

**Analysis of Parasitic Boost Active Voltage Quality Regulator without Transformer for Power Quality Improvement**¹Ms. Harshali Wani, ²Mr. S. M. Shembekar¹PG Student, Dept. of Electrical Engineering, SSBT's College of Engineering, Jalgaon, Maharashtra.²Assistant Professor, Dept. of Electrical Engineering, SSBT's College of Engineering, Jalgaon, Maharashtra

Abstract: The most common disturbances in the Source voltage are voltage sags and swells. Voltage sag 10% lasting for 5-10 cycles can result in costly damage in critical loads to mitigate the problems caused by poor quality of power supply, series connected compensators are used. In this paper, the ride through is provided by Dynamic sag corrector. The position of shunt and series converter is changed according to the structure difference between the DVR. As it is a transformerless the proposed Active voltage quality regulator(AVQR) is cost effective solution for long duration sags that are lower than 50% of nominal voltage. Additionally, the DC-link adaptive control method is applied to obtained high operating efficiency. Analysis along with simulation and modeling of DySC and Parasitic Boost AVQR is presented to verify feasibility and effectiveness of the proposed topology.

Keywords- Voltage sag, series connected compensator, Dynamic voltage restorer(DVR), Dynamic sag corrector(DySC), DC-link voltage.

I. INTRODUCTION

Power Quality Problem is the major issue in Industrial and Commercial Section as they can affect large the distribution number of sensitive end users. Studies indicate that Voltage sags, Transients and Momentary interruptions constitute 92% of all the Power Quality problems occurring in power systems [1]. Among the power quality problems, the supply voltage problems are considered most critical and significant, especially voltage quality problems of the point of common coupling. The rapid increase of voltage sensitive load equipment has made industrial processes much more criticism to degradation in the quality of the power supply [2]. the voltage generated by power stations has sinusoidal waveform with a constant frequency. Any disturbances to voltage waveform can result in problems related with the operation of electrical and electronic devices. Users need constant sine wave shape, constant frequency and symmetrical voltage with a constant rms value to continue the production. This increasing interest to improve overall efficiency and remove variations in the industry have resulted more complex instruments that are sensitive to voltage disturbances [3]. In fact, voltage sags have always been a huge threat to the industry, and even 0.25 s voltage sag is long enough to interrupt a manufacturing process resulting enormous financial losses[4],[5]. Voltage sags are generally classified according to its depth and duration of time. Sag can be drop between 10% and 90% of the rated RMS voltage. It has the duration time of 0.5 cycles to 1 min [6]. According to the data presented in [7], majority of the sags with long duration time obviously cannot be ignored as they are more intolerable than shallow and short duration sags to the sensitive electrical consumers.

II. VOLTAGE SAGS

Voltage sags which can cause equipment impacts are caused by faults on the power system. Motor starting also results in voltage sags but the magnitudes are usually not severe enough to cause equipment miss operation.

A single line to ground fault condition results in a much less severe voltage sag than 3-phase fault Condition due to a delta--star transformer connection at the plant. Transmission related voltage sags are normally much more consistent than those related to distribution[12]. Because of large amounts of energy associated with transmission faults, they are cleared as soon as possible. This normally corresponds to 3-6 cycles, which is the total time for fault detection and breaker operation Normally customers do not experience an interruption for transmission fault. Transmission systems are looped or networked, as distinct from radial distribution systems. Most of the voltages were 10-30% below nominal voltage, and no momentary interrupts were measured at the plant during the monitoring period (about a year).

A. Voltage-Sag Analysis- Methodology

The methodology is outlined in chapter 9 (proposed) of IEEE Gold book (IEEE standard 493, Recommended practice for the design of reliable industrial and commercial power system) The methodology basically consists of the following four steps.

1.Load Flow: A load flow representing the existing or modified system is required with an accurate zero-sequence representation. The machine reactance X_d'' or X_d' is also required. The reactance used is dependent upon the

post fault time frame of interest. The machine and zero-sequence reactance are not required to calculate the voltage sag magnitude.

2. Voltage Sag Calculation: Sliding faults which include line-line, line to ground, line to line- to ground and three phase are applied to all the lines in the load flow.

3. Voltage Sag Occurrence Calculation: Based upon the utilities reliability data (the number of times each line section will experience a fault) and the results of load flow and voltage sag calculations, the number of voltage sags at the customer site due to remote faults can be calculated. Depending upon the equipment connection, the voltage sag occurrence rate may be calculated in terms of either phase or line voltages dependent upon the load connection. For some facilities, both line and phase voltages may be required. The data thus obtained from load flow, Voltage sag calculation, and voltage sag occurrence calculation can be sorted and tabulated by sag magnitude, fault type, location of fault and nominal system voltage at the fault location.

4. Study of Results of Sag- Analysis: The results can be tabulated and displayed in many different ways to recognize difficult aspects. Area of vulnerability can be plotted on a geographical map or one - line diagram. These plots can be used to target transmission and distribution lines for enhancements in reliability. Further bar charts, and pie-charts showing the total number of voltage sags with reference to voltage level at fault point, area/zone of fault, or the fault type can be developed to help utilities focus on their system improvements. To examining the existing system, system modifications aimed at mitigating or reducing voltage sags can also be identified, thus enabling cost benefits analysis. Possible such system structural changes that can be identified include.

B. Equipment Sensitivity Studies:

1. Process controllers can be very sensitive to voltage sags: An electronic component manufacturer was experiencing problems with large chiller motors tripping off-line during voltage sag conditions.

2. Chip Testers: Electronic chip testers are very sensitive to voltage variations, and because of the complexity involved, often require 30 minutes or more to restart. In addition, the chips involved in the testing process can be damaged and several days' later internal electronic circuit boards in the testers may fail. A chip tester consists of a collection of electronic loads, printers, computers, monitors etc. If any one component of the total package goes down, the entire testing process is disrupted. The chip testers can be 50 KVA or larger in size.

3. DC Drives: DC drives are used in many industrial processes, including printing presses and plastics manufacturing. The plastic extrusion process is one of the common applications where voltage sag can be particularly important. The extruders melt and grind plastic pellets into liquid plastic. The liquid plastic may then be blowup into a bag or processed in some other way before winder winds the plastic into spools. During voltage sag, the controls to the D.C. drives and winders may trip. These operations are typically completely automated and an interruption can cause very expensive clean up and starting requirements. Losses may be of the order of Rs. 15 lakhs /event and a plant fed from a distribution system is likely to experience at least one event per month.

4. Programmable Logic Controllers: Their overall sensitivity to voltage sags varies greatly by portions of an overall PLC system have been found to be very sensitive. The remote I/O units have been found to trip for voltages as high as 90% for a few cycles.

B. Solutions to Voltage Sag Problems:

Efforts by utilities and customers can reduce the number and severity of sags.

1. Utility solutions:

Utilities can take two main steps to reduce the detrimental effects of sags –Prevent fault and Improve fault clearing methods

Fault prevention methods include activities like tree trimming, adding line arrests, washing insulators and installing animal guards. Improved fault clearing practices include activities like adding line recloses, eliminating fast tripping, adding loop schemes and modifying feeder design. These may reduce the number of duration of momentary interruptions and voltage sags but faults cannot be eliminated completely.

2. Customer solutions:

Power conditioning is the general concept behind these methods. Power conditioning helps to Isolate equipment from high frequency noise and transients also Provide voltage sag ride through capability

III. SOLUTIONS TO PROVIDE RIDE-THROUGH CAPABILITY TO CRITICAL LOADS

The following are some of the equipments to mitigate the voltage sags by providing ride-through capability when the grid voltage differs from its desired voltage waveform.

1. Motor generator sets (M-G sets)
2. Uninterruptible Power supply (UPS's)
3. Ferro-resonant Constant Voltage Transformer (CVT's)
4. Magnetic synthesizers
5. Super conducting storage devices (SSD's)
6. Static Voltage Regulator (SVR)
7. Dynamic Voltage Restorer (DVR)

MG sets usually utilize flying wheels for energy storage. They completely decouple the loads from electric power system. Relational energy in the flywheel provides voltage regulation and voltage support during under voltage conditions. MG sets have relatively high efficiency and low initial cost. UPS's utilize batteries to store energy which is converted to usable form during an outage or voltage sag. UPS technology is well established and there are many UPS configurations to choose from.

CVT's can be used to enhance voltage sag ride through capability. CVT's (Fig.1) are basically; transformers which are excited high on their saturation curves, thereby supplying output voltage which is fairly independent of input voltage variations. Magnetic synthesizers are generally used for larger loads. A load of at least several KVA is needed to make these units cost effective. They are often used to protect large computers and other sensitive electronic equipment. This is an electromagnetic device which generates a clean three phase ac output waveform regardless of input power quality. SSD's utilize a super conducting magnet store energy in the same way a UPS uses batteries to store energy. SSD's occupy less space and use fewer electrical connections as compared to UPS's thus promising better reliability. They are also expected to become economically competitive.

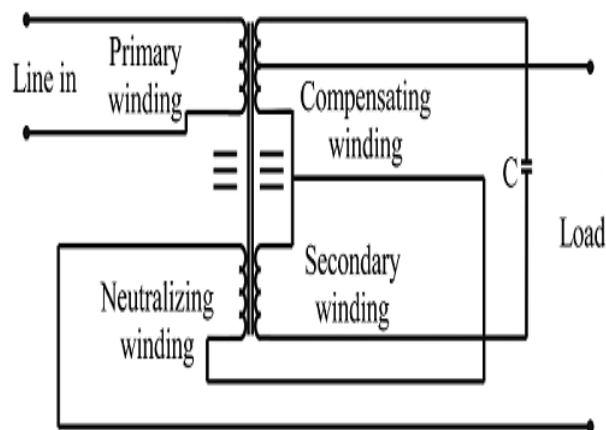


Figure.1 Ferroresonant constant voltage transformer

Static Voltage Regulator (SVR) simply regulates the voltage to equipment operational levels (Fig.2). Unlike conventional load tap changers, which are equipped with a time-delayed mechanical tap changer, static tap changers are designed to respond instantaneously by selecting the appropriate voltage tap, on a sub-cycle basis, without the need to progress through a series of lower voltage taps. The SVR does not require the use of energy storage [8], and it has a relatively small footprint for the amount of load it can protect. Also, it is designed to be installed outdoors so it does not intrude in the manufacturing space.

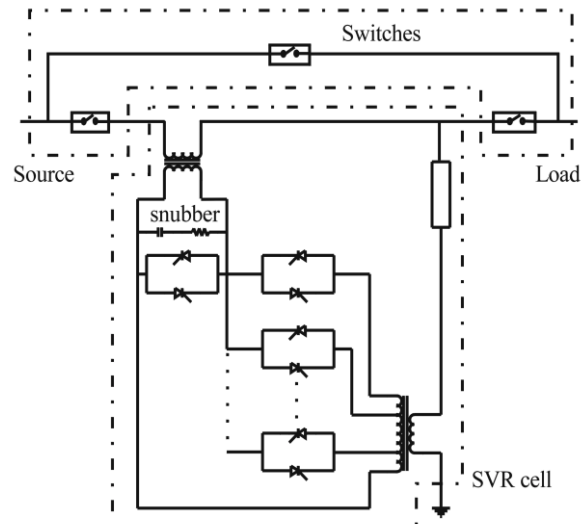


Figure 2. Static Voltage Regulator

Dynamic Voltage Restorer (DVR) (Fig.3) have been installed to protect microprocessor fabrication plants, paper mills etc. Typically, DVRs are made of modular design with a module rating of 2 MVA or 5 MVA. They have been installed in substations of voltage rating from 11 kV to 69 kV. A DVR has to supply energy to the load during the voltage sags. If a DVR has to supply active power over longer periods, it is convenient to provide a shunt converter that is connected to the DVR on the DC side. As a matter of fact one could envisage a combination of DSTATCOM and DVR connected on the DC side to compensate for both load and supply voltage variations. The voltage source converter is typically one or more converters connected in series to provide the required voltage rating. The DVR can inject a (fundamental frequency) voltage in each phase of required magnitude and phase. To improve power quality a custom power device Dynamic Voltage Restorer can be used to eliminate voltage sags and swells[9]. DVR is an inverter based voltage sag compensator. DVR protects the precision manufacturing processes and sophisticated sensitive electronic equipments from the voltage fluctuations and power outages. DVR offers sub-cycle protection, restores the quality of electric power delivered to the sensitive load. The DVR regulates voltage within acceptable tolerances and meet the critical sensitive power quality needs. The DVR has been developed by Westinghouse for advance distribution. DVR injects a set of three single-phase voltages of an appropriate magnitude and duration in series with the supply voltage in synchronism via booster transformer to restore the power quality.

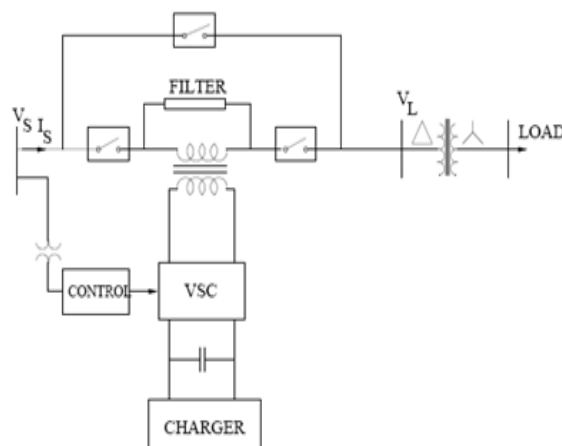


Figure. 3 Dynamic Voltage Restorer

The injection voltages are of controllable amplitude and phase angle. The reactive power exchange between the DVR and distribution system without capacitors or inductors. The DVR is a series conditioner based on a pulse width modulated voltage source inverter, which is generating or absorbing real or reactive power independently. The DVR injects the independent voltages to restore the line voltage to sensitive loads from sags caused by unsymmetrical line-to-ground, line-to-line, double-line-to-ground and symmetrical three phase faults. The output voltage waveform of DVR is highly regulated and clean. The DVR provides harmonic compensation and mitigates voltage transients.

III. BASIC CONCEPTS OF DYSC

The DVR topology is not cost effective solution for long duration deep sags as it includes a series transformer that is heavy, bulky and costly operating line frequency. To overcome with this drawback the type of transformerless SD topology Dynamic Sag Correctors (DySC) is proposed pronounced “disk”. The DySC mitigates voltage sags, transients and momentary loss of power. The transformerless implementation of the DySC constitutes the rating of 1.5 KVA single phase to 500 KVA three phase in a transformerless implementation and above 500 KVA upto 2000 KVA in series transformer is injected with the device. The unique features[11] of the DySC that are: i) It is transformerless ii) Features single stage power conversion iii) minimizes stored energy iv) Optimally matches protection time to system characteristics[10].

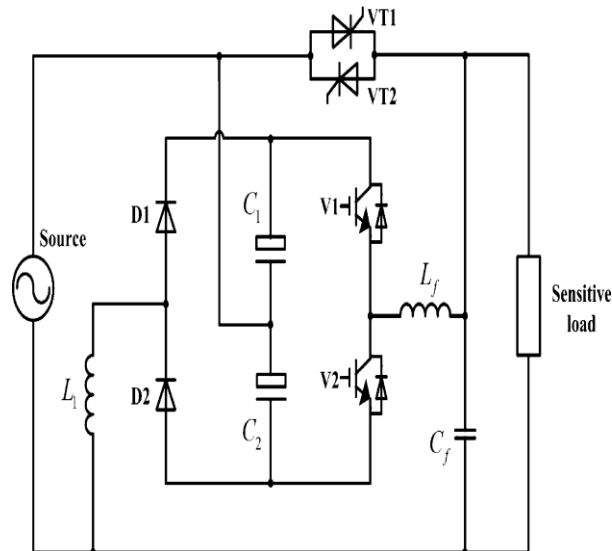


Figure. 4 Single phase DySC

Fig. 4 describes the single phase configuration of single phase DySC. When the grid voltage differs from its desired voltage waveform, a missing voltage is injected and filtered by the DySC through its half bridge series converter (V1, V2) and output filter (L_f , C_f) to maintain the load voltage at its rated value. Simultaneously the energy needed for the compensation is supplied by the residual supply via a passive shunt converter (D1, D2, L_1) and stored in the dc-link capacitors (C_1 , C_2). so, the dc-link voltage should always be lower than the peak value of the supply voltage, and it means that the DySC can only compensate for voltage sags no deeper than 50% since the largest injection voltage of the DySC is solely determined by its dc-link voltage. As mentioned in [10], the ride-through time of the DySC in deeper voltage sags is limited by the dc-link energy storage, and it is inadequate to provide reliable protection for sensitive loads.

So, although the DySC is an excellent solution for sags in many cases, it is invalid for long-duration deep sags as its compensation ability is limited by the passive rectifier. In this paper, position of the shunt converter and series converter in the DySC is changed according to the structure differences between the DVR with the load-side-connected shunt converter and the DVR with the supply-side-connected shunt converter. As a result, the shunt converter together with the series converter formed a boost charging circuit and the dc-link voltage will be charged to exceed the peak value of the supply voltage. This obtained novel topology is called the transformerless active voltage quality regulator with the parasitic boost circuit (PB-AVQR), and it is capable of mitigating long duration deep voltage sags without increasing the cost, volume, and complexity compared with the traditional DySC topology. The dc-link voltage adaptive control method is applied in the PB-AVQR to improve its operation efficiency.

V. TOPOLOGY AND PRINCIPLE

As shown in Fig. 5, the PB-AVQR topology is mainly consists of five parts, which includes a static bypass switch (VT1, VT2), a half-bridge inverter (V1, V2), a shunt converter (VT3, VT4), a storage module (C_1 , C_2), and a low-pass filter (L_f , C_f). The operating mode and applied control strategies are similar to as described in [2]. Under normal operating conditions, the static bypass switch is controlled to switch on and the normal grid voltage is delivered directly to the load side via this bypass switch. When an abnormal condition is detected, the static bypass switch will be switched OFF and the inverter will be controlled to inject a desired missing voltage in series with the supply voltage to ensure the power supply of sensitive loads. There are totally two different kinds of control strategies in the proposed PB-AVQR system.

When the grid voltage is lower than the rated voltage, an in-phase control strategy will be adopted and a phase-shift control strategy will be applied when the supply voltage is higher than the nominal voltage.

Working principle of the PB-AVQR is different compared with that of the DySC due to its unique shunt converter structure. When the proposed configuration is analyzed, both the operating states of the switches (V1, V2) and the trigger angles of the thyristors (VT1, VT2) should be taken into consideration. So, a simplified PB-AVQR (SPB-AVQR) circuit shown in Fig. 5 where two thyristors (VT3, VT4) in the proposed PB-AVQR are replaced by two diodes (D1, D2), is firstly introduced to better explain its working principles. The following analysis will be based on the SPB-AVQR which can be regarded as a special type of PB-AVQR.

The only difference between these two configurations is that the shunt converter of the PB-AVQR is controllable while the shunt converter of the SPB-AVQR is uncontrollable. That is to say, the dc-link voltage of the SPBAVQR represents the upper limit of the dc-link voltage in the PB-AVQR structure.

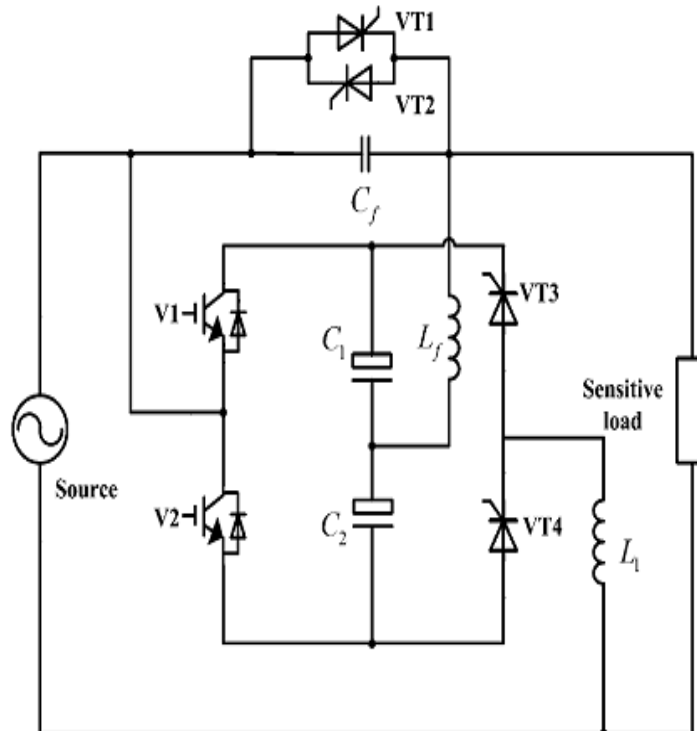


Figure. 5 Proposed AVQR Topology

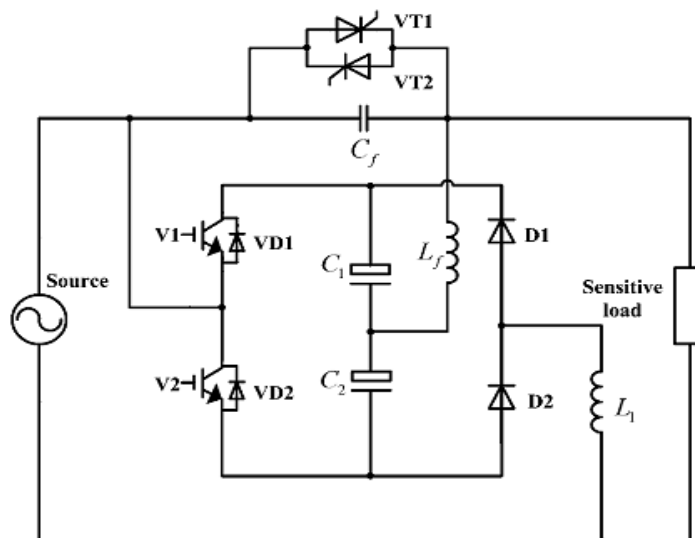


Fig. 6 SPB – AVQR topology

So, theoretical conclusions drawn with the SPB-AVQR are basically applicable to the PB-AVQR. As shown in Fig. 2, switches V1 and V2 are now also parts of the parallel circuit, which means that the dc-link voltage will be affected by the on/off status of the switches. So, the turn on and turn off conditions of the compensation process should be considered to understand the working principles about the parasitic boost circuit of the SPB-AVQR. Figs. 3 and 4 illustrate four different operating conditions of the SPB-AVQR within one switching cycle during the positive and negative half-cycle of the sinusoidal supply voltage separately. Both the compensation process and charging process can be explained based on these operating conditions.

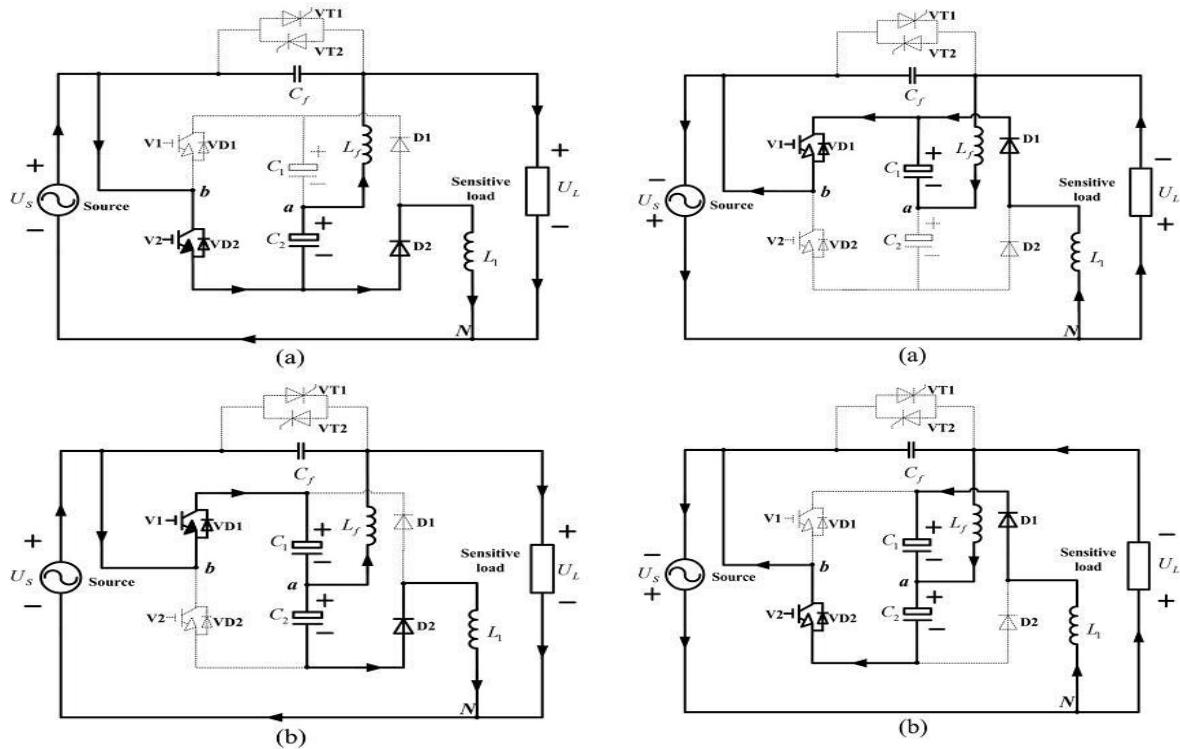
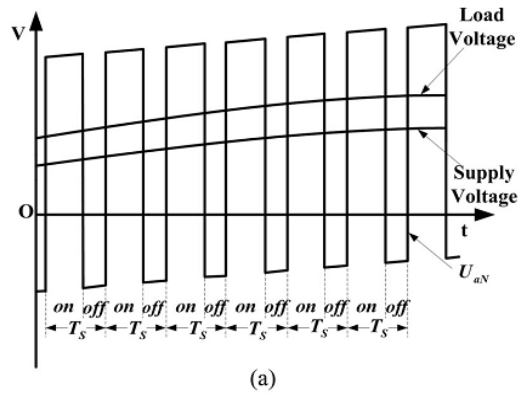


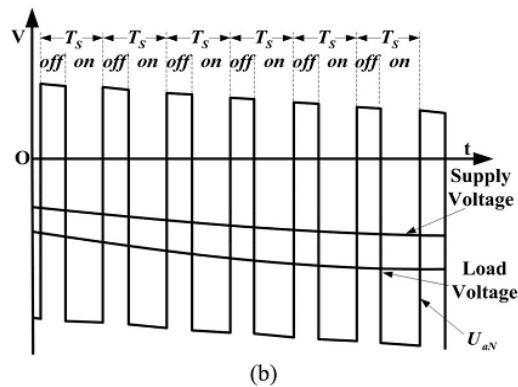
Figure.7. Operating conditions during positive half-cycle. Figure.8 Operating conditions during negative half-cycle.
 (a) V2 switched on. (b) V2 switched off. (a) V1 switched on. (b) V1 switched off.

In Figs. 7 and 8, the solid line means that there is current flowing through and arrows depict directions. Operating conditions during the positive half-cycle are illustrated in Fig. 7. When V2 is switched on, as shown in Fig. 7(a), the grid charges the inductor L_1 via the diode D_2 and the capacitor C_2 discharges to maintain the load voltage. When V2 is switched off, as shown in Fig. 7. (b), the energy stored in the inductor during previous period is released to dc-link capacitors C_1 and C_2 through VD_1 which is the anti parallel diode of V1. Operating conditions during the negative half-cycle are given in Fig. 8. When V1 is switched on, as shown in Fig.8 (a), the inductor L_1 is charged via the diode D_1 , and the load is compensated by the capacitor C_1 . When V1 is switched off, as shown in Fig. 8(b), the energy stored in L_1 is released through VD_2 , which is the anti parallel diode of V2, to capacitors C_1 and C_2 . So, in each half-cycle of the grid, one capacitor of the dc-link discharges to provide the energy needed for the compensation, and this energy is actually obtained from the supply source via the charging process described earlier. Apparently, the charging circuit of the proposed configuration works exactly like a boost circuit and the dc-link voltage in this situation is controlled by the duty ratio of the two switches.

So, the compensation ability of the SPB-AVQR is unlimited as long as the grid is strong enough to provide the needed power. However, as the boost circuit is parasitic on the series inverter, and the two switches are actually controlled according to the missing voltage, there still exist some restrictions. Figs 7 and 8. , two endpoints of the inverter are marked as a and b. Parts of the waveforms obtained at the inverter side and load side under four operating conditions are schematically shown in Fig.9, where U_{aN} represents the voltage between a and N. As shown in Fig.10, when V1/V2 is switched on/off, the dc-link voltage will be added/subtracted to the supply voltage to get a switching pulse voltage U_{aN} and the switching harmonics of U_{aN} will be filtered by L_f and C_f to get a smooth load voltage.

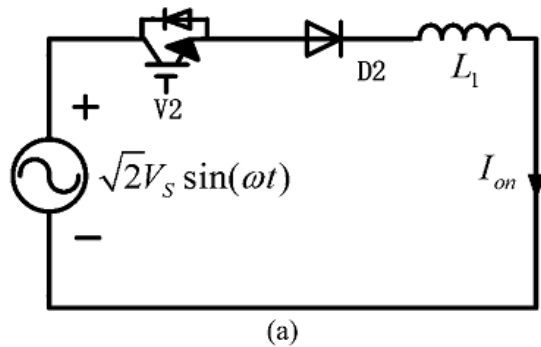


(a)

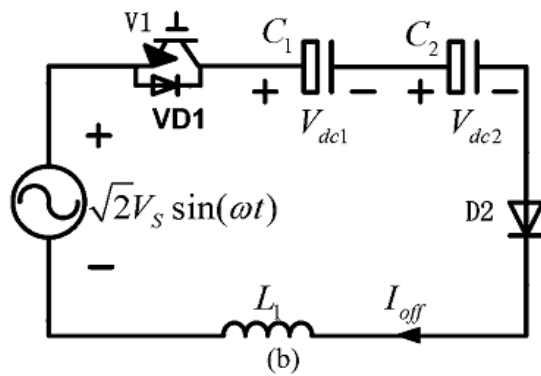


(b)

Figure.9. Waveforms of supply voltage, load voltage, and U_{aN} .
(a) V2 on/off. (b) V1 on/off.



(a)



(b)

Figure.10. Simplified circuit model
(a) V2 turned on. (b) V2 turned off

So, the load voltage will be maintained at its rated value if the inverter is properly controlled according to the required missing voltage during sags.

VI. MATLAB/SIMULINK RESULTS

Fig. 11 and Fig. 12 shows the MATLAB/Simulink model of DySC and PB-AVQR with different supply voltages respectively. The simulation is carried out using PI- controller method first. The results obtained from PI-Controller method are then compared with Fuzzy Logic Controller method.

In the simulation (Fig.13), the supply voltage drops to 180 V at 0.1 s and then falls to 100 V at 0.4 s. As shown in Fig. 13, when the supply voltage is 180V, the DySC can effectively compensate for the voltage sag; however, when the supply voltage drops to 100 V, the load voltage becomes not sinusoidal as the maximum injected compensation voltage is limited by the low steady-state dc-link voltage.

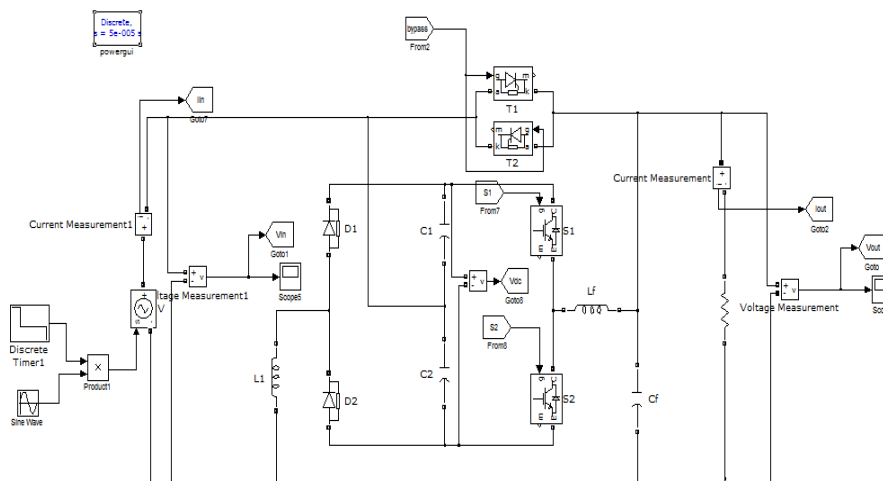


Figure. 11 MATLAB/SIMULINK Model of DySC Topology by using MATLAB/Simulink Platform

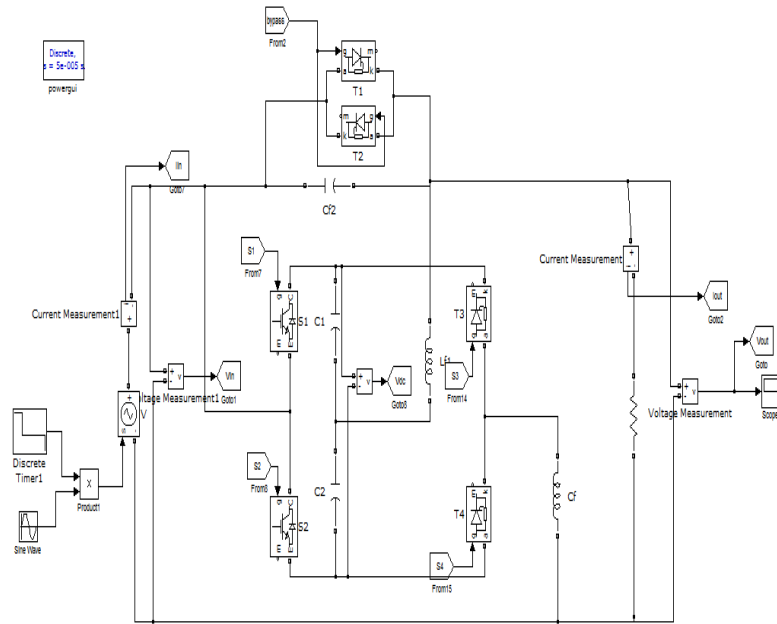


Figure. 12 MATLAB/SIMULINK Model of PB-AVQR Topology by using MATLAB/Simulink Platform

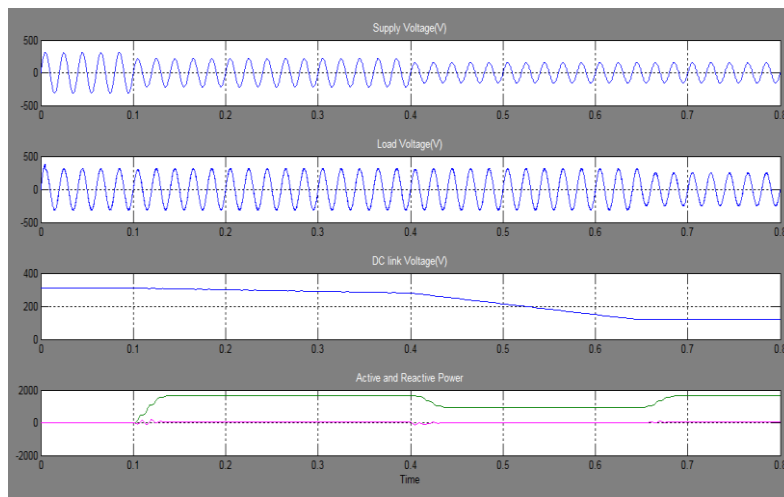


Figure. 13 Simulation Results of DySC

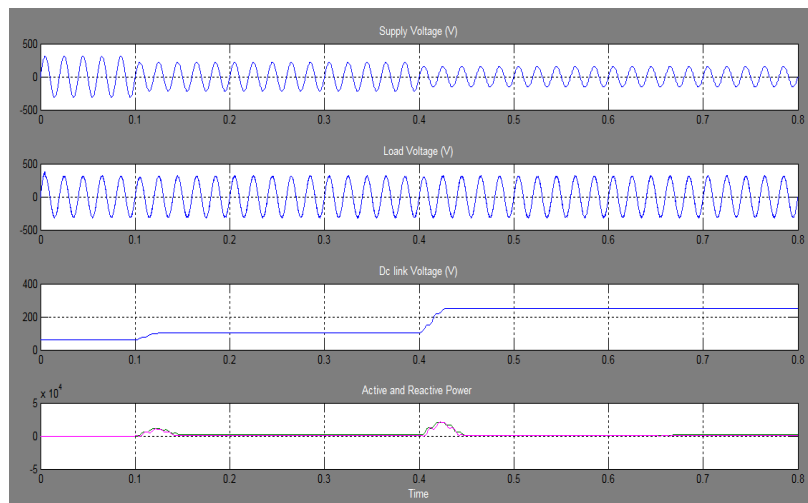


Figure. 14 Simulation Results of PB-AVQR

Fig. 13 also indicates that the DySC can only mitigate deep sags for a few line cycles depending on the energy stored in dc-link capacitors as its steady-state dc-link voltage is always lower than the peak value of the supply voltage. The graphics of the active and reactive power are also included in Fig. 13. When the supply voltage is 180 V, the dc-link voltage does not reach its steady state value with limited simulation time, so the active power of the supply is lower than the load power and its value is about 1.6 kW. When the dc-link voltage reaches its steady-state value with 100 V supply voltage, the active power of the supply is about 1.65 kW which means that the load voltage is no longer maintained.

The simulation results of the proposed PB-AVQR topology under the same condition is shown in Fig. 14. As can be seen in Fig. 14, when supply voltage changes, the dc-link voltage precisely tracks missing voltage and it also remains enough high for the compensation even with a 100 V supply voltage. Fig. 14 also indicates that the transient response here is not very good, but this can be improved by increasing the set value for dc-link voltage. The active power of the supply during the steady-state compensation is 2 kW, and it is the same as the load power which means that the load voltage is effectively ensured. The reactive power during the steady-state compensation is about 1.1 kvar with 180 V supply and is about 1.4 kvar with 100 V supply. The reactive power of the proposed PB-AVQR is higher than that of the DySC due to the dc-link voltage adaptive control method. Additionally, the instantaneous value of the active and reactive power can be suppressed by properly designing missing voltage and the charging time of the capacitors.

VII. CONCLUSION

This paper has presented a novel transformer less active voltage quality regulator with parasitic boost circuit operates under PI control and Fuzzy logic control to mitigate long duration deep voltage sags with good stability factor and low error components. The proposed PB-AVQR topology is derived from the DySC circuit and the compensation performance is highly improved without increasing the cost, weight, volume, and complexity. It is a relatively cost-effective solution for deep sags with long duration time compared with the traditional DVR topology with load-side-connected shunt converter also the series transformer is no longer needed. The working principles are given through theoretical analysis. The operating efficiency of the proposed PB-AVQR system also remains at a relatively high level as the dc-link voltage adaptive control method is adopted.

In a conclusion, the proposed PB-AVQR topology in this paper provides a novel solution for long duration deep voltage sags with high reliability and compensation performance.

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