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Reduction of Power Quality Issues in Micro-Grid Using Fuzzy Logic Based DVR

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Abstract
Power quality is one of major issues in the present world. It has become relevant, especially, with the addition of sophisticated devices, whose performance is very sensitive to the quality of power supply. Power quality issue is an occurrence noted as a nonstandard voltage, current or frequency that may results in a failure of end use devices. One of the major issue dealt here is the power sag & swell. In this paper, we present a novel methodology for the prevention of voltage sag & swell. To solve this issue, custom power devices are adopted. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. Its advantages include lower cost, smaller size, and its fast dynamic response to the disturbance. This paper presents modeling, analysis and simulation of a Dynamic Voltage Restorer (DVR) using MATLAB. In this model, a PI controller and Fuzzy logic controller is used for comparison. In the proposed method, Fuzzy logic controller implemented is replaced by the conventional PID controller to develop the performance of the system. The function of the controller is made faster than conventional technique based controller. By MATLAB simulation tool, the performance can be studied.

Keywords: Power Quality, DVR, Fuzzy Logic Controller

INTRODUCTION

At present, latest industrial equipment is normally operating on power electronic devices like programmable logic controllers and adjustable speed drives. The electronic devices are mainly responsible to disturbances and hence less tolerable to power quality issues like voltage sags, swells and harmonics. The important severe disturbances to the industrial equipment are voltage dips [13].

DVRs usually are a type of custom power equipment for giving consistent distribution power quality. They utilize a series of voltage boost technology with solid state switches for voltage sags/swells compensation [12]. The DVR are most commonly used for sensitive loads that may be largely affected by system voltage fluctuations.

Different power quality issues like sags, swells, harmonics etc.., voltage sags are the most affected severe disturbances. Using the custom power devices, these problems can be rectified. DVR is the most efficient and effective latest custom power device utilized in power distribution networks [10]. It is the newly proposed series connected solid state device which injects voltage into the system for controlling the load side voltage. It is normally equipped in a distribution system in between the utility and the critical load feeder at the point of common coupling.

DVR works with PI Controller and Fuzzy Logic Controllers to enhance the system performance. The main idea of the above model is to increase the power quality of the system during different types of faults like three phase fault, single line to ground fault and double line to ground fault points are to be pointed out in this paper.

BASIC CONFIGURATION OF DVR

The basic configuration of the DVR comprises of the following main units.

1. An Injection/ Booster transformer
2. A Harmonic filter
3. Storage Devices
4. A Voltage Source Converter
5. DC charging circuit
6. A Control and Protection system

➢ Injection/ Booster Transformer

The Injection / Booster transformer is usually designed transformer that tries to limit the coupling of noise and transient voltage from the primary side to the secondary side [1, 5]. Its main tasks are given below.

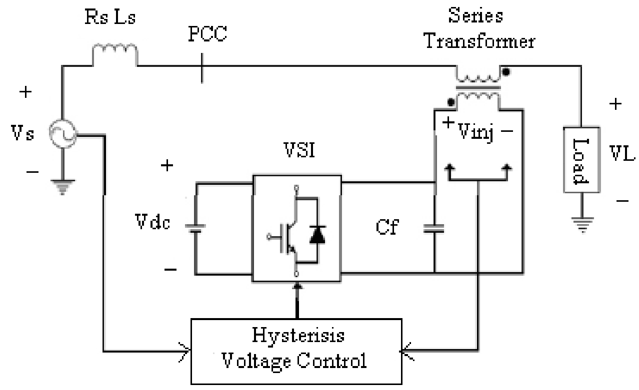

Figure 1 Schematic Diagram of DVR.

1. It links the DVR to the distribution network utilizing the HV- winding of the transformer and couples the injected compensating voltages developed by the voltage source converters to the supply incoming voltage.
2. Also, the Injection/Booster transformer helps in isolating the load from the system (VSC and control mechanism).

➢ **Voltage Source Converter**

A VSC is a power electronic converter comprises of a storage device and switching equipment, which can give a sinusoidal voltage at any important frequency, magnitude and phase angle. In the DVR uses, the VSC is utilized to briefly replacing the supply voltage or to develop the part of the supply voltage which is missing [11].

The main intention of the storage devices is to give the necessary energy to the VSC using a DC Link for the production of injected voltages. The different types of energy storage devices are superconductive magnetic energy storage (SMES) [6,8], batteries and capacitance [2].

➢ **DC Charging Circuit**

The dc charging circuit has two main jobs.

1. The first job is to charge the energy source after a sag compensation procedure.
2. The second task is to keep DC Link voltage at the nominal DC Link voltage.

EQUATIONS RELATED TO DVR

The load impedance Z_{th} depends on the fault level of the load bus. When the system voltage (V_{th}) drops, the DVR injects a series voltage V_{DVR} through the injection transformer, hence the desired load voltage magnitude V_L can be maintained. The series injected voltage of the DVR can be written as

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

V_L: The desired load voltage magnitude

Z_{th}: The load impedance

I_L: The load current

V_{th}: The system voltage during fault condition

The load current I_L is given by,

$$I_L=[P_L+jQ_L]/V_L \quad (2)$$

When V_L is considered as a reference equation can be rewritten as,

$$V_{DVR}\angle\alpha = V_L\angle 0 + I_L Z_{th}\angle(\theta-\beta) - V_{th}\angle\delta \quad (3)$$

α, β, δ are angles of V_{DVR}, Z_{th}, V_{th} respectively and θ is load power angle.

The complex power injection of the DVR can be written as,

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

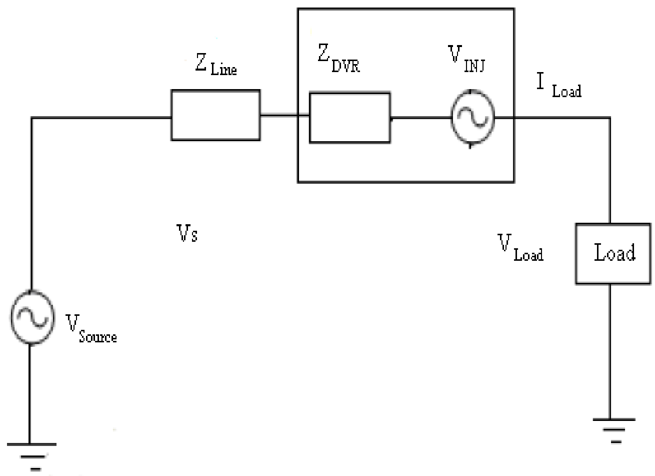

Figure. 2 Equivalent Circuit Diagram of DVR.

CONTROL STRATEGIES

There are different control techniques proposed for DVR like Voltage Space Vector PWM explained by Changjiang Zhan et al in [3 & 4]. Teke K. Bayindir et al [12] suggested the Fuzzy Logic Control. These reviews tell that the transient response of the FLC is better than that of PI Controller. A new method to estimate symmetrical components for controlling the DVR was proposed by Mostafa I. Marei et al [9].

H. Ezoji et al [7] suggested the use of DVR based on hysteresis voltage control. Hysteresis voltage control based on unipolar pulse width modulation has been utilized to control DVR. The hysteresis voltage control in terms of fast controllability and easy implementation hysteresis band voltage control has the largest rate among other control techniques.

➢ PI Controller

The important of the control technique is to limit constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only checks the root mean square (RMS) voltages at the load terminals, i.e., no reactive power measurements are needed. The VSC switching approach is based on a sinusoidal PWM method which suggests simplicity and good response. Since custom power is a comparatively low-power need, PWM techniques provides a better flexible alternative than the Fundamental Frequency Switching (FFS) techniques. Besides, high switching frequencies can be utilized to get better on the efficiency of the converter, without affecting considerable switching losses.

The controller input is an error signal obtained from the reference voltage and the RMS value at the terminal voltage measured. Such an error is controlled by a PI Controller, the output angle is δ, which is given to the PWM signal generator. An error signal is developed by comparing the reference voltage with the RMS voltage measured at the load point [12]. The PI Controller controls the error signal, then generates the required angle to drive the error to zero, i.e., the load RMS voltage is brought back to the reference voltage.

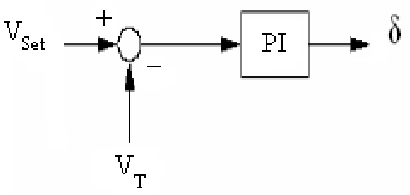

Figure. 3 PI Controller.

➢ Hysteresis Voltage Control

Hysteresis voltage control is utilized to get better the load voltage and divert switching signals for inverters gates. An important need of the hysteresis voltage control is based on an error signal between an injection voltage (V_{inj}) and a reference voltage of DVR (V_{ref}) which develops appropriate control signals [7]. There is a Hysteresis Band (HB) above and under the reference voltage. When the difference between the reference and inverter voltage reaches to the upper/ lower limit, the voltage is forced to decrease/increase as shown in Fig.4.

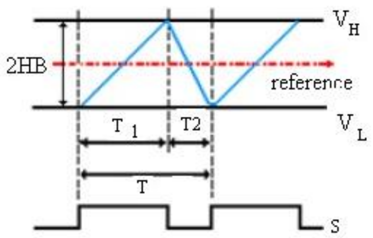

Figure. 4 Hysteresis Band Voltage Control.

➢ Fuzzy Logic Controller

The fuzzy logic controller for the proposed DVR has two real time inputs measured at every sampling instant, named error and error rate and one output defined as actuating-signal for each of the phases. The input signals are fuzzified and represented in fuzzy set notations by membership functions. The defined 'if … then …' rules develop the linguistic variables and these variables are defuzzified into control signals for comparison with a carrier signal to generate PWM inverter gating pulses.

Fuzzy logic control comprises of three steps: fuzzification, decision- making and defuzzification. Fuzzification converts the non-fuzzy (numeric) input variable measurements into the fuzzy set (linguistic) variable that is a clearly defined boundary.

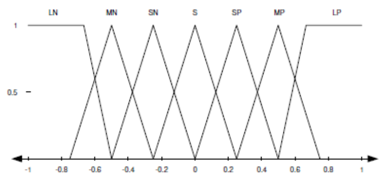

Figure.5 Membership function Input variable "Error"

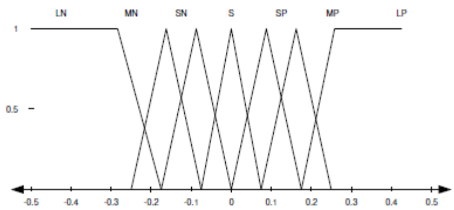

Figure. 6 Membership function Input variable "Error rate"

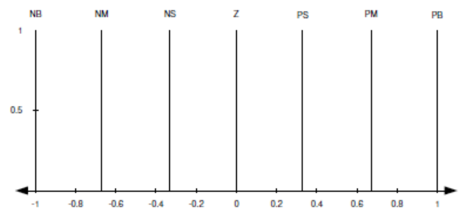

Figure.7 Membership function for output

In the proposed controller, the error and error rate are specified by linguistic variables such as large negative (LN), medium negative (MN), small negative (SN), small (S), small positive (SP), medium positive (MP) and large positive (LP) characterized by memberships. The memberships are curves that specifies how each point in the input space is mapped to a membership value between 0 and 1. The membership functions belonging to the other phases are identical.

Membership functions for the inputs are shown in Fig.5 and Fig.6. The membership function of output variable is shown in Fig.7.

Table 1 Decision table for fuzzy logic control

		Error Rate						
		LP	MP	SP	S	SN	MN	LN
Error	LP	PB	PB	PB	PM	PM	PS	Z
	MP	PB	PB	PM	PM	PS	Z	NS
	SP	PB	PM	PM	PS	Z	NS	NM
	S	PM	PM	PS	Z	NS	NM	NM
	SN	PM	PS	Z	NS	NM	NM	NB
	MN	PS	Z	NS	NM	NM	NB	NB
	LN	Z	NS	NM	NM	NB	NB	NB

There are 49 rules to carry out optimum control function and each rule points out the operating condition in the system as shown in Table 1. The person's experience and knowledge gained about the system behavior help to explain the rules. The correct combinations of these rules enhances the system performance. All rules are evaluated in parallel and the order of the rules is not defined. The decision table for fuzzy logic control rules is shown in Table 1.

SIMULATION OF DVR WITH PI CONTROLLER AND FUZZY LOGIC CONTROLLER

Matlab simulation has become an indispensable part of the power electronics design process. DVR is a custom power electronics device which comprises of voltage source converter as an important block. The overall design technique can be reduced through the use of computer simulations, since it is usually easier to study the influence of a parameter on the system behavior in simulation. Main system simulation model without DVR has been created in Matlab/Simulink as shown in Fig 8.

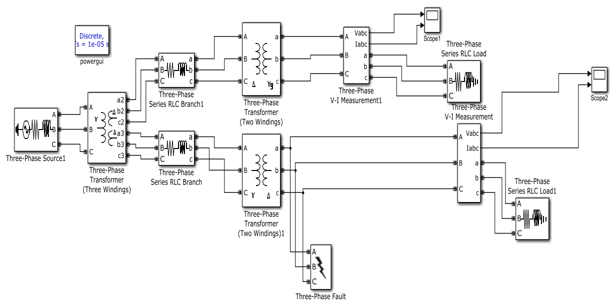

Figure. 8 Main System without DVR.

The test system considered here to carry out the simulations for DVR with Fuzzy Logic Controller is given Fig 9. Such system is composed by a 13 kV, 50 Hz generation system, feeding two transmission lines through a 3-winding transformer connected in Y/Δ/Δ, 13/115/115 kV. Such transmission lines feed two distribution networks through two transformers connected in Δ/Y, 15/11 kV.

To check the working of a DVR employed for voltage compensation a fault is applied at point X at resistance 0.66 Ω for time duration of 500 ms. The DVR is simulated to be in operation only for the duration of the fault. The capacity of the dc storage device is 5 kV.

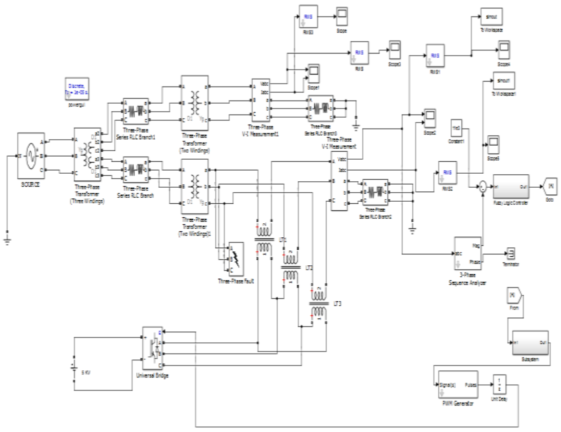

Figure. 9 Main diagram of DVR with Fuzzy Logic Controller.

SIMULATION RESULTS

The first simulation was done with no DVR and a three phase fault is applied to the system at point with fault resistance of 0.66 Ω for a time duration of 500 ms. The second simulation is carried out at the same scenario as above but a DVR is now introduced at the load side to compensate the voltage sag & swell occurred due to the three phase fault applied.

Figure 10 shows the rms voltage at load point when the system operates with no DVR and a three phase fault is applied to the system. When the Fuzzy Logic DVR is in operation, the voltage interruption is compensated almost completely and the rms voltage at the sensitive load point is maintained at normal condition and is shown in Figure 11.

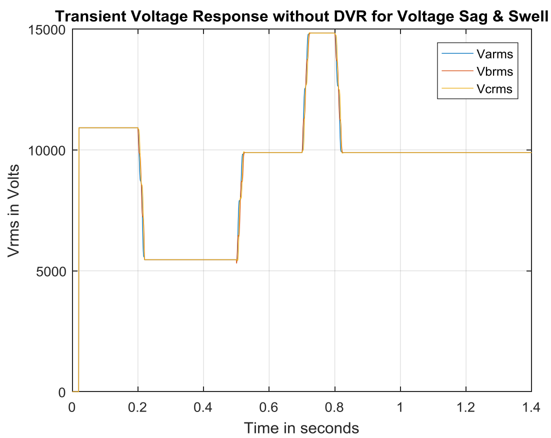

Figure. 10 Voltage VRMS at the load without DVR

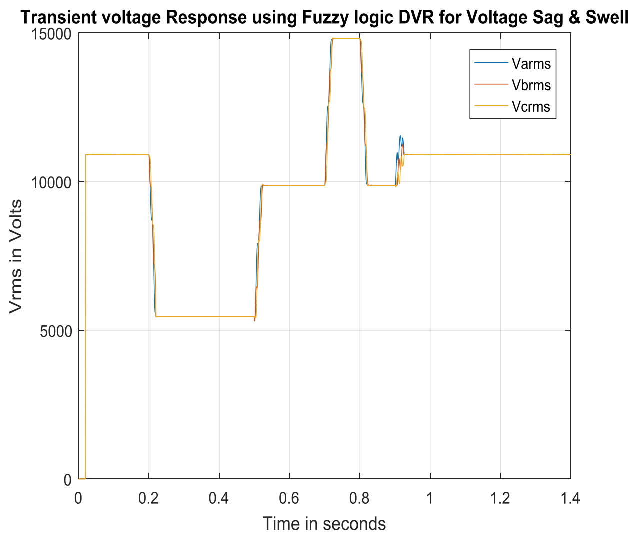

Figure. 11 Voltage VRMS at the load with Fuzzy logic DVR

SUMMARY

DVR is a recently proposed series connected solid state device that injects voltage into the system in order to maintain the load side voltage. It is normally equipped in a distribution system between the supply and the critical load feeder at the point of common coupling. Other than voltage sags and swells compensation, DVR can also added other features, those are line voltage harmonics compensation, reduction of transients in voltage and fault current limitations and then check the dynamic and steady-state performance of DVR. The results of voltage waveforms of DVR using Fuzzy Logic Controller with voltage sag & swell during three phase fault are analyzed. DVR with Fuzzy Logic Controller performs better among DVR with PI Controller.

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