Analysis of Voltage Sag & Swell Minimization Using DVR

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Abstract-- The power quality is one of the major concerns for industrial and distribution consumers. Here, a series active filter used for voltage sag & swell minimization with compensation power theory for a three-phase system with non-linear load. The simulation has been designed using SIMULINK SimPower toolbox. The control scheme provides better unbalance voltage compensation and voltage regulation for three phase systems with non-linear loads which operates in different conditions. The design and simulation of series active filter performance results were presented in this research to show effectiveness of controller. Simulation result shows the effectiveness of the DVR in mitigating voltage swell/sag during wide range of system disturbances.

Keywords— DVR (Dynamic Voltage Restoration), Matlab, Simulink, Powergui, Injected Voltage, Voltage Swell, Voltage Sag.

1. INTRODUCTION

In the modern world today, problems with power quality presents the primary concern for both consumers and businesses invested heavily on power. Power quality problems are mainly due to the power semiconductor devices, which presents a profound conundrum as the electronic controllers which are used in industries are very sensitive to voltage quality. Due to poor voltage quality, the harmonics of the system increases leading to poor power quality. The different power quality mitigation techniques like SVC, STATCOM, TCSC and UPQC comes under the FACTS controllers mainly designed for enhancing the power quality improvement and reliability.

Power quality is a set of limits or conditions of electrical properties that allow electrical devices to function in their planned manner without loss of performance. Without the proper power, an electrical utility may malfunction, fail permanently, or not operate well. There are many possible ways in which electric power can be of poor quality and many more causes or effects of such poor-quality power [1-4]. Configuration of UPQC needs two inverters side by side. UPQC solves the source current and load voltage imperfections. The structure of UPQC shown in Fig.1.1

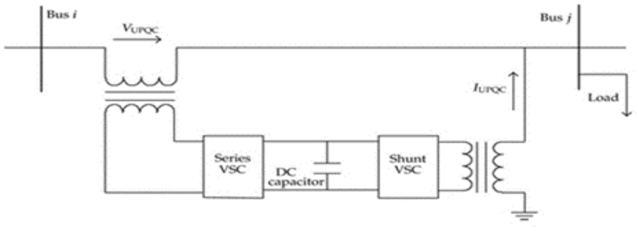


Fig. 1.1: Schematic diagram of UPQC [3]

The performance of an active filter is influenced by the DC-link capacitor voltage values. For the shunt active filter, DC link capacitor voltage rating must be greater than the line to the neutral voltage. For distortion free compensation, the DC link voltage required must be greater than or equal to 1.6 times the phase voltage. Similarly, for a better series compensation of voltages, the series active filters DC link voltage maintained at a value to the peak of line to line voltage [3-7]. In the case of UPQC, the capacitor value is not the same for both the shunt and series filters. The controller plays an important role in the performance of UPQC. Some of the control strategies mentioned in literature [6-10] which were used for UPQC are P-q-r theory, modified p-q theory, synchronous reference frame theory, unit vector template technique, etc. [10-15] In this paper, UPQC is mainly tested for the power quality improvement by a) reducing the THD's of source currents and load voltages b) power factor correction.

Voltage swell is always an uncertain fact for power system transmission and distribution. It is not only dependent on load nature or load switching but also sometimes be impacted by natural phenomenon (ex: thunder, raining, connecting with moistures trees) or facts also conduct with voltage swell issue. [15-20]

1.1 Motivation

Power quality issues lead to further increase in the use of DVR products in every field. Additionally, increased utilization of industrial electronics and power electronic devices, demand for improved reliability over distribution networks, and increasing number of research and development activities are some of the factors supporting the growth of the DVR market. Moreover, low cost maintenance enabled by DVR further enhances its likability for power management. The demand DVR comes from utilities and process industries that are continuously implementing computer-controlled and automated manufacturing processes for improving productivity and to stay competitive. Additionally, a rapidly growing semiconductor industry, which relies chiefly on regions such as Taiwan and China for semiconductor manufacture, is spurring the demand for dynamic voltage restorers in the region. Presently, these semiconductor companies are assigning considerable amount of funds to research and development activities with the ultimate aim of offering technically advanced products at reasonable prices to the end users.

The dynamic voltage restorer market is segmented by voltage level and end-user industries. DVR operates on two voltage levels as low and medium voltage levels. Multiple end-user industries served by DVR comprises of utilities mining industry, electronics (computer manufacturers and consumer electronics). Some of the major companies in the global market include: ABB Ltd., S&C Electric Company, Realtek semiconductors, and Hykon Power Electronics Private Ltd. among others.

1.2 Objectives

Objectives of this research are followings

1. Mathematical modelling of DVR to reduce voltage sag & swell in Simulink.

2. Analysis of voltage sag & swell minimization from simulated outputs.

2. POWER QUALITY IMPROVEMENT: CAUSES & EFFECTS

The term power quality embraces all the aspects associated with amplitude, phase and frequency of the voltage and current waveforms existing in the power circuit. Poor power quality may occur due to transient conditions in the power circuit or from the installation of non-linear loads. There is an increasing use of sensitive loads, such as computers, industrial drives, communications and medical equipment. These days, power quality is a more complex problem than in the past because the new loads are not only sensitive to power quality, but also responsible for adversely affecting the quality of power supply. Although, the distribution of power systems may have an impact on the quality of power, it becomes significantly worse at the points where the loads are connected to the distribution grid. A single customer may cause significant reductions in power quality for many other customers. Understanding power quality issues is a good starting point for solving any power quality problem.

2.1 Core terms of power quality improvements

Core terms and definitions that are used in association with power quality are:

- Voltage sag -Voltage sag is a decrease in RMS voltage at the power frequency for durations from 0.5 cycles to one minute. Voltage sags are caused by abrupt increases in loads like short circuits or faults, motors starting, or electric heaters turning on, or they're caused by abrupt increases in source impedance, typically caused by a loose connection. Voltage swells are nearly always caused by an abrupt reduction in load on a circuit with a poor or damaged transformer, although they'll even be caused by a damaged or loose neutral connection.
- Voltage swells – An oversupply of voltage from the power from 0.5 cycles to one minute. Switching off large loads, capacitor banks energizing, and transfer of loads from one power source to another cause voltage swells.
- Interruption –Loss of supply voltage in one or more phases for one minute or more than one minute.
- Transients – voltage disturbances shorter than sags or swells, which are caused by sudden changes in the power systems.
- Voltage unbalance –The voltages of a three-phase voltage source are not identical in magnitude or the phase differences between them are not 120 electrical degrees.
- Harmonics – Steady-state deviation within the voltage or current waveform from a perfect undulation, which are sinusoidal voltages or currents having frequencies that are whole multiples of the frequency at which the availability system is meant to control (50 Hz).
- Long duration voltage interruption – Complete loss of supply voltage within the RMS supply voltage at fundamental for period exceeding one minute.

3. SIMULATION AND ANALYSIS

Simulink provides a graphical editor, customizable block libraries, and solvers for modelling and simulating dynamic systems. It's integrated with MATLAB, enabling us to include MATLAB algorithms into models and export simulation results to MATLAB for further analysis.

Engineers everywhere use Simulink to induce their ideas off the bottom, including reducing fuel emissions, developing safety-critical autopilot software, and designing wireless LTE systems. We are going to now assess how Simulink can facilitate your complete your projects.

3.1 Power system analysis toolboxes

SIMULINK has a built-in power system analysis toolbox which enables us to simulate power system work, research and simulation. Further we can collect extra tools and also design own tool. Such as PSTOOL is an extra power system analysis toolbox.

3.2 Simscape Simpower toolbox

Simscape Simpower is a power system analysis toolbox build in SIMULINK. It consists of overall Power system tools such as Driver, Electronics, mechanics, Power systems, electrical source and interface, utilities etc.

3.3 Analysis

This chapter covers our successful output of MATLAB SIMULINK simulation with necessary curves and explanation. We have records and analysed grid voltage, injected voltage, load voltage etc. The simpower's powergui tool helps us to get FFT analysis data graphically. So, things are more accurate and easier to analysis.

3.4 Simulated Diagram

The simulated diagram of DVR with series active filter to minimize voltage swell is given bellow. Whole diagram is consisting of individual subsystem called model in SIMULINK.

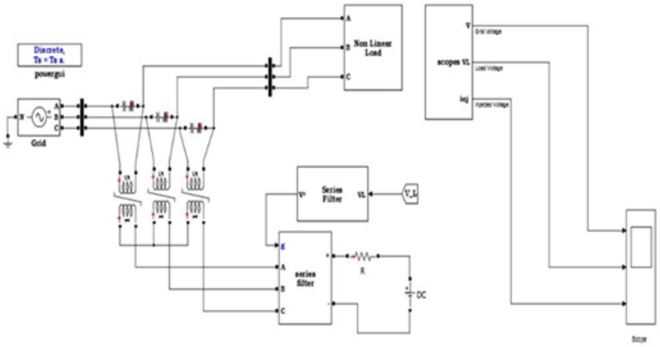


Fig. 3.1: Main diagram of simulation

In our main project diagram there is a three-phase programmable AC voltage source. There is 3 phase transmission line from. We have connected a measurement bus to measure input or grid voltage with waves. After that there is saturated bidirectional transformer. This transformer connected to series active filter. While there is swell it measured and series active filter make an equivalent injected voltage. As the transformer is bidirectional and connected to series, it injects equivalent voltage to keep load voltage stable. A measurement bus connected to the load end. This used to measure load side voltage. A non-linear RLC load is connected as load. Finally, all these things connected to oscilloscope to show grid, injected and load voltage.

3.5 FFT analysis

Powergui toolbox provide required data analysis such as simulation configuration of parameters we used, Steady state datum, linear time variant analysis, FFT analysis and so on. So here we use simpower's powergui for our data analysis. The powergui during simulation window seen in the figure given bellow,

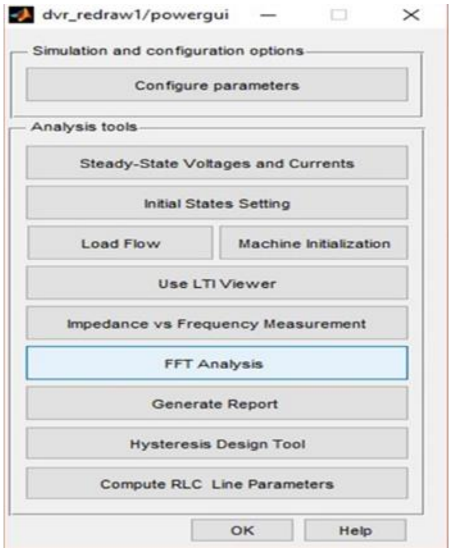
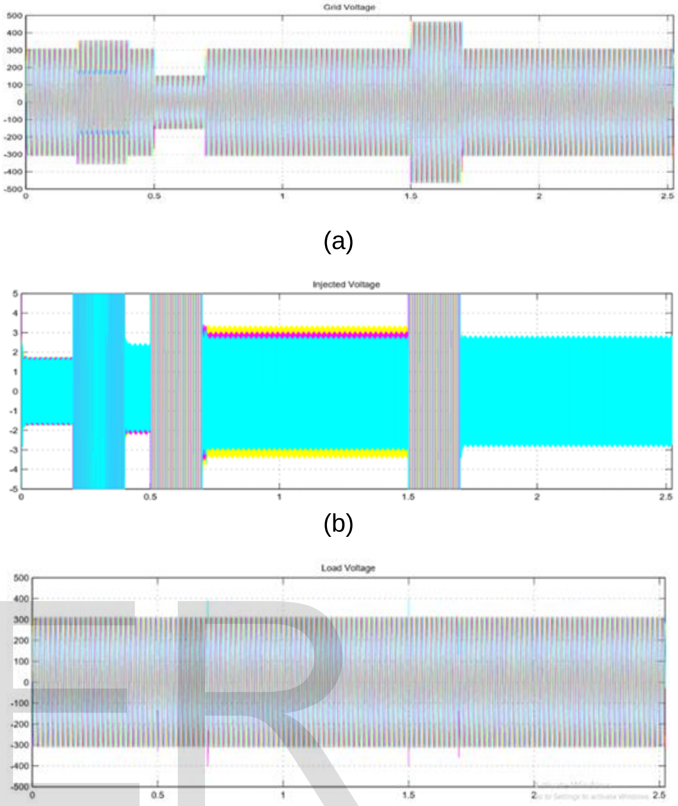


Fig. 3.2 Simpower's Powergui toolbox

3.6 Combined Output

To monitor output result from one window we used connected scope within same window. This shows combined output shapes of simulation. This helps us to compare grid voltage, injected voltage, and load voltage visually and mathematically.



(a)

(b)

(c)

Fig. 3.3: (a) Grid voltage (b) Injected Voltage (c) Load Voltage

3.7 Individual Analysis

Here we've are explaining each model of the simulation separately. In the first figure is a grid voltage figure which consists of swell and sag. So, the main job of this thesis to restore these sag & swell instantly by use of a filter circuit and restorer. In the second figure, there is injected voltage which is equivalent to sag or swell distortion in line. Finally, in the third figure we include restorer voltage. As demonstrated, the harmonics are Nil or Negligible in the load voltage values.

3.7.1 Grid voltage

Here we demonstrate three phase programmable voltage source used which will provide 310V per phase. Due to dynamic load behaviour, the voltage will fluctuate with time and load behaviour. For example, in an instant time we got 279.2V with high THD 19.02%.

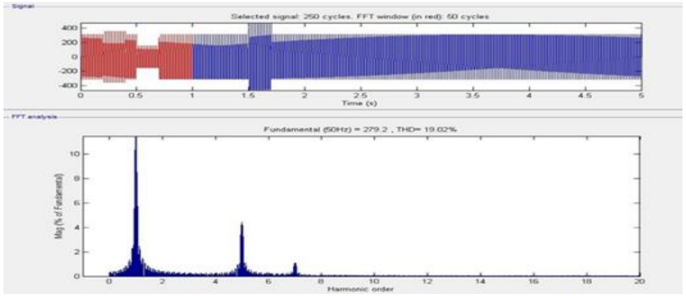


Fig. 3.4: Grid voltage output analysis

Figure 5.4 show FFT analysis of grid voltage. In first row is signal and second row is its FFT analysis of fundamental magnitude VS harmonic order.

3.7.2. Injected voltage

As per voltage swell occur series active filter, inject necessary voltage instantly to grid to load voltage. This allows it to meet the distortion of output. Here fundamental value of injected value is 30V in an instant of time. And injected voltage is highly harmonics as its makeup distortion in grid. There is no constant value from injected voltage. Here in FFT analysis %THD of injected voltage is 166.06%.

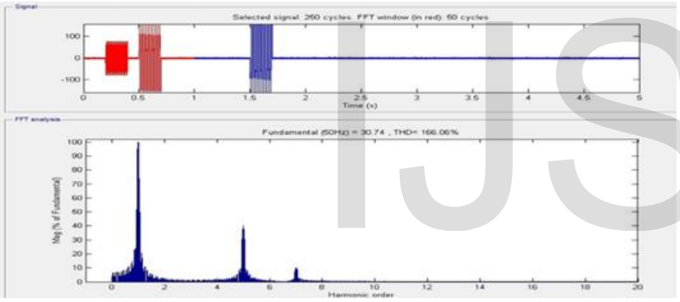


Fig. 3.5: Inject voltage FFT analysis

3.7.3. Load voltage

After filtering and minimizing voltage swell the load side voltage and harmonics are improved. Here is some output analysis of load voltage. In first figure fundamental frequency is 50HZ, load voltage is 310 and %THD is 0.78. However, THD is not practice here. It is instants analysis value. THD is slightly more in next figures.

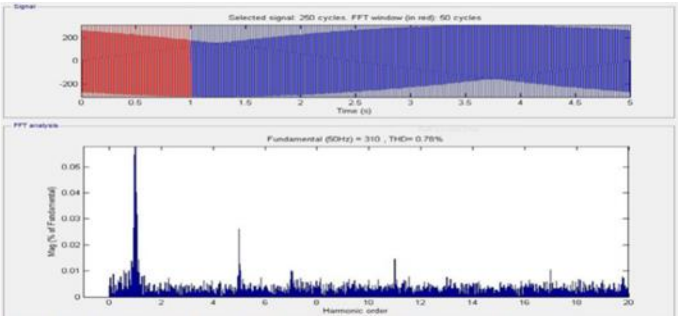


Fig. 3.6: Load side FFT analysis

In second analysis load voltage is 309.9V i.e. ~310V; fundamental frequency is same and %THD is here more practical 1.69%.

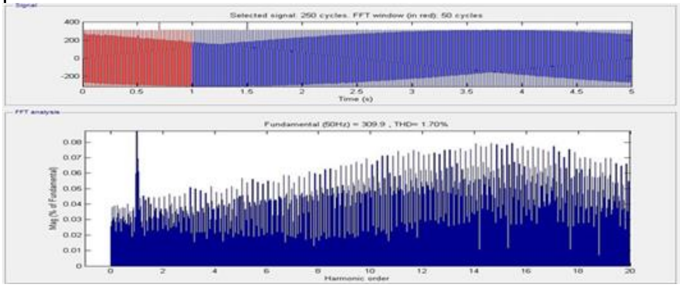
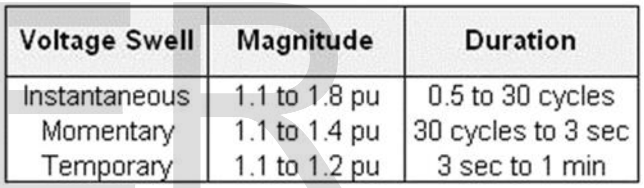


Fig. 3.7 Phase two FFT analysis of load voltage

3.8 Voltage swell minimization

A momentary increase within the power-frequency voltage delivered by the mains, outside of the traditional tolerances, with a duration of quite one cycle and fewer than some seconds. Voltage Swell is defined by IEEE 1159 because the increase within the RMS voltage level to 110% - 180% of nominal [17]. Voltage swells are characterized by their RMS magnitude and duration.

Table. 3.1 Nominal swell level [17]



Voltage Swell	Magnitude	Duration
Instantaneous	1.1 to 1.8 pu	0.5 to 30 cycles
Momentary	1.1 to 1.4 pu	30 cycles to 3 sec
Temporary	1.1 to 1.2 pu	3 sec to 1 min

Now are explaining voltage swell minimization from output figure analysis from Vabc, Iabc Input, V_L, I_L Output, Vinj and injected voltage after series active filter.

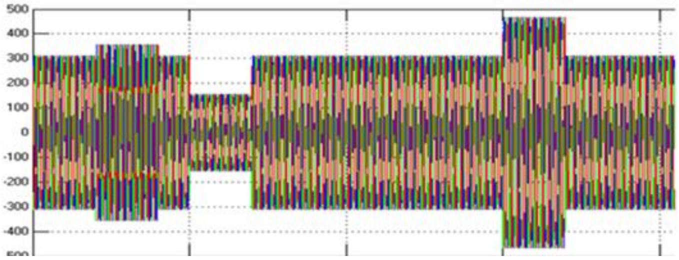


Fig 3.8 swell in input voltage

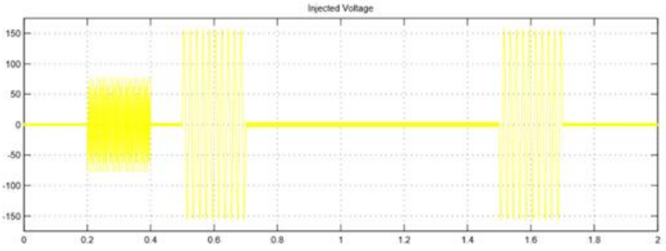


Fig 3.9: Injected voltage

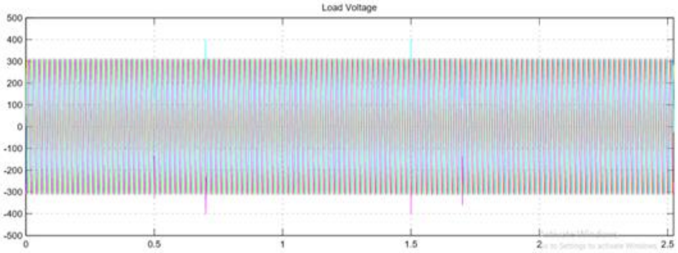


Fig 3.10: Load voltage

Table 3.2 Voltage swell log in input

No.	Time(s)	Voltage	Swell	Duration	remarks	Injected Voltage
1	0-0.23	310	0	-	-	
2	0.24-0.45	~350	40	0.21	-	40
3	0.46-0.5	310	0	-	-	
4	0.6-0.75	150	-	-	sag	
5	0.76-1.5	310	0	-	-	
6	1.6-1.76	460	150	0.16	-	150
7	1.77-3	310	0	-	-	

Total voltage swell in from 0 to 3s i.e., in 3s = (40+150) = 190V

So, total voltage swell in 1 sec is = (190/3) = 63.33V

Total swell duration for 63.33V = 0.37s in 3s

So, swell per second is = 0.123

So, swell per minute in second duration = 0.123*60= 7.38s

∴ Swell per minute in voltage ~467

Comparison:

- Grid voltage in an Instant time we got 279.2V
- Fundamental value of injected value is 30V in an instant of time.
- Finally load end voltage is lying 309~310V

4. CONCLUSION

In order to improve the power quality from energy generated by the photovoltaic systems connected to the network, this paper presents the results of two types of filters, the first one is the active power filter that comes with conventional control scheme and second one is active power filter that comes with selective control schemes that it can lessen the harmonic content put in by the inverter in a photovoltaic system. The results are shown and compared through harmonic distortion (individual and THD). This is a novel proposal, since studies before to this, always have been interested in the compensation of harmonics arising from non-linear loads but rarely from a voltage source, as in this case.

After analysing three outputs FFT analysis we've found improved results. In load side FFT analysis we found output voltage is approximately fixed at 310V and THD improved to ~1.70%. The results shown here reflect what we desired at the beginning of this research.

4.1 Limitation of Active filters

Limitations for active filters used in this thesis.

- Requires D.C power supply for their operation.
- Active filter can't handle large amount of power.
- It is only suitable for low or moderate frequencies.
- Susceptible to inter-modulation, oscillations.
- Susceptible to parasitic from DC output offset voltage and input bias currents
- Op-amp gain bandwidth constrained
- Op-amp slew rate constrained
- can require many components

5.2 Future works

Following advancements can be achieved by this research

- Advanced system for voltage swell minimization.
- Reducing complexity.
- Adding programmable blocks in simulation.
- Overall efficiency improvement.
- Extra-large load caused swell handling.

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