A Control Scheme for Dynamic Voltage Restorer using PSCAD
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Abstract---The Dynamic Voltage Restorer (DVR) is a custom power electronic device to compensate the problems of voltage sags and voltage swells in the distribution lines. The main function is to inject the voltage difference (which can be determined as difference between the pre-sag and sag voltage) to the power line and helps to maintain the pre-sag voltage condition in the load side. Different type of control ideas are implemented depending on the techniques for compensation purpose. A new control scheme for the single phase voltage sags based on in-phase compensation technique. In this scheme, the Dynamic voltage restorer tracks the phase angle of the supply voltage and produces a reference voltage signal with the rated load voltage magnitude. If there is any phase jump generated at the supply voltage, then phase angle of the reference voltage signal is adjusted slowly leads to track the phase angle of the supply voltage. Then the injected voltage which is the difference between the reference and measured voltage is injected by the DVR. The simulation was simulated out using EMTDC/PSCAD (Electromagnetic transients including DC/Power system computer aided design Professional software version 4.1.0) and their results show various levels of compensation for voltage sags.

Keywords: Dynamic Voltage Restorer, Voltage Sag, PSCAD Software, Inverter

I. INTRODUCTION

The Voltage sag and swell is the most common power quality related problems among the industries. Such type of voltage sag and swell have a major tremble on the enforcement of the microprocessor based loads and sensitive type loads. In a power line voltage sags and swells can generate due to following conditions such as motor starting, load switching, faults, lightning, on-linear loads. According to the IEEE 519-1992 and IEEE 1159-1995 interpret the Voltage sag and sags as shown in Table 1.

Table 1:

<table>
<thead>
<tr>
<th>Type of disturbance</th>
<th>Voltage(in PU)</th>
<th>Duration</th>
</tr>
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<tbody>
<tr>
<td>Voltage sag</td>
<td>0.1-0.9 pu</td>
<td>30 cycles</td>
</tr>
<tr>
<td>Voltage swell</td>
<td>1.1-1.8 pu</td>
<td>30 cycles</td>
</tr>
</tbody>
</table>

Dynamic Voltage Restorer is a custom as well as commercially power device which is used to compensate the problems of the power quality such as voltage sag.

II. POWER CIRCUIT OF DVR

Dynamic Voltage Restorer is a series connected custom power device. It consists of DC energy storage unit, PulseWidthModulation inverter, low pass filter and a voltage injection transformer. The basic function of the DVR is to encounter any type of voltage sag and swell obtained in the power line and then inject the balance voltage from the DVR. This can be done either by absorbing or injecting the active and reactive power .The Figure 1 shows a power circuit of the DVR.

A. DC energy storage unit:

This unit provides the real power requirement of the DVR during the compensation schedule. Storage devices such as Lead-acid batteries, Flywheels, Super conducting Magnetic Energy Storage (SMES) and Super capacitors can also be used as the storage devices. For Batteries and SMES, DC to AC conversion (inverters) is required and for flywheels AC to AC conversion is required. Lead acid batteries are having high response during charging and discharging mode. But the discharge rate is dependent on the chemical reaction rate of the battery so that the available energy inside the battery is determined by its discharge rate.

B. Voltage Source Inverter (VSI):

VSI is implemented to convert the DC voltage supplied by the energy storage device to an AC voltage as output. In DVR power circuit the voltage step up injection transformer is used. Mostly the rating of the VSI is low voltage and high current due to the use of step up injection transformers.

C. Filter:

Low pass passive filters are implemented to convert the PWM inverter pulse waveform signal into a sinusoidal waveform signal. This can be done by removing higher order harmonic components which generated from the DC to AC conversion in the VSI. These filters can be placed either in the high voltage side or in the low voltage side of the injection transformers. When the filters are placed in the lower side higher order harmonics are prevented from passing through the voltage transformer as well as overcome the stress on the injection transformer. There can be drop in phase shift as well as in voltage of output. This can be overcome by placing the filter in the load side. But in this case since the higher order harmonic currents do perforate the secondary side of the transformer, a higher rating of the transformer is required.

D. Voltage Injection Transformer:

The important function is to step up the AC low voltage supplied by the VSI to the required voltage. For three phases DVR, three single phase injection transformers can be used. The rating of the inverter and the injection transformer become a limiting factor when the maximum value of
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III. OPERATING MODES OF DVR

A. During a voltage sag and swell on the line
The DVR injects the difference between the pre-sag and the sag voltage, by supplying the real power requirement from the energy storage device together with the reactive power. The maximum injection capability of the DVR is limited by the ratings of the DC energy storage and the voltage injection transformer ratio. In the case of three single-phase DVRs, the magnitude of the injected voltage can be controlled individually.

B. During the normal operation mode
Under normal condition the DVR is not injecting any voltages to the system. In that case, if the energy storage device is fully charged then the DVR operates in the standby mode or otherwise it operates in the self charging mode. The energy storage device can be charged either from the power supply itself or from a different source.

C. During a short circuit or fault in the downstream of the distribution line
The by-pass switch is activated to make an alternate path for the fault currents. Hence the inverter is protected from the flow of high fault current through it, which can damage the sensitive power electronic components of the system.

IV. CONTROL SCHEME

Voltage sag is produced by a magnitude change with or without a phase shift of the supply voltage. Therefore it is determined and correct for phase shift to compensate for the voltage sags. At the steady state of the control the reference waveform was tracked to the supply and both are synchronized in phase angle. The reference voltage waveform was created with the help of the reference phase angle and rated rms load voltage. The resultant voltage that used to be injected by the DVR which was calculated by subtracting the measured supply voltage waveform from the reference voltage waveform.

A. Find the phase angle of the supply waveform
The supply voltage waveform is measured and readily available. The starting and ending point of each cycle can be easily obtained. During each cycle the phase angle of the input voltage waveform is varying from 0° to 360°. The phase angle waveform of the supply voltage (Ameasured) can be obtained.

B. Reference phase angle waveform generation

The supply voltage Vs is passing through zero crossing detector as input and a limiter respectively used to detect only the positive gradient zero crossing points of the supply voltage waveform. The output zero code detector signal is used to clear the resettable integrator to which input signal of constant value of 314.1593, where f is equal to 50 hertz. The main role is to reset during each cycle.

1) Calculate the angle error between the reference and measured phase angle
The Comparator will generate an output of 1 when the input (supply phase angle in radians) is between the limit given i.e. 2.5-3.5. Except this limits, it will automatically generate a zero output known as angle error. A two way input selector switch which was used to generate an output only when the triggering pulse is present i.e. when it is 1. The angle error was multiplied by a factor 10 to speed up the synchronization to get better synchronization.

2) Regulate the error and reduce the harmonics

Low pass filter: A filter with a second order transfer function was used. The Gain and the damping ratio were put to be 1 to maintain the same magnitude and the wave shape of the input during filtering.

PI controller: Used to regulate the error between the measured (supply) and the reference phase angle to zero.

3) Generating the reference phase angle
They generate phase angle of reference signal waveform. The gradient of the reference signal is calculated and the value of reference phase angle should vary from 0 to 2π (6.2832) radians. The combination of comparator and a resettable integrator are used for resetting purpose. The integrator clear signal is passed by the comparator output.
The comparator compares the magnitude of the Aref signal with the set value of (6.2832)radians and when the Aref > 6.2832, the integrator clear signal is going to be reset and thus the integrator output set to zero.

The reference phase angle synchronized with the phase angle of supply. Next step is to develop the reference voltage waveform from the reference phase angle. From the phase angle obtained a sinusoidal waveform was generated with help of nominal supply voltage magnitude (240 rms = 340 peak value).

The above block was implemented to calculate the control voltage by taking the difference between the reference and the supply voltage. A delay time of 4 sec is introduced. In normal condition (no voltage sag), both the supply and the reference voltage waveforms are in phase and same in magnitude thus the voltage to be injected by the DVR circuit would be zero. The control voltage will be used to inject only during the voltage sag.

V. POWER CIRCUIT OF DVR IN PSCAD

The power circuit of DVR was shown in Fig no. DC batteries rated to total of 100 V were used as the energy storage device. Leg switching signals are the inputs to the PWM inverter. A low pass filter is used to overcome the problem of harmonics. A 1: n ratio of step up transformer is used in series connected distribution line. Voltage sag is created by closing the contacts of circuit breaker in duration of 5.21 second to 5.28 seconds i.e. 70 msec. the resistor is connected in series with circuit breaker.

VI. SIMULATION RESULTS

The total system was simulated by the help of PSCAD/EMTDC and the following results are obtained.

A. System1:-
when load = 100Ω and fault =0.01Ω. The peak voltage injected during the synchronization process= 11V, the peak voltage after synchronization = 18 V
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**Fig. 10:** Voltage waveform during the synchronization

**Fig. 11:** Voltage waveform during the DVR is engaged

**B. System 2:**
when load = 100 Ω and fault = 0.3183mH

**Fig. 12:** Voltage waveform during the synchronization

**Fig. 13:** Voltage waveform during the DVR is engaged

**C. System 3:**
when load = (80Ω+0.191H), fault = 0.03183mH

**Fig. 14:** Voltage waveform during the synchronization

**Fig. 15:** Voltage waveform during the DVR is engaged

**D. System 4:**
when Load = 100Ω, Fault = 0.005Ω Sag created t = (5.102-5.189) sec

**Fig. 16:** Voltage waveform during the synchronization

**E. System 5:**
When Load=100Ω, Fault=0.01Ω, Supply voltage= 240 rms (contains harmonics) Sag created t = (5.102-5.189) sec

**Fig. 17:** Voltage waveform during the synchronization

**Fig. 18:** Voltage waveform during the DVR is engaged

The total system was simulated by the help of PSCAD/EMTDC and desired results were found. Figure shows that sag was created at time of 5.21 sec to 5.28 sec i.e. of 70 msec. During that time the load voltage should maintained at presage voltage. The drop in load voltage due to voltage drop which was occurred in the impedance of DVR. This can be solved by the help of PI controller used in simulation. According to the IEEE standards shown in Table 1, this drop is falling under operating condition. Therefore the scheme of DVR is the effective method to compensate single phase voltage sags of the system

**VII. CONCLUSIONS**
This paper presents a compensation technique especially for a single phase dynamic voltage restorer which was based on Synchronizing compensation techniques. The total system has been simulated using professional version of PSCAD software. With the help of simulation results we can show that the implemented control technique compensates for the power quality problems such as voltage sags and swells thus shows its effective performance. As we observe that, this control technique is very more effective, accurate and simply automated for a single phase voltage sag compensation.

**REFERENCE**


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