ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 4, April 2016

Review of Voltage Sag Compensation Techniques

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ABSTRACT: Maintaining a clean power supply to the consumer has always been the main motto of electricity suppliers. Power quality includes several aspects such as voltage sag, swell, flicker, harmonics, etc., which may last only for a few cycles, but can damage industrial as well as domestic equipments. Voltage sag is a temporary drop in voltage below 90% of the nominal voltage level and lasts for 50 to 170 milliseconds. There should not be any confusion between voltage sags and brownouts, which are reduction in voltage lasting from a few minutes to hours. Voltage sags are the most common power quality problem and can cause by many reasons. Some of them are abrupt increase in load, motor starting, electric heaters turning on etc. Voltage sags arrives from the utility, but most of the time sags are generated inside a building. This paper overviews the methods proposed for the compensation of voltage sag, different solutions for enhancing the performance of the power system.

KEYWORDS: voltage sag, flicker, harmonics, power quality.

I. INTRODUCTION

Increasing population increases the demand for electricity, and not just the power demand has increased in recent years, but also the quality and reliability of power supply have become the essential requirement of today's era. Short duration power disturbances affect most of the industrial processes and into that long and deep voltage sag is the main concern for industries. The use of sensitive electronic equipments for automation purpose has been increased considerably in the past few years. Even a small amount of voltage sag affects these sensitive electronic equipment. They may cause loss in production and also finical loss of industry. Along with loss in production, voltage sags also damage equipments reducing their efficiency ultimately leading to consumer dissatisfaction. The high cost associated with these disturbances is the main reason of increasing interest of researchers developing mitigation techniques.

Before starting the analysis of various techniques and methods for voltage sag mitigation, it is important to understand the causes of voltage sag in power system. Short circuit fault occurring either in an industrial facility or on the utility system is the main cause of voltage sag, motor starting event in industries also results in a voltage sag, but these are not very severe. The voltage drop due to short circuit falls to zero at a fault position. A typical voltage sag waveform is shown below in Fig 1.

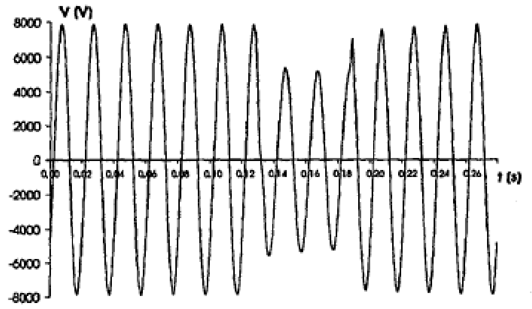

Fig. 1 Typical waveform of voltage sag

This paper gives the overview of various topologies, methods used for mitigating the voltage sag problem. A dc link storage based transformerless boost circuit is proposed for better compensation of voltage sag [1]. Various power devices used by the customers to prevent their sensitive equipments from voltage sag have been proposed [2].

Dynamic sag correctors is also proved to be helpful in mitigation of voltage sag problem along with cost effective method [3]. Most of the voltage topologies are categorized into two groups the inverter based regulator and direct AC-AC converter [4]. Also AC voltage sag/swell compensator are classified into three groups according to their combination as electromagnetic, electric and hybrid voltage compensators [5]. There are also many series connected devices used by consumers, one of these series connected device (SD) which mitigate the sag by injecting missing voltage in the series with grid. Dynamic voltage restorer (DVR) is one of the commonly used SD topology, its designing and effectiveness in compensating voltage sag is investigated. When the source side voltage has disturbed, the use of a DVR is one of the most effective solution in restoring the quality of voltage at load side [6].

II. MITIGATION TECHNIQUES

A. Transformerless AVR topology

Taking into consideration the threat of voltage sag to sensitive electronic equipment, a new high operation efficiency technique, applying dc-link voltage adaptive control method is proposed. The deeper voltage sags are more dangerous and more intolerable than short duration voltage sag, that's why they cannot be ignored. The methodology claims to mitigate long duration deep voltage sag. The proposed topology has been derived from dynamic sag corrector topology (DySc).In this paper change in position of converters in DySc results in formation of boost circuit. The shunt converter in combination of series converter will charge the dc-link voltage to exceed the peak value of supply voltage. The circuit diagram of proposed PB-AVQR topology is as shown below.

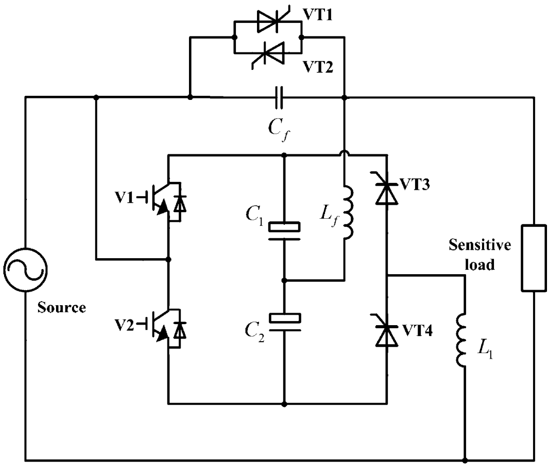

Fig. 2 Proposed PB-AVQR topology

As shown in Fig. 2, the PB-AVQR topology is mainly consists of five parts, including a static bypass switch (VT1, VT2), a half-bridge inverter (V1, V2), a shunt converter (VT3, VT4), a storage module ($C1$, $C2$), and a low-pass filter (Lf , Cf). In normal operating conditions, i.e. when there is no sag occurring, the static bypass switch is controlle-d to switch ON the normal grid voltage and supply it directly to the load. After the detection of abnormal condition, the static switch is OFF and that will control the inverter to inject a desired missing voltage in series with the supply voltage to ensure the power supply of sensitive loads. The author in this paper proposed two different kinds of control strategies. Which are, when the grid voltage is less than rated voltage. An in phase control strategy was adopted and a phase-shift control was adopted when the voltage is higher than nominal voltage. This is the basic operating principle of PB-AVQR topology. As the transformers are not used, the circuit complexity reduces also this methodology proves to be cost effective [1].

B. Power devices for voltage sag mitigation.

Power devices have proven to be an attractive solution to the short duration voltage sag problem. Methods used in the mitigation of voltage sags. Different solutions for improving the performance of the power system, as well as the immunity of the equipment, are described. Finally, mitigation devices *to* be installed at the system-load interface for power quality enhancement are presented.

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ISSN (Online): 2278 – 8875

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Vol. 5, Issue 4, April 2016

The paper is organized into three sections. The first section has described that, the changes in the system will lead to performance improvement. According to author, reducing in number of faults results in reduction of voltage sag along with reduction in frequencies of long and short interruption. Methods and equipments for reducing the number of faults has also been given in this section. A modern static circuit breakers should be used to reduce the fault clearing time, which in turn will reduce the voltage sag suggests the author. Also, how distribution system design will help in system enhancement is described by the author. A simple radial structure is usually preferred. The next section describes the effect of voltage sag on the performance of computers and control equipments, AC drives, DC drives, etc. and how such equipments can be protected and how their immunity will be increased by making some changes or by adding supporting devices. In last section various power devices and their working have been described. Some of them are motor generator set, transformer based devices, inverters based devices, etc. Shortly the importance of various power devices which are used by consumers to mitigate the voltage sags, [2].

C. Dynamic Sag Corrector

Dynamic sag corrector is also one of the voltage compensator whose unique circuit allows operation with opened up circuit breaker. The Author has described the operating principle of dynamic sag corrector (DySc) and validation of performance [3]. The three types of disc models analysed is as given below.

1. *Single phase mini disc*:

The single-phase inverter used was configurable to operate in voltage boost or bypass mode, and was competent of providing 100% boost to the incoming AC line voltage. Fig. 3. Shows the single phase DySc topology. The static bypass switch is common to the entire disk product line which remains ON under normal operating condition. This permits very efficient single-stage power throughput having no harmonic voltage content added. When voltage sag occurs the static bypass switch is turned off and the IGBT inverter begins operating. The inverter supplies only the missing voltage, but the circuit is designed to add this voltage with supply voltage for full compensation. According to author The smaller DySC unit has sufficient energy storage to compensate for 100% missing voltage for 6 cycles.

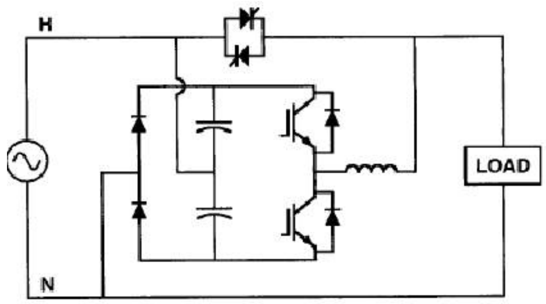

Fig. 3 Single phase DySc topology

2. *The Three-phase ProDySC and MegaDySC*:

This is the second design where for lower power three-phase 4- wire up to 300KVA single phase DySc is adopted for realization of three phase protection in ProDySc. According to author for higher power application the transformer coupled devices provide better solution.

3. *MegaDySc Combinations*:

For equipments like UPS, generator and multiple distribution feeds where ultra reliability of power is required, the mega DySc combinations have been designed. Author here proposed an innovative approach to combine a fast vacuum transfer switch with a dynamic sag corrector to deliver extremely reliable and available power, as shown in Fig. 4

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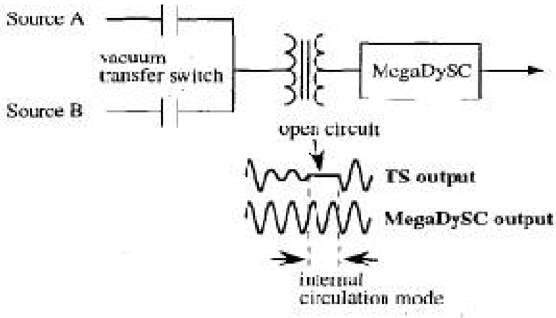

Fig. 4 Ultra-reliable power is supplied cost-effectively by using a vacuum transfer switch plus a voltage sag corrector with ride-through capability

D. Interphase AC-AC topology

To compensate the voltage sag, a new interphase ac-ac topology has been developed. The proposed topology does not need a storage device. A single phase compensator has designed with two transformers and two choppers. The required voltage is made available by controlling the duty cycle of each ac chopper. The Paper provides analysis, simulation results and also verification through prototype. The logic used in other sag supporters of correcting the sag by drawing power from affected phase itself further worsen the severity of the sag. But in the proposed topology the input power is taken from the other two phases and not from the affected phase. The voltage sag supporter is independent of other two phases, and this is to be taken into considerations. The proposed method is very reliable and cost effective due to the absence of any storage device. Further real power injection and ride through capability is not compulsory. Working principle for This controller is also simple. Unbalanced sag compensation is also possible with proposed topology. The schematic diagram of topology proposed is shown in Fig 5. The figure shows how voltage sag in phase *a* is compensated. This voltage sag supporter is connected between point of common coupling and load. When the PCC experiences voltage sag, the compensator injects an appropriate voltage in series with the supply voltage to deliver the desired load voltage. There are two ac choppers and two isolation transformers in each phase. The transformers are connected in the way so that the two chopper output voltages are added and isolated. The voltages which are required from phase *b* and phase *c* are obtained by individuals as copper and connected to the primary of the each transformer. Now to compensate the sag in phase *a* the added secondary voltage is injected in series with the line. Similarly, for phase *b* and phase *c*, individual sag supporters are provided [4].

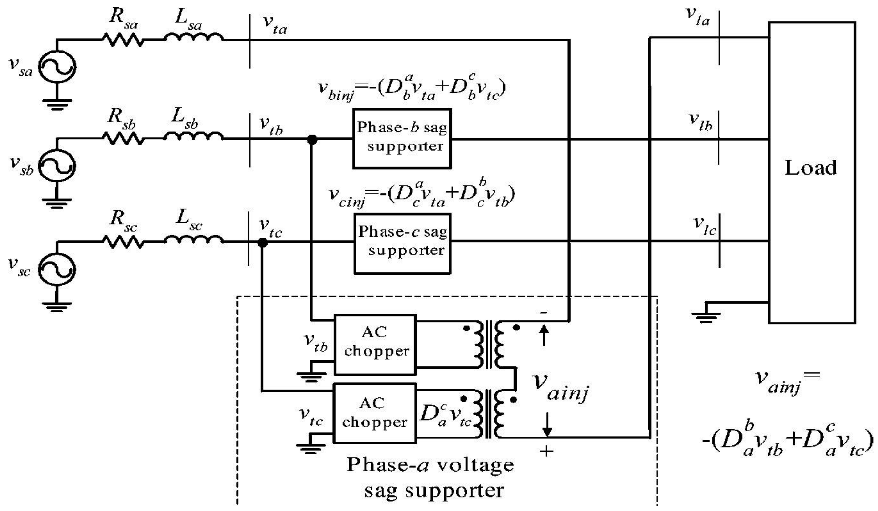

Fig. 5 Schematic diagram of the proposed inter-phase ac-ac voltage sag supporter

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E. AC Voltage Sag/Swell Compensator Based On-Three Phase Hybrid Transformer

The parameters of electrical energy such as voltage amplitude are very important, particularly from the viewpoint of the final consumer and sensitive loads connected to the grid. Author classified the voltage compensators into three groups first is electromagnetic. This group has included conventional electromagnetic transformer with tap changer. The second group is Electric group, under this group AC-AC PWM converter and AC/DC/AC converter fall. In third group called hybrid group, conventional transformer and in that combination AC/DC/AC converter are used. Simulation results, theoretical analysis and experimental test results from 2KVA laboratory model has been presented. This paper presents the steady and transient-state properties of the three-phase voltage compensator. The arrangement consists of a transformer and buck–boost MRC-because of which this solution is called a hybrid transformer (HT) (see Fig. 6). The concept here is that a single-phase transformer cooperates with a single-phase matrix ac chopper. The range of change of voltage transmittance obtained is $0.66 < HU < 2$.

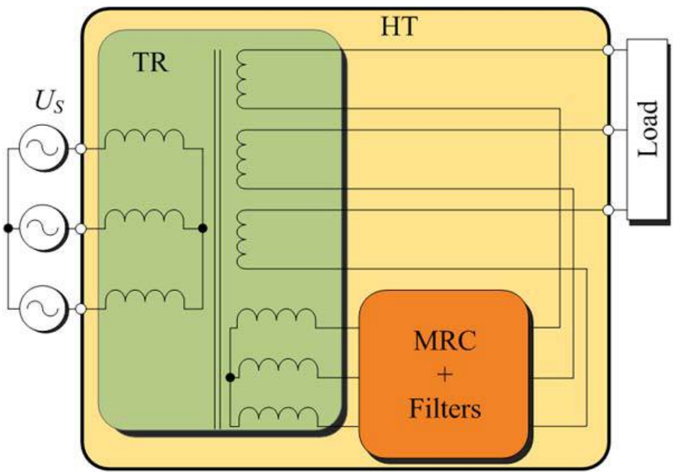

Fig. 6 Simplified scheme of three-phase HT

F. DVR

A novel dynamic voltage restorer(DVR) topology based on reduced-order matrix converter modules has been proposed. The topology has employed two modules for selective and independent sequence voltage synthesis. As a result, the DVR designed can mitigate balanced as well as unbalanced voltage sags/swells. The realization of each model has done using a vector-switching matrix converter. The entire topology is energy storage free, and each module was pulse width modulated using simple dc duty ratios. The author through this paper provides detailed modeling, equivalent circuit, and feedback controller design. Computer simulation and experimental prototype have been used to validate the approach. A main advantage of the use of vector switching converters (VeSc) against DC-link based topologies, was the elimination of the phase-locked-loop system. This is because VeSC converters do not make any frequency change, and hence, input and output voltages and currents synchronization is possible by default. AC grid fed to VeSc based DVRs and, hence, may draw large currents from the ac mains while providing voltage sag compensation.

These ideas are further expanded throughout the paper. The paper proceeds giving a overview of VeSC converters along with the principle of operation of modular sequence voltage synthesis. After that in section II and III the VeSC-based DVR topological realization and feedback control design guidelines are provided. Computer simulations and experimental results are presented in Sections IV and V, respectively. Finally, by conclusion made in Section VI close this paper. Fig 7 shows the conceptual diagram of DVR proposed in this paper. The same shunt phase shifter transformer (SPT) connect each module to it, but their outputs are added via two separate series injection transformers (SIT)

 DOI:10.15662/IJAREEIE.2016.0504027

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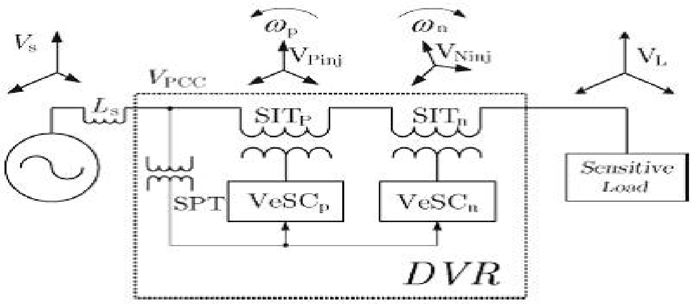

Fig. 7 Block diagram of two- module VeSc based DVR

The result of this is that, each module's duty ratio controls the sequence voltage synthesis, thus, is modular and independent. The figure also illustrates the switch realization using power semiconductors. The proposed methodology has provided a much simpler modulation strategy based on DC duty ratios. Furthermore, the full pole current is conducted by two power semiconductors due to realization based on the traditional matrix converter with two IGBT–diode pairs connected in series. The proposed topology have separate the pole current into sequences, and each sequence current is conducted by only one power semiconductors, leading to a more efficient operation [6].

III. CONCLUSION

Various voltage sag mitigation technologies have been studied and discussed. Every topology varies from each other in complexity, performance and cost. Among all the topologies discussed, the PB-AVQR topology, without the use of any bulky transformers, found to be very cost effective and highly reliable solution to improve power quality by compensating deep voltage sag. All other topologies has their own advantages like DVR based topology and AC-AC topology for voltage sag supporter, have the advantage of dc-link storage free operation, but they involve transformers' and choppers. Many customer power devices have also been discussed which are very attractive solution to the short duration voltage sags, but the PB-AVQR topology provides long duration voltage sag. The per sequence vector switching DVR based topology have the advantage of compensating balanced as well as unbalanced voltage sags. The use of hybrid transformer for voltage sag mitigation is also an effective solution, but only in the case of a circuit where compensation of a source voltage interrupt is not necessary. However, according to need and usefulness, industries and distribution systems uses any of the above voltage sag mitigation technologies.

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