Power Quality Improvement Using Dynamic Voltage Restorer

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Abstract— In this paper a FACTS device named, Dynamic Voltage Restorer (DVR) is used for power quality improvement by compensating the voltage sags is proposed. Power quality is an existence expressed as an unusual voltage, current or frequency which causes malfunctioning of equipment at the end. The voltage sag is the major cause for power quality distortion. The main concept of the DVR is to detect the voltage sag and inject the missing voltage in series to the bus with the help of an injection transformer. The DVR is the modern technique introduced in FACTS device for power system optimization. It is most efficient and cost effective devices available for maintaining the power quality. The control method implemented is hysteresis control because it has a quick response and can control voltages sag as well as other power quality problems like voltage swell and harmonics.

keywords: power quality; voltage sag; dynamic voltage restorer (dvr); hysteresis controller.

1. INTRODUCTION

In this paper, a FACTS device named Dynamic Voltage Restorer (DVR) is used for one of the power quality problems, that is, voltage sag based on voltage control technique. At present, electronics devices for example programmable logic controllers and electronic drives are mainly used in new industrial schemes. The interest in voltage sags is mainly due to the reason that it shares maximum percentages for the power quality problems and they cause problem on several types of equipment like adjustable-speed drives, process control equipment, and computers as they are notorious for their voltage sensitivity. The various method used to control voltages sags is transformer taps changers however adjusting the tap changer over load is expensive, DSTATCOM, SVC, etc. The Dynamic Voltage Restorer (DVR) is the recent FACTS device used in network of power distribution for most efficient and effective outcomes. It can also control active power flow. The topology of the used DVR is based on a dc capacitor supported DVR. The various mode of operation is also explained. The controller used will be hysteresis controller as it controls voltage sag as well as harmonics which can be considered as an additional benefit when compared with other controllers of DVR.

2. POWER QUALITY PROBLEMS

Any power quality problem results in voltage, current or frequency deviations which causes failure or disoperation of customer equipment. Power quality is eventually a consumer-driven concern and the user's end point is taken as reference. The power quality influence the direct economic of many industrial consumers. It can be reason for system crashes, equipment failure, scrambled data and interrupted communications etc. as modern devices like microprocessor-based load equipment are very much sensitive for a short disturbance also. The power quality problem are characterised as

a. Voltage Sags
b. Voltage Regulation
c. Flicker
d. Transients
e. Harmonic distortion.

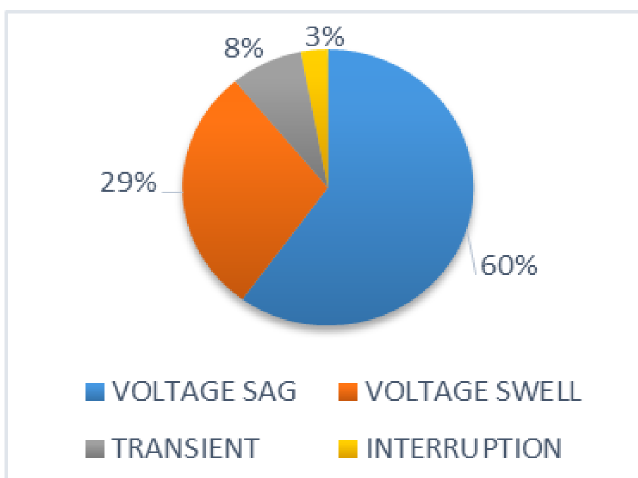

Fig 1. Percentages of power quality problems[3]

3. VOLTAGE SAG

As per IEC 60050, voltage sag as any sudden reduction of the voltage at a point in the electrical system, followed by voltage recovery after a short period of time, from half a cycle to a few seconds. [3]

As per IEEE 1159, voltage sag is a variation in the rms voltage of duration greater than ½ a cycle and less than 1 minute with a retained voltage of between 10 % and 90 % of nominal. [3]

The voltage sag can be characterized by during sag the magnitude of voltage persisted and sag duration.

It occurs when there is a large voltage drop in line or a very high current is drawn due to lighting, various faults and starting of a large motor.

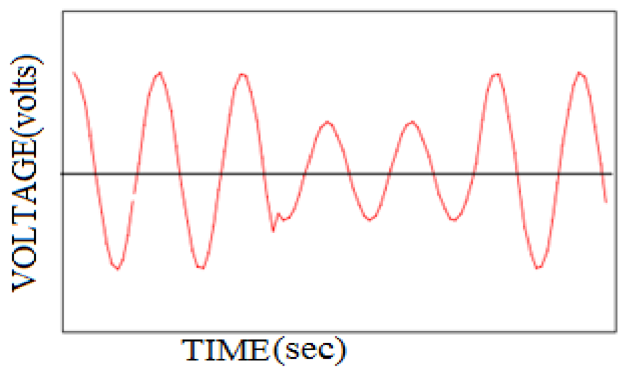

Fig. 2 Voltage sag- Reduced voltage for limited time period

4. CHARACTERIZATION AND MEASUREMENT OF VOLTAGE SAG

Voltage sag can measured by specialized power quality monitoring instrumentation. The instrumentation must be configured with a sag threshold voltage. That is, a voltage level that will a hang catch when the rms voltage falls underneath it. Voltage hangs are described by reporting the length of time for which the voltage variety persevered underneath the droop edge joined with the most extreme diminishment in rms voltage otherwise called profundity. The profundity is accounted for as the held voltage. The depth is reported as the retained voltage.

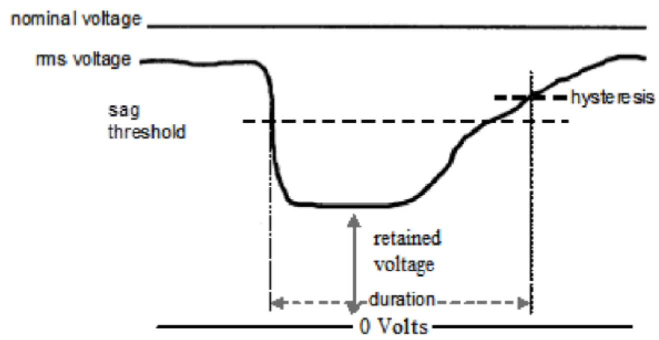

Fig. 3 Example of voltage sag

The graphical representation of a voltage sag including the sag threshold and the parameters such as duration and retained voltage used to report sag. The hysteresis value is used to prevent voltage levels which close to sag threshold crossing the threshold multiple times and triggering multiple sags which are basically due to same event.

5. CAUSES OF VOLTAGE SAG

The voltage sags occurred due to

i. The starting of motor, short circuit faults and energization of transformer will increase the current for short duration. It will create the voltage sag in system

ii. Rural location remote from power source.

iii. Unbalanced load on three phase system.

iv. Long distance from distribution transformer with interposed load.

v. Unreliable grid system.

vi. Equipment not suitable for local supply.

vii. When there is a large voltage drop in line or high current is drawn due to lighting various faults and starting of a large motor.

viii. The bad weather like thunderstorm and lighting also causes significant no of voltage sag.

6. EFFECT OF VOLTAGE SAG

The various effect of voltage sag are as follows

i. Voltage Sag can cost loss of million dollar by damaging the products, lost in production, restarting expenses and breakdown danger.

ii. In induction motor, the voltage sag causes loss in speed, torque and current peaks.

iii. Due to voltage sag there sudden fall of speed, rise of oscillating torque, loss in synchronism and over current rise.

iv. Today many equipment comprises power electronics circuits and it is very sensitive towards the voltage change. So voltage sag may cause damage to that equipment.

v. It may cause unwanted tripping of the equipment.

vi. The lamps get disrupted because of voltage sag. The low voltage bulbs will blink for few seconds which is not a serious problem but a high voltage bulb will switch-off and for reignite it will take few minute.

7. DYNAMIC VOLTAGE RESTORER

There are various approach to bound the effect of the voltage sag and one of the apppoarch is to connect the voltage source converter in series between the supply side and sensitive load, these devices is known as Dynamic voltage restorer.

Dynamic voltage restorer (DVR) is a series-connected flexible ac transmission systems (FACTS) controller used to compensate voltage sags and swells during abnormal conditions in distribution systems and have added feautre ,that is, reduction of transients in voltage, fault current limitations and line voltage harmonics compensation.

DVR is a newly introduced solid state device which is connected in series and for manitaining the load side voltage it injects voltage into the system.The DVR is based on a shunt rectifier fed series inverter through dc-to-dc step up converter. It is mostly placed at the distribution system in middle of the critical load feeder and the supply on the PCC (POINT OF COMMON COUPLING).

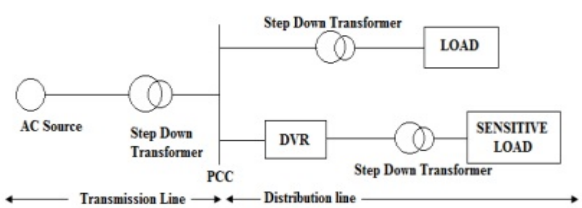

Fig. 3 Location of DVR

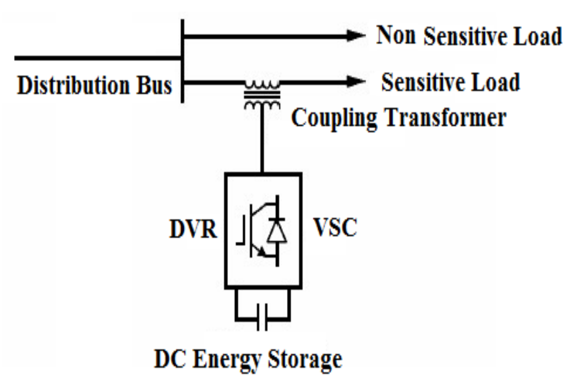

Fig. 4 Basic arrangement of DVR

8. EQUATION RELATED TO DVR

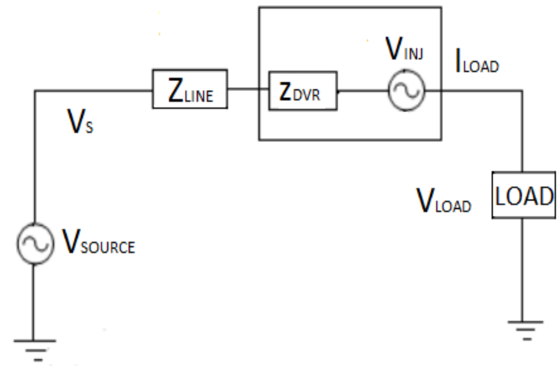

Fig. 5 Equivalent circuit diagram of DVR

The load bus fault level depends upon the system impedance Zth. For maintaining the load magnitude VL the DVR injects the series voltage VDVR via injection transformer when the system voltage Vth drops. The below equation represents the injected voltage.

$$VDVR = VL + ZTH\ IL - VTH$$

Where,

VL is the required load voltage magnitude

ZTH is the load impedance

IL is the load current

VTH is the system voltage at the fault

The load current IL can be calculated by

$$IL = (PL+j\ QL)/V$$

Considering VL is reference, the equation can be written as

$$VDVR\angle\alpha = VL\angle 0 + ZTH\angle(\beta-\theta) - VTH\angle\delta$$

Where,

α, β and δ are angles of VDVR , ZTH and VTH correspondingly.

θ is the load angle and it can be calculated by

$$\theta = \tan\text{^}(-1)[\theta_L/P_L]$$

DVR is proficient of generating the reactive power. The injection of reactive power is done by complex power injection of the DVR which can be written as

$$S_{DVR} = V_{DVR} I_L^{*}$$

9. CONTROL STRATEGY

The power electronic based system and other static equipment that regulate the one or more AC transmission parameters is know as controller. There are many controller like hystersis controller, proportional intergal (PI) controller, fuzzy logic controller , sinosiudal based PWM controller etc. which is used for DVR voltage control technique.

The fuzzy controller method used to generate a five level voltage at the converters output, to reduce the switching losses and to improve the behavior of DVR. The fuzzy controller has two inputs

1) The difference between the reference voltage and injected voltage.
2) The derivation of the error.

The fuzzy logic controller consists of three stages a) fuzzification b) rule execution c) defuzzification.

In the first stage, the crip variables e(k) are converted into fuzzy variable error E(k) and error rate dE(k). E(k) and dE(k)is divided into seven fuzzy sets ,that is, LP (large positive), MP (medium positive), SP (small positive), S (small), SN (small negative), MN (medium negative) and LN (large negative).

In the second stage of FLL, the fuzzy variables E and dE are processed by an inference engine that executes a set of control rules. There are 49 rule set for the control action to be perfomed by the fuzzy set. Here each rule set depicates operating condition as shown in table. The rules can be defined the data and familiarity of the system to a person. The performance of the system gets improved with the correct combination of the rule set. The control rules are formulated using the knowledge of the DVR behaviour. Different interfence algorthims can be used to used to produce fuzzy set valves for the output fuzzy variables PL (positive large), PM (positive medium), PS (positive small), Z (zero), NS (negative small), NM (negative medium) and NL (negative large).

The defuzzification stage convert the interfence engine output into crip value. The FLC method's outputs are the control signal that generates switching signal of PWM inverter by matching a carrier signals.

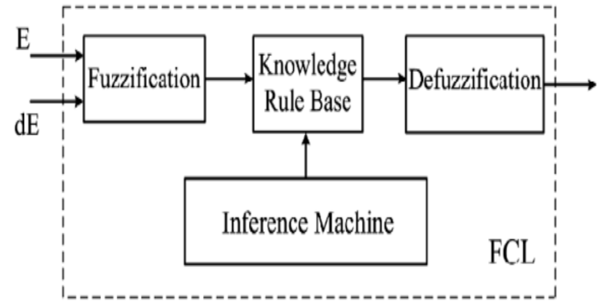

Fig. 6 Block diagram of fuzzy logic controller

		ERROR RATE						
		LP	MP	SP	S	SN	MN	LN
ERROR	LP	PL	PL	PL	PM	PM	PS	Z
	MP	PL	PL	PM	PM	PS	Z	NS
	SP	PL	PM	PM	PS	Z	NS	NM
	S	PM	PM	PS	Z	NS	NM	NM
	SN	PM	PS	Z	NS	NM	NM	NL
	MN	PS	Z	NS	NM	NM	NL	NL
	LN	Z	NS	NM	NM	NL	NL	NL

Table 1 Rule base of fuzzy logic voltage controller

The hystersis controller is used because it has variable frequency switching , working is simple , response is quick and can be used for harmonic control also when compared with other controller.

The load voltage is controlled by hystersis band voltage controller. It will also regulate the number of signals to be switched for inverter's switch. The reference voltage which is above and below point is know as hystersis band. The voltage is forced to decrease when the difference between reference voltage and inverter reaches the upper limit and vice versa.

The relationship used in this method is $T_C = T_1 + T_2 = 1/f_C$; where f_C is switching frequency

The hysteresis band (HB) can be stated as difference between highest voltage (V_H) and lowest voltage (V_L) i.e HB =(V_H - V_L). It is inversely proportional to switching frequency.

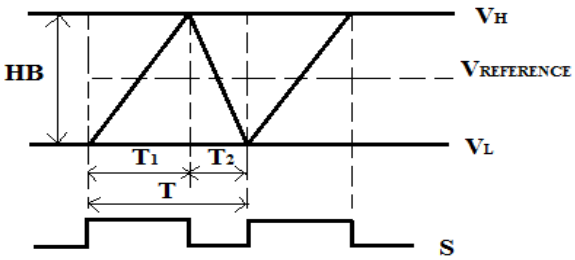

Fig. 7 Hystersis voltage band

10. SIMULATION AND RESULT

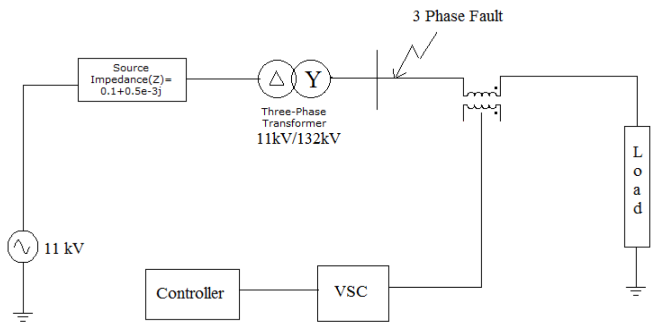

Fig. 8 Single Line Diagram of Test System

The test system for DVR has a single line diagram which is shown in figure above. It has 11kV, 50Hz as generating system and has a transmission line connected with the generating station through three phase transformer 11kV/132kV. The transformer is connected in delta at LV side and star at HV side. To study the operation of DVR the fault is applied at a point of resistance 0.1 for the time interval of 0.2 to 0.3sec. The DVR is simulated for 0.4 sec and the output of DVR is measured during the fault conditions.

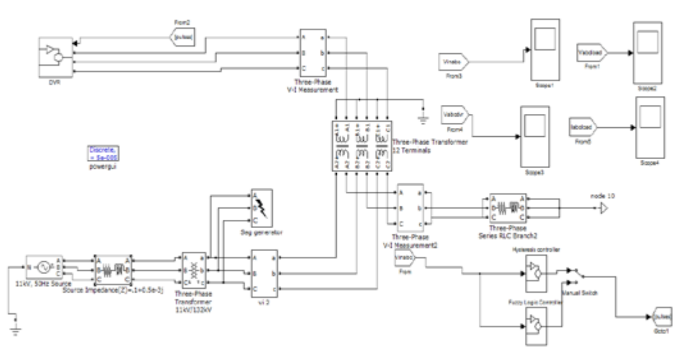

Fig. 9 Matlab/Simulink Model

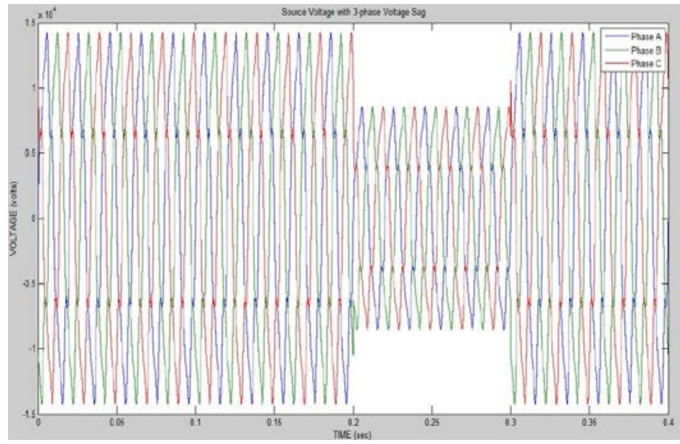

Fig. 10 Source voltage with 3-phase sag

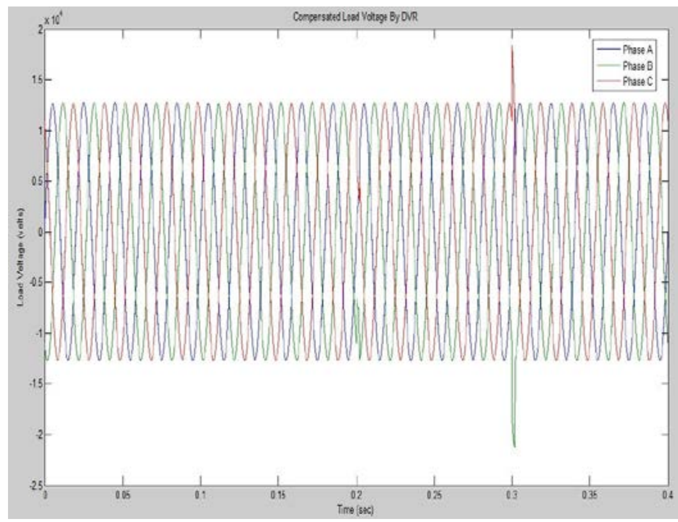

Fig. 11 Compensated Load voltage with DVR

11. CONCLUSION

As the power quality is major issue in power system and there are various cause such as voltages sag, transients, harmonics and interruption which decreases it. Since poor power quality result in economic loss to industry and also causes damages to the equipment. In order to maintaining it many techniques used in power system. DVR is the modern, most effective and cheap technique used to maintain a good power quality but it compensate mainly voltage sag. The controller used here would be hysteresis controller and fuzzy logic because they a new technique with a quick response. The hysteresis controller is suitable for low level voltage sag as it based on the principle of switching frequency which will generate resonance problem. Thus restrict the application of hysteresis control. The fuzzy control need the extra components like computer and hardware and somewhat skilled employ. The fuzzy logic is robust, interface is convenient to use which make easy for end user to operate, allows integrated control because it combines the regulation algorithms and logic reasoning, can be easily modified and improved, can use multiple inputs and output and very quick and cheap to implement whereas in hysteresis controller uses hysteresis voltage band and it can be used to other power quality problems like swell and harmonics and have fast transient response.

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