanambal I. New cascaded h-bridgemultilevel inverter withimproved efficiency. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*. 2013; 2(4): 1264-1270.
[6] Elnady M, Salama A. Mitigation of voltage disturbances using adaptive perceptron-based control algorithm. *IEEE Transection power Delivery*. 2005; 20(1): 309–318.
[7] Nielsen G, Newman M, Nielsen, Blaabjerg F. Control and testing of a dynamic voltage restorer (DVR) at medium voltage level. *IEEE Transection on Power Electronics*. 2006; 19(3): 806-813.
[8] Al-Hadidi K, Gole M, Jacobson A. A novel configuration for a cascade inverter-based dynamic voltage restorer with reduced energy storage requirements. *IEEE Transection power Delivery*. 2008; 23(2): 881-888.
[9] Mahendran S, Gnanambal I, Maheswari A. Quality Enhancement of AC Chopper Using Genetic Algorithm. *Telkomnika Indonesian Journal of Electrical Engineering.* 2015; 16(1): 30 – 37.
[10] Kim B, Lee H, Moon W, Youn J. Synchronous PI decoupling control scheme for DVR against a voltage sag in the power system. *Journal of Power Electronics*. 2004; (4)3: 180-187.
[11] Woodley H, Morgan L, Sundaram A. Experience with an inverter based Dynamic voltage restorer. *IEEE Transection power Delivery.* 1990; 14(3): 1181-1186.
[12] Garcia-Vite M, David M, Ramirez M Per-sequence vector-switching matrix converter modules for voltage regulation. *IEEE Trans. Ind. Electron.* 2013; 60(12): 5411–5421.
[13] Sanchez R, Acha E, Calderon O, Feliu V, Cerrada G. *A versatile control scheme for a dynamic voltage restorer for power-quality improvement*. IEEE Transection power Delivery. 2009; 24(1): 277-284.
[14] Perez V, Cardenas V, Moran L, Nunez C. Single phase ac-ac converter operating as a dynamic voltage restorer (DVR*)." in Proc. IECON*, 2006:1938-1943.
[15] Lam S, Wong C, Han D. Voltage swell and overvoltage compensation with unidirectional power flow controlled dynamic voltage restorer. *IEEE Transection power Delivery*. 2008; 23(4): 2513–2521.
[16] S Saravanakumar S, Mahendran S, I Gnanambal. Harmonic reduction in PWM AC chopper using fuzzy based technique. *International Journal of Applied Engineering Research*. 2015; 10(9): 7644-7647.
[17] Hietpas M, Naden M. Automatic voltage regulator using an AC voltage-voltage converter. *IEEE Transection on Industrial Application.* 2000; 36(1): 33–38.
[18] Jayaprakash P, and Kothari P. Adaline based control of capacitor supported DVR for distribution system. *Journal of Power Electronics.* 2009; 9(3): 386-395.
[19] Jimichi T, Fujita H, Akagi H. Design and experimentation of a dynamic voltage restorer capable of significantly reducing an energy storage element. *IEEE Transection on Industrial Application*. 2008; 44(3): 817–825.
[20] Saravanakumar S, Mahendran S Gnanambal I. Improving voltage regulation and elimination of harmonics in PWM AC chopper using artificial intelligent technique*. IJAICT*. 2014; 1(8):722-725.