



Analysis of Fuzzy Based AC-AC Dynamic Voltage Restorer for Mitigation Sag

Kamatam. Mamatha

M-tech Student Scholar Department of Electrical & Electronics Engineering, Narasimha Reddy Engineering College, Telangana, India.

R. kumara swamy

Assistant Professor Department of Electrical & Electronics Engineering, Narasimha Reddy Engineering College, Telangana, India

Abstract—

A Dynamic Voltage Restorer (DVR) based on a matrix converter without energy storage devices is proposed to cope with voltage fluctuations. The ac/ac power converter takes energy from the grid during voltage sag/swell. By connecting the matrix converter's input terminals on the load side and injecting the compensation voltages on the supply-side, it is possible to hold a constant input voltage, resulting in an efficient solution for compensating deep voltage sags and swells. Different solutions have been developed to protect sensitive loads against such disturbances but the DVR is considered to be the most efficient and effective solution. Its appeal includes lower cost, smaller size and its dynamic response to the disturbance. This research described DVR principles and voltage restoration methods for balanced and/or unbalanced voltage sags and swells in a distribution system.

Index Terms— Dynamic Voltage Restorer (DVR); Single Phase Matrix Converter (SPMC)

I.INTRODUCTION

Modern power systems are complex networks where hundreds of generating stations and thousands of load centers are interconnected through long power transmission and distribution network. The main concern of consumers is the quality and reliability of power supplies at various load centers where they are located. Even though the power generation in most well developed countries is fairly reliable, the quality

of the supply is not entirely reliable. Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. Voltages in power distribution systems are commonly affected by disturbances. According to the Canadian Electric Associate (CEA) and the Electric Power Research Institute (EPRI), among various power quality problems the majority of events are associated with either a voltage sag or a voltage swell [1-2]. Such events are a common reason for failures in production plants, sensitive loads malfunctions, and economic losses [3]. Many solutions to these problems have been published in recent years. The existing methods include tap changers, FACTS devices such as the distribution STATCOM (D-STATCOM), the Unified Power Quality Controller (UPQC), and the Dynamic Voltage Restorer (DVR) [4-7].

The series compensation device DVR was introduced for voltage sag mitigation and has been adopted as a common solution to the problem.

The DVR's operating principle is to inject the "missing" voltage in series with the supply in order to maintain an undisturbed load voltage, Fig. 1. Since the first DVR introduced in 1994, several topologies have been developed, along with different control methods and with harmonic compensation purposes [8-9]. Most of the DVR topologies presented in the literature [10] can be classified within two categories: (i)

using stored energy (batteries, capacitors, flywheel, etc.) to supply the delivered power and, (ii) having no significant internal energy storage. In the latter case, the energy is taken from the faulted grid supply. These topologies share one same specific characteristic: the dc-link. In order to eliminate the drawbacks imposed by the use of dc-link passive elements some researchers have focused their efforts to the topologies based on ac/ac power converters, which results in reduced maintenance requirements and improved power density [11-13]. DVR topologies with energy storage are highly favored to compensate deep level voltage sags in sensitive loads within a wide power factor range. However, this type of systems has significant drawbacks regarding complexity and overall cost (energy storage and power converter).

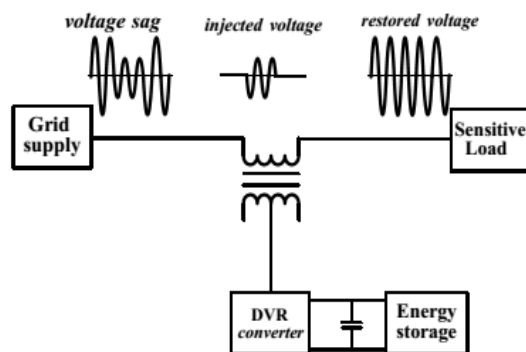


Fig.1. Principle of operation of the dynamic Voltage Restorer

Among the existing DVR topologies with energy storage in ac form, various different types of switching power converters have been employed, being the matrix converter an attractive solution due to its operative advantages.

The advantages of these FACTS devices are their excellent in dynamic capability on mitigating disturbance. However these sag mitigation devices are based on inverter systems which consist of energy storage and power switches, this energy storage is well known for its short lifespan and its high cost.

II. DYNAMIC VOLTAGE RESTORER (DVR)

Dynamic voltage restorer (DVR) is a power device connected in series to preserve the sensitive load when there is disturbance occurs at the point of common coupling (PCC). The typical DVR consisted of injection transformer connected in series with the distribution grid, a voltage sourced inverter connected to the secondary side of the injection transformer, passive filter and an energy storage device connected across the dc-link of the inverter circuit [3]. Fig. 2 describe the overall block diagram for a typical DVR system while a schematic diagram showing the DVR topology in a distribution network is shown in Fig. 3 The main function of DVR is to inject a voltage with the required magnitude, phase angle and frequency in series with the grid to maintain the desired load voltage when there is disturbance occur to the system. Although the main function of the DVR is to mitigate the sag and swell, additional function such as harmonic mitigation can also be applied to the device[4] Past researches on DVR are basically focused on using an inverter where it converts the supply from DC to AC and usually a DC link or energy storage is needed. In [5] a three phase DVR system has been presented utilizing direct ACAC conversion. However this paper used d-q-o transformation or Park's transformation which can only be applied in a three phase system. In [4] matrix converter has been introduced as a direct AC-AC converter. However it required additional switches since it presented a fictitious dc link. There are some papers discussed on the use of AC/DC/AC converter [6]. Due to its considerably large number of switching problem, new switching control strategy need to be investigated. There are fewer researches have been published on single phase direct AC-AC converter towards mitigating voltage sag and less used matrix converter as the AC-AC converter. However, a new topology for dynamic voltage restores without dc link has been investigated in [7], [4]. In [8] the energy storage is eliminating by replacing with the SPMC, however the switching control uses SVPM which is difficult

to control. A SPMC which converts AC to AC with no DC link has been introduced in[9], though it use direct AC converter in the DVR system, it require additional switch after the passive filter. There is also a need to investigate on a strategic control topology to be employed in the proposed dynamic voltage restoration scheme. Various types of control topologies are used in the various dynamic voltage restoration techniques [10, 11].

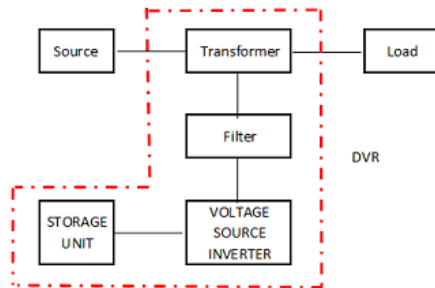


Fig. 2 the Block Diagram of Conventional DVR

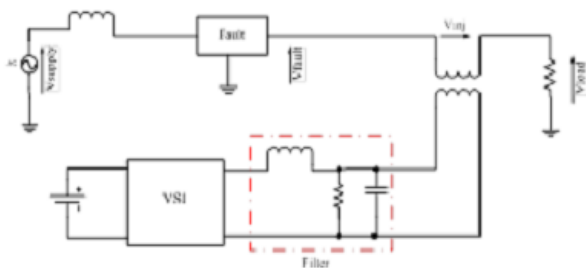


Fig. 3 Conventional DVR

III. DEVELOPED TOPOLOGY

Based from the existing DVR topologies, the main parts of the DVR are the voltage source converter (VSC) and the controller method. This paper proposes a single phase matrix converter (SPMC) topology as a direct AC-AC converter to eliminate the dc link or energy storage used in a typical DVR system. DC link or energy storage is well known for its high cost and short lifespan. Since the DC link is the most expensive part and therefore many researches tried to eliminate the use of this energy storage element [12]. SPMC is used to replace the voltage source inverter since the SPMC is well known for its capabilities in

producing different waveforms using different switching techniques.

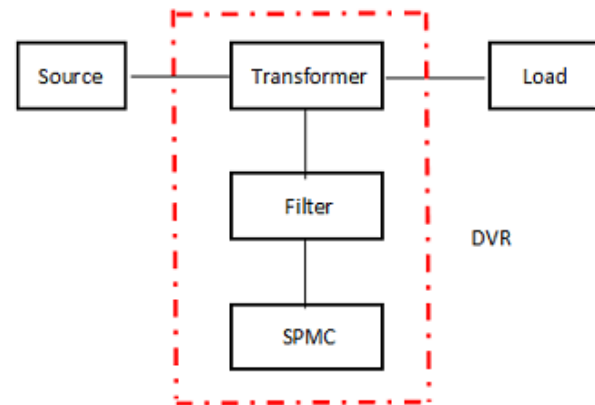


Fig. 4 Proposed Block Diagram of DVR

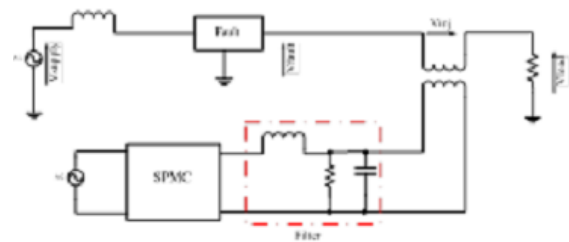


Fig. 5 Proposed Block Diagram of DVR

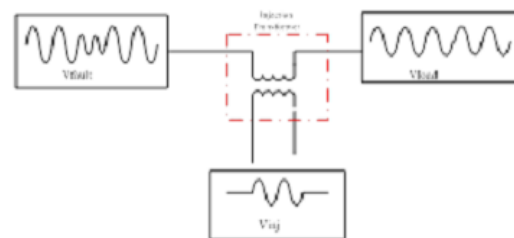


Fig. 6 Basic DVR topologies

By applying Kirchhoff's voltage law, the system equation for Fig. 6 is obtained as follows:

$$V_L(t) = V_F(t) + V_I(t) \quad (1)$$

Where $V_L(t)$ denote the nominal load voltage, $V_F(t)$ for the fault voltage, and $V_I(t)$ for the inject voltage. Assuming pure sinusoidal waveforms for $V_L(t)$, $V_F(t)$, and $V_I(t)$, the following equations can be written;

$$V_L = V_L \sin(\omega t) \quad (2)$$

$$V_F = V_F \sin(\omega t) \quad (3)$$

$$V_I = V_I \sin(\omega t + \theta) \quad (4)$$

Where $V_L(t)$, $V_F(t)$, $V_I(t)$ denotes the peak values of the load, fault/supply and the injected voltage respectively.

IV.DVR with Matrix Converter

Dynamic voltage restorer (DVR) is a power-electronic converter based device capable of protecting sensitive loads from all supply-side disturbances [5]. DVR can be assumed as an external voltage source with controllable amplitude, frequency and phase connected in series with distribution feeder, through a coupling transformer. Conventional DVR uses bulky and costly electrolytic capacitors at dc-link. This results increase in systems size, weight, cost and losses and also large input and output filters are necessary for harmonic reduction. In these DVRs, one-directional power transfer has to be carried out only. To overcome the disadvantages of traditional DVR a new ac/ac converter (Matrix Converter) based DVR is introduced to compensate both voltage sag and swell [9]. This converter has the ability of ac-ac conversion with no dc link to eliminate the energy storing element. The system is mainly composed of a source, injection transformer, bypass switch, low pass filter, matrix converter and an output load. During normal operating condition, the bypass switch is in closed position and input voltage is transferred to the load. When any abnormal condition arises, matrix converter switches are turned on and provide required compensating voltage at the output. At this time the bypass switch is in off position. The output of the converter is filtered and it is injected in series with the line through a transformer. This injected voltage is added up with the sag voltage and full output is obtained at the load.

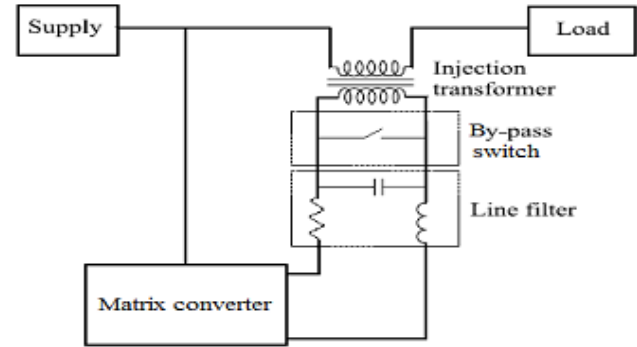


Fig. 7: Schematic diagram of DVR with matrix converter [5]

In equation (1) L , G and inj subscripts are the load, grid, and injected quantities respectively. Also, subscript k refers to the number of phases and its value is 1, 2 and 3. During voltage swell condition, a negative voltage is injected to the line. A Least Mean Square Error method [7], [10], is used to control the switching operation of matrix converter. It can compensate voltage sag, swell and flicker, because it uses bidirectional switches. There are two possible configuration ways of building the bi-directional switch; one consisting of a transistor embedded in a diode bridge arrangement while the alternative configuration consists of two anti paralleled transistors and anti-parallel diodes. The later configuration can be implemented as either a Common Emitter (CE) or a Common Collector (CC). Here Common Emitter arrangement of switch is used [11].

V.DVR CONTROLLER DESIGN

Single Phase Matrix Converter (SPMC) topology is used in the voltage source converter part in the basic DVR system. Fig.8 shows the basic SPMC connection with a single phase supply voltage connected to the IGBT which is arranged in 2x2 matrix form. The bidirectional IGBTs is used as the main switching devices with common collector bidirectional connection. This connection provides voltage blocking and current flowing through both directions. The IGBT is chose because of its well-known high speed

switching capabilities and high current carrying capacities amongst researches for high-power applications [13]. Several strategies have been proposed on commutation problem which can be classified current-controlled commutation and voltage-controlled commutation [3]. In this paper the SPMC topology are used to operate as the AC-AC converter using sinusoidal pulse width modulation (SPWM) as the switching methods. A high triangular frequency as a carrier, V_c , is compared with a sinusoidal waveform V_{ref} . The crossover points are used to determine the switching instants in Fig.9 [14]. Since the SPMC topology used in this system is 50Hz input and in order to have a 50Hz output, the switching operation for switch S1a to S4b are shown in Table 1. Note that, during the positive half cycle of the grid voltage, switches S1a and S2a are enable and switch S4a is driven by SPWM. During negative half cycle, S1b, S2b are ON, while S4b are driven by SPWM. The output from the SPMC is based from the switching pulse of the IGBT and will be fed to the injecting transformer and thus will compensate the voltage drop at the load side.

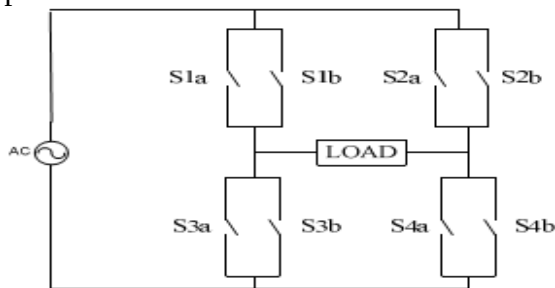


Fig.8. Basic Single Phase Matrix Converter

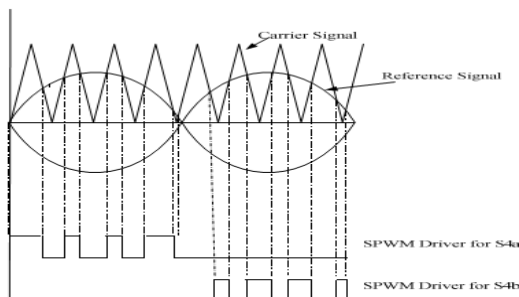


Fig.9 SPWM Signal Generations

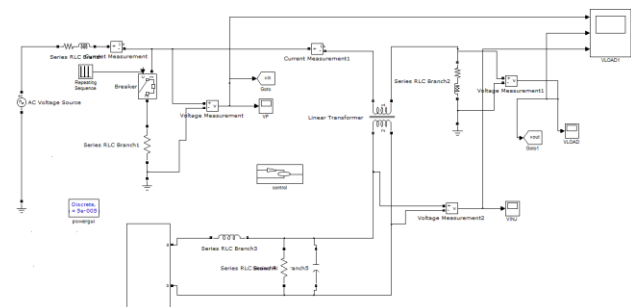
Table 1 Switching Operation

Operation		
Switches	Positive Cycle	Negative Cycle
S1a	ON	OFF
S1b	OFF	ON
S2a	ON	OFF
S2b	OFF	ON
S3a	OFF	OFF
S3b	OFF	OFF
S4a	SPWM	OFF
S4b	OFF	SPWM

VI. MATLAB/SIMULINK RESULTS

Here simulation is carried out in several cases, in that 1) Compensation of Voltage Sag for Proposed Single Phase Matrix Converter Based DVR, 2). Compensation of Voltage Swell for Proposed Single Phase Matrix Converter Based DVR.

Case 1: Compensation of Voltage Sag for Proposed Single Phase Matrix Converter Based DVR



(a) With DVR

Fig.10 Matlab/Simulink Model of Proposed Single Phase Matrix Converter Based DVR for Voltage Sag Compensation.

Fig.10 shows the Matlab/Simulink Model of Proposed Single Phase Matrix Converter Based DVR for Voltage Sag Compensation using Matlab/Simulink platform.

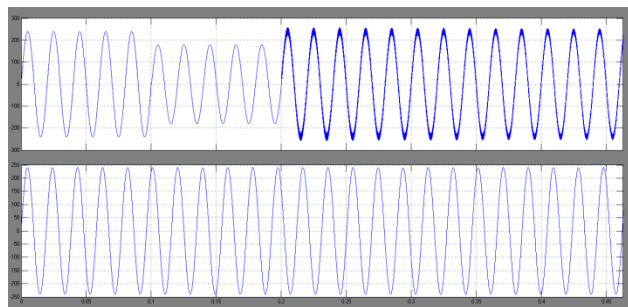


Fig.11 Source Side & Load Side Voltages

Fig.11 shows the Source Side & Load Side Voltages of Proposed Single Phase Matrix Converter Based DVR for Voltage Sag Compensation.

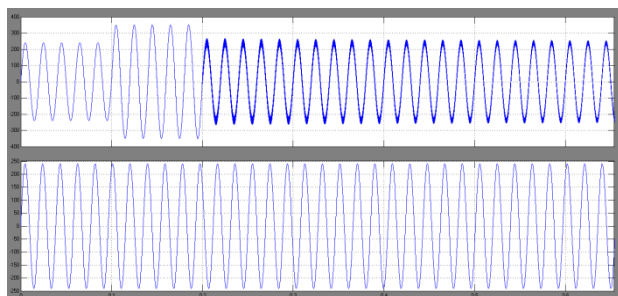


Fig.12 Source Side & Load Side Voltages

Fig.12 shows the Source Side & Load Side Voltages of Proposed Single Phase Matrix Converter Based DVR for Voltage Swell Compensation.

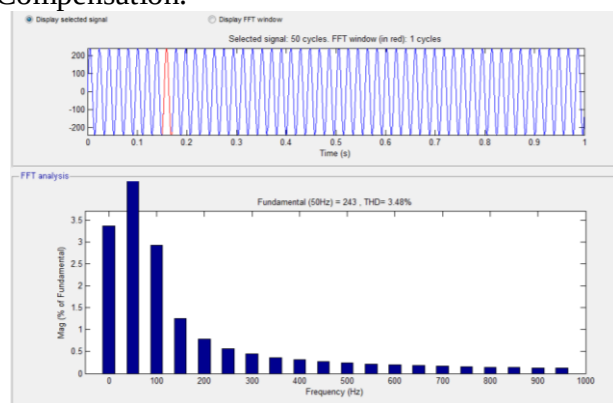


Fig.13 shows the THD analysis of voltage sag condition using PI controller

Case 2: Compensation of Voltage Swell for Proposed Single Phase Matrix Converter Based DVR using fuzzy controller

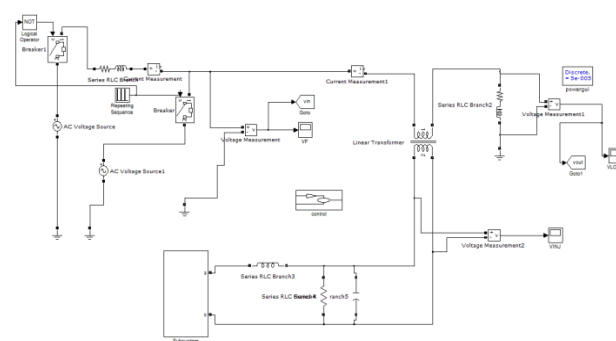


Fig.14 Matlab/Simulink Model of Proposed Single Phase Matrix Converter Based DVR for Voltage Sag Compensation

Fig.14 shows the Matlab/Simulink Model of Proposed Single Phase Matrix Converter Based DVR for Voltage Sag Compensation using Matlab/Simulink platform.

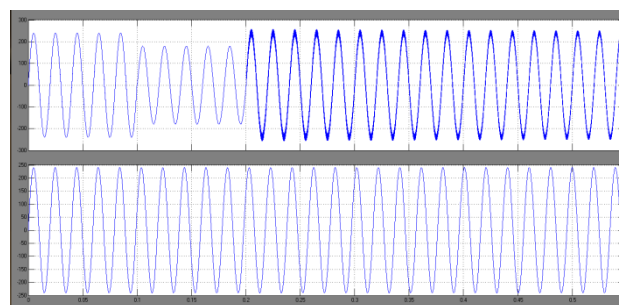


Fig.15 Source Side & Load Side Voltages

Fig.15 shows the Source Side & Load Side Voltages of Proposed Single Phase Matrix Converter Based DVR for Voltage Sag Compensation.

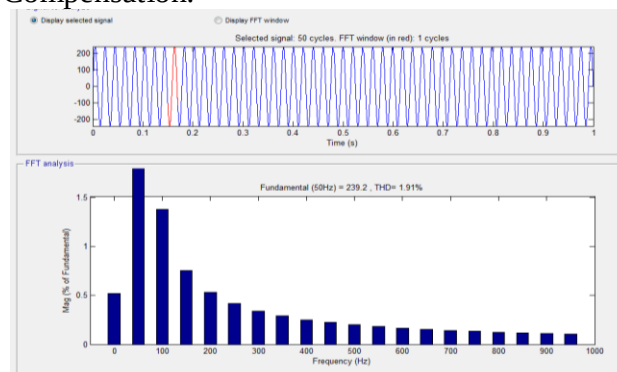


Fig.16 shows the THD analysis of voltage sag condition using fuzzy controller



VII.CONCLUSION

Performance of a DVR in mitigating voltage sags/swells is demonstrated. The DVR handles both sag/swell problem situations without any difficulties and injects the appropriate voltage component to correct any anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value. The results are obtained and compared by using PI and fuzzy controllers. A modeling and simulation was done using MATLAB/Simulink to observe the SPMC capability to operate as an AC-AC converter in the DVR system. The matrix converter used Sinusoidal Pulse Width Modulation (SPWM) as the switching technique and a PID to synthesis the output signal. PID is installed to reduce the harmonic distortion and thus attain a better result. Based from the simulation result achieved, it is proven that the SPMC is capable in producing the desired output voltage via injecting transformer to the load.

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