# Compensation of Voltages Sag and Swell of Short-Term Voltages in the Power System using SVPWM-based DVR

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***Abstract*— Power quality problems are generally generated from two main sources including the errors occurring in the distribution system and transfer lines, on one hand, and nonlinear and dynamic loads and the interaction between load and network, on the other, which result in errors such as voltage oscillation, harmonic current, voltage sage, and instant voltage failure, etc. Recently, a solution was proposed to deal with this problem called as "custom power". This solution, which mostly uses FACT and switching devices, considerably reduces power quality problems. FACT facilities which are on basis of voltage source conversion are installed in the system in series or parallel form and perform power injection or adsorption processes. One equipment proposed for dealing with voltage sag and surge is dynamic voltage restorer, which treats with this phenomena by series injection of voltage into the system. In this paper, sinuous pulse width modulation and space vector pulse width modulation are applied to generate convertor toggling signals of the voltage source, dynamic restore control system is studied for these modulations using MATLAB simulation, and performance of dynamic voltage reflection is analyzed for both modulations.**

***Keywords*— Power quality, voltage Sag, Swell, Signal pulse wide modulation(SPWM), Space vector pulse wide modulation(SVPWM), Dynamic voltage Restorer (DVR)***

## I. INTRODUCTION

Quality of electrical power has received an ever-increasing attention by the power suppliers and subscribers. The term "power quality" has been among the most frequently used concepts of power industry since 1980. This concept is widely used for different types of power system disturbances. The fast-growing voltage sensitive electrical equipment such as PLC, speed regulation drivers, thyristor loads, and robotic systems, which are sensitive to both voltage amplitude and phase, the made industrial process vulnerable to voltage sage and surge, so that over the past years the methods for dealing with voltage sag and surge have been highly focused. The main cause for emerge of the term power quality is the fact that the poor power quality results in negative effects on product quality and impose high loss costs to the system.

A. In general, four reasons are mentioned for the high focus on power quality:

1) Sensitivity of the present electrical equipment is boosted as compared the previously used equipment in terms of power quality variations. Now, many facilities of subscribers have power microprocessor controllers and electrical parts which are sensitive to disturbances.
2) The increase in use of electronic power equipment along the capability of engine speed regulation, etc. has increased harmonic level of the power grids.
3) The ever-increasing knowledge of the subscribers about power quality issues and informing the users about subjects such as voltage shortage and toggling transitions have made power companies to have a revolutionary improvement in their power quality.
4) Connection of power grids to each other and formation of large grids has caused to emerge of more undesired consequences in the case of damage in one element. However, the main motive behind these reason is to boost subscribers' productivity.

B. Power quality problems are mainly caused by two major factors:

1) Errors occurring in the distribution system and transfer lines; and
2) Nonlinear dynamic loads and interaction between load and grid which results in some errors such as voltage disturbance, harmonic current, voltage sag, instant voltage failure, etc.

Recently, a term known as "custom power" has been introduced for dealing with the mentioned problems. This solution reduces power quality problems and mainly utilizes FACT and toggling equipment. Fact equipment which is on basis of voltage source conversion is installed in the system in series or parallel form and perform power injection or adsorption tasks. Dynamic voltage restorer (DVR), which deals with voltage sag and surge by injecting series voltage to the distribution system, is among the facilities introduced for dealing with voltage sag and surge. To generate converter toggling signals of the voltage source in DVR, sinuous pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM) were utilized and the DVR was simulated based on each of these modulations in the MATLAB environment and their DVR performances were analyzed.

### C. Short-term voltage variations

Short-term voltage variations are created due to the short-term connection conditions, energizing the large loads which need great launching current, or by lack of strong wiring connection. These variations are as follows:

1) Failure

A failure occurs whenever the supply voltage or current is reduced to less than 1 per unit for shorter than 1 minute.

2) Voltage shortage

Voltage shortage is the 1.0 to 9.0 per unit drop in effective voltage at the nominal frequency for the time range of 5.0 cycles to 1 minute.

3) Voltage swell

Voltage swell is defined as a 1.1 to 85.1 per unit increase in effective voltage or current at the nominal frequency for the time range of 5.0 cycles to 1 minute.

### D. Long-term variations

The long-term variations involve any change in the effective voltage at nominal frequency for time period greater than 1 minute. The long-term variations can be in the form of voltage surge, voltage sage, and consistent failure:

1) Voltage surge

Voltage surge is called to a minimum 10% increase in effective voltage at nominal frequency for at least 1 minute.

2) Voltage sag

Voltage sag is called to the minimum 10% drop in effective voltage at nominal frequency for at least 1 minutes.

3) Consistent failure

The drop in supply source voltage to zero for at least 1 minute is considered as the consistent failure.

4) Distortion in wave shape

Distortion in wave shape in steady state is called to the deviation of a sinuous wave at nominal frequency which is recognized by its spectrum content. There are five types of distortion in wave form:

1) DC offset
2) Harmonics
3) Semi-harmonics
4) Gap
5) Noise

## II. FLEXIBLE AC TRANSFER SYSTEMS

The Flexible AC transfer systems, which are also known as FACT equipment, is a new idea and concept to improve controllability and development of network transfer capacity, which recommends and motivates implementation of controllers and power electronic facilities. Recently, there are different types of FACT facilities applied in power systems. The main FACT facilities are as:

1) Static Var compensator (SVC)
2) Thyristor control series capacitor
3) Phase shifter transformer (PS) or phase angle regulator (PAR)
4) Static compensator (STATCOM)
5) Static synchronic series compensator (SSSC)
6) Unified power flow controller (UPFC)
7) Interline power flow controller (IPFC)
8) Changeable static compensator (CSC)

The FACT systems are able to control parameters and characteristics of the transfer line such as series impedance, shunt impedance, and phase angle which serve as the main limitations for increasing the grid capacity. The main idea behind FACT compact is to empower the transfer system by activating its elements and components. Indeed, FACT plays a key role in enhance the power transfer flexibility and dynamic stability safety of the power systems. The main improvement of these facilities in the future might be combining different elements of FACT to develop their performance range; e.g., STATCOM and TCSC. Moreover, the complicated and more elaborate control systems would be developed to for improving performance of these facilities. The advances in technologies of semi-conductor with high current capacity and breakdown voltage can considerably reduce price of these facilities, develop their application ranges, and ultimately result in development of super-conductors technology towards facilities such as SCCL and SMES. Since boosting the power quality and supplying a power without any disturbance is among the demands of present users, several solutions exist to enhance power quality; for example, using the FACT facilities in distribution systems. Because of the increase in sensitive loads throughout the power grid, power quality problems have been increasingly noticed in the manufactural industries, over the past years. According to the works conducted in different countries, voltage shortage is among the most essential quality problems in power energy distribution section, which mainly affects industrial automotive processes and, consequently, is followed by high economic losses. Since the temporary contacts are among the highly probable phenomena in the power systems and its prevention is almost impossible, the sensitive subscribers are required to install compensator to prevent the economic loss induced by this phenomenon. Todays, custom power quality compensator facilities such as D-STATCOM, DVR, and UPQC are among the most effective compensators for power quality problems in distribution grids. The economic and technical works conducted on voltage shortage compensation reveal that the subject of this research, i.e., DVR is the optimum alternative for protection of sensitive loads against industrial-scale voltage shortage. DVR is among the facilities which efficiently perform voltage compensation. Different states of DVR components, selection of appropriate transformer and filter parameters, open-circle and closed-circle control methods and response rate of each method, as well as coherent and post-disturbance and energy minimization methods are completely studied in this work. It can be concluded that the minimum energy method is superior over the other methods since it involves a very low energy consumption and energy is an important factor in compensator. Minimum energy method compensates most of generated errors without active power injection and, consequently, results in energy save. Coherent and post-disturbance methods are placed after minimum energy method in terms of their efficiency. The before disturbance method is of high importance for sensitive loads as load voltage compensation by this method is carried out in a complete mode. Furthermore, as previously mentioned, pwm is utilized for pulse generation for the convertor. The research shows that the higher number of toggles in the convertor results in a higher control over the asymmetric voltage generation. Our examinations on closed and open circle control methods revealed that closed circle control method produces a better dynamic response, involves less enduring error, and has a better damping as compared to the open circle method.

The proposed structure of dynamic voltage Restorer was studied in this paper is shown in Figure 1.

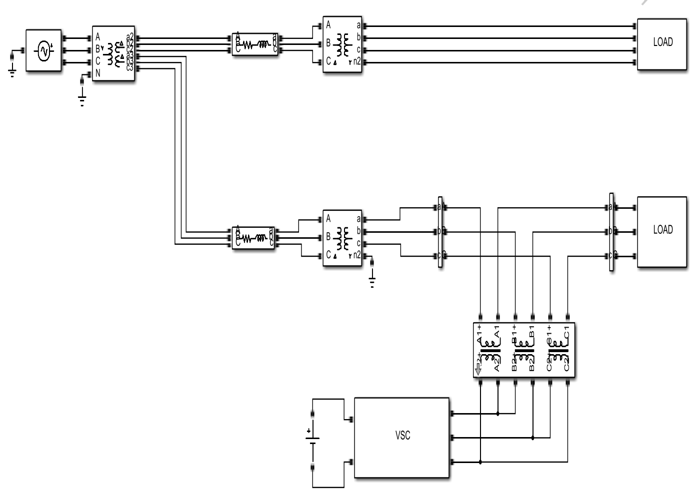


Figure 1. Structure dynamic voltage Restorer

Using the KVL rule, gives:

$$V_{th} - Z_{th} I_L + V_{DVR} = V_L \quad (1)$$

$$V_{th} + V_{DVR} = V_L + Z_{th} I_L \quad (2)$$

Therefore, the injected series voltage can be calculated by DVR using the following equation:

$$V_{DVR} = V_L + Z_{th} I_L - V_{th} \quad (3)$$

Thus, the apparent injection power of DVR is:

$$S_{DVR} = D_{DVR} I_L^* \quad (4)$$

The main function of control system is to maintain voltage of loads sensitive to voltage fluctuations under disturbance conditions.

## III. THE CONTROL SYSTEMS STUDIED IN THIS PAPER

### A. Pulse width modulation method

In this method, control system Pulse Width VSC inverter circuit is shown in Figure 2.

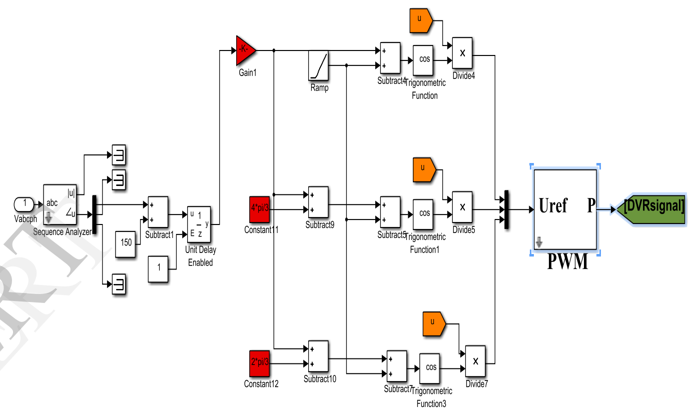


Figure 2. Pulse width modulation control system, VSC inverter circuit

### B. Space vector modulation method

In this method, there is a minimum toggling frequency shown in Fig. 3 and Fig. 4 as the vector switching gate and toggling state, respectively. The target of SVPWM control circuit is to reach reference voltage vector (Uref) through a combination of switching state.

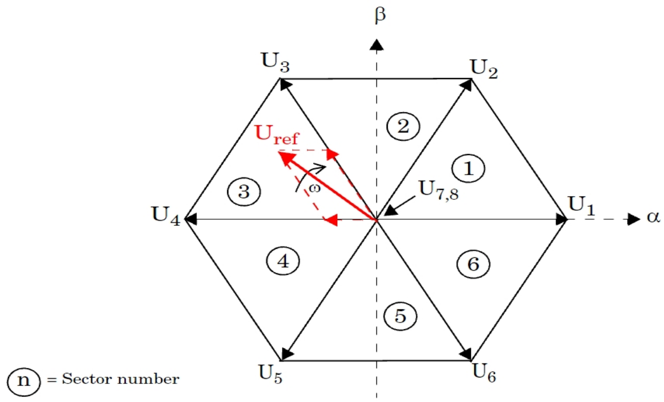


Figure 3. Vector switching Gates


Figure 4. switching mode

Space vector pulse width modulation method, the VSC inverter circuit is shown in Figure 5.

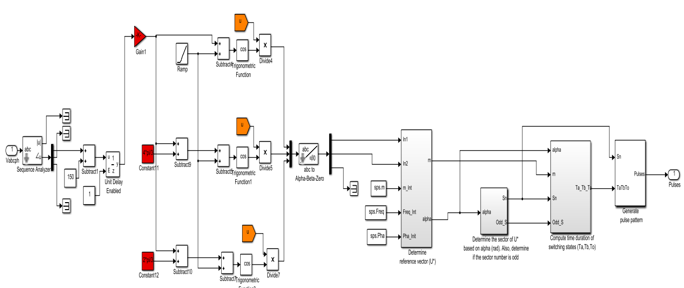

Figure 5. Systems, space vector pulse width modulation control circuit inverter VSC

## IV. DVR simulation based on SPWM and SVPWM

Evaluation of the studied system at two SPWM and SVPWM control modes are illustrated in Fig. 6-11. For time range of 0.3 to 0.6 sec, the three phase short connection error occurs in the system. The information of studied system is summarized in Table 1.

Figure 6. Load rms Voltage, short circuit in time 0.3 until 0.6 and without DVR

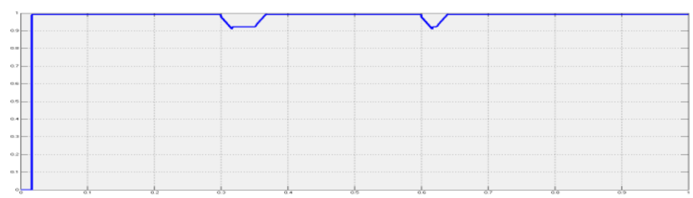

Figure 7. Load rms Voltage, short circuit in time 0.3 until 0.6 with DVR-PWM controller

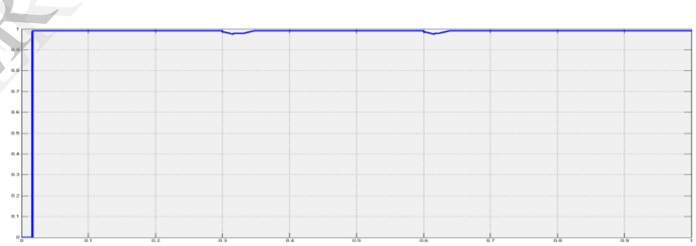

Figure 8. Load rms Voltage, short circuit in time 0.3 until 0.6 with DVR-SVPWM controller

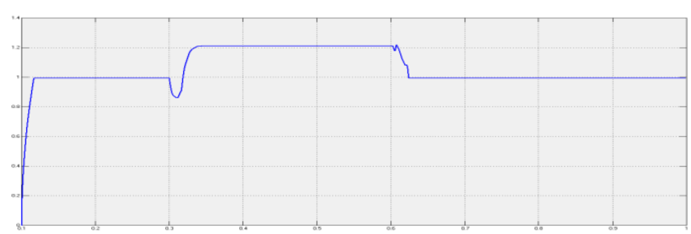

Figure 9. Load rms Voltage, Swell in time 0.3 until 0.6 without DVR

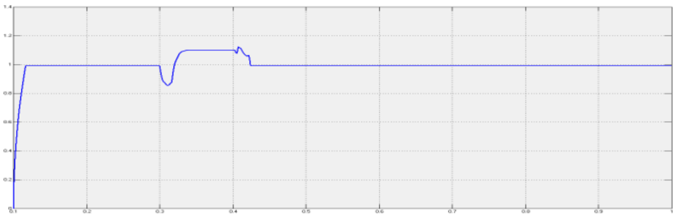

Figure 10. Load rms Voltage, Swell in time 0.3 until 0.6 with DVR-PWM controller

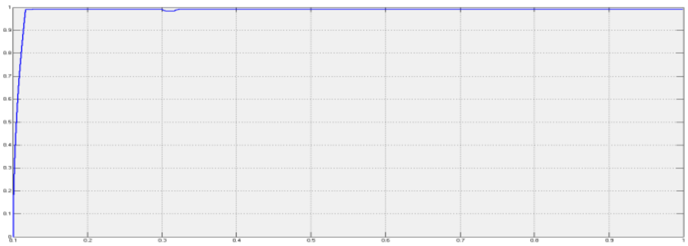

Figure 11. Load rms Voltage, Swell in time 0.3 until 0.6 with DVR-SVPWM controller

Table 1. The system parameters

| | |
|---|---|
| Vsource = 14.31Kv | Frequency = 50HZ |
| Fs = 20 khz | Fault resistances= 5Ω |
| Nominal power Transformer YΔΔ=100MW<br>Winding 1 parameters V1 =14.31Kv, R1(pu)= 0.01 , L1(pu)= 0.08<br>Winding 2 parameters V2 =115Kv , R2(pu)= 0.01 , L2(pu)= 0.08<br>Winding 3 parameters V3 =115Kv , R3(pu)= 0.02 , L3(pu)= 0.08 | |
| Two Transformer in two line<br>Nominal power Transformer $\Delta Yn$=100MW<br>Winding 1 parameters V1 =115Kv , R1(pu)= 0.01 , L1(pu)= 0.008<br>Winding 2 parameters V2 =11.2Kv, R2(pu)= 0.01 , L2(pu)= 0.008 | |
| Series Transformer<br>Nominal power Transformer =17MW<br>Winding 1 parameters V1 =11Kv , R1(pu)= 0.0002 , L1(pu)= 0.005<br>Winding 2 parameters V2 =11Kv, R2(pu)= 0.0002 , L2(pu)= 0.005 | |
| Vdc= 11000/1.73 | RS_Vdc_side=0.1Ω |

## V. CONCLUSION

This paper investigates electronic elements of power in energy transfer system and distribution systems, as well as their application for power quality improvement, which is among the demands of present subscribers. Moreover, performance of DVER against voltage shortage and swell were analyzed using the SPWM and SVPWM in MATLAB and the DVER performance results were compared for each modulation. For both voltage shortage and swell cases, SVPWM analyzes load voltage in a more effective manner as compared to SPWM. Another important subject studied of this work is the harmonics of voltage and current generated by DVR. In this work, not only the control modes of SPWM and SVPWM were studied, but also they were investigated at switching frequencies of 2,000 HZ, 6000 HZ, 10 KHZ, 20 KHZ, and 100 KHZ, which are ignorable considering the connecting transformer between DVR and power system.

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