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Multifunctional Dynamic Voltage Restorer Implementation For Emergency Control In Distribution Systems

R.Roja[1], E.Mythili[2],T.Geethapriya[3]
[1,2&3] Department of Electrical and Electronics Engineering, Vel Tech Multi Tech Dr.Rr Dr.Sr Engineering College Avadi, Chennai-62.

Abstract

The dynamic voltage restorer (DVR) is one of the modern devices used in distribution systems to protect consumers against sudden changes in voltage amplitude. In this paper, emergency control in distribution systems is discussed by using the proposed multifunctional DVR control strategy. Also, the multiloop controller using the Posicast and P+Resonant controllers is proposed in order to improve the transient response and eliminate the steady-state error in DVR response, respectively. The proposed algorithm is applied to some disturbances in load voltage caused by induction motors starting, and a three-phase short circuit fault. The current limitation will restore the point of common coupling (PCC) (the bus to which all feeders under study are connected) voltage and Protect the DVR itself. The innovation here is that the DVR acts as virtual impedance with the main aim of protecting the PCC voltage during downstream fault without any problem in real power injection into the DVR.

1.Introduction

Voltage sag and voltage swell are two of the most important power-quality (PQ) problems that encompass almost 80% of the distribution system .voltage sag, it can be found that this is a transient phenomenon whose causes are classified as low- or medium-frequency transient events. The DVR is to improve the PQ and compensate the load voltage. The state feed forward and feedback methods, symmetrical components estimation, robust control, and wavelet transform have also been proposed as different methods of controlling the DVR In all of the aforementioned methods, the source of disturbance is assumed to be on the feeder which is parallel to the DVR feeder. In this paper, a multifunctional control system is proposed in which the DVR protects the load voltage using Posicast and P+Resonant controllers when the source of disturbance is the parallel feeders.

Although this latest condition has been described in using the flux control method, the DVR proposed there acts like a virtual inductance with a constant value so that it does not receive any active power during limiting the fault current. But in the proposed method when the fault current passes through the DVR, it acts like series variable impedance (unlike where the equivalent impedance was a constant).

DVR

The major objectives are to increase the capacity utilization of distribution feeders (by minimizing the rms values of the line currents for a specified power demand), reduce the losses and improve power quality at the load bus. The major assumption was to neglect the variations In the source voltages. This essentially implies that the dynamics of the source voltage is much slower than the load dynamics. Voltage sags of even 10% lasting for 5-10 cycles can result in costly damage in critical loads. The voltage sags can arise due to symmetrical or unsymmetrical

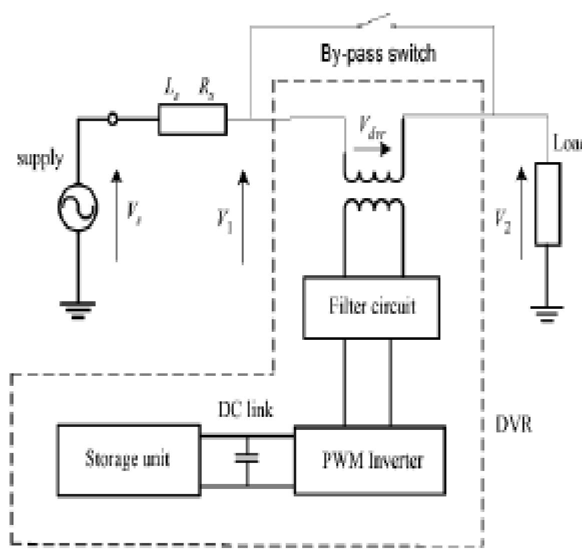

Fig.1Typical DVR-connected distribution system

faults. Uncompensated nonlinear loads in the distribution system can cause harmonic components in the supply voltages. To mitigate the problems caused by poor quality of power supply, series connected compensators are used.

VOLTAGE SOURCE CONVERTER (VSC)

This could be a 3 phase - 3wire VSC or 3 phases - 4 wires VSC. The latter permits the injection of zero-sequence voltages. Either a conventional two level converter (Graetz bridge) or a three level converter is used.

BOOST OR INJECTION TRANSFORMERS

Three single phase transformers are connected in series with the distribution feeder to couple the VSC (at the lower voltage level) to the higher distribution voltage level. The three single transformers can be connected with star/open star winding or delta/open star winding. The latter does not permit the injection of the zero sequence voltage. The choice of the injection transformer winding depends on the connections of the step down transformer that feeds the load. If a ¢ ¡ Y connected transformer is used, there is no need to compensate the zero sequence voltages.

PASSIVE FILTERS

The passive filters can be placed either on the high voltage side or the converter side of the boost transformers. The advantages of the converter side filters are (a) the components are rated at lower voltage and (b) higher order harmonic currents (due to the VSC) do not °own through the transformer windings. The disadvantages are that the filter inductor causes voltage drop and phase (angle) shift in the (fundamental component of) voltage injected. This can affect the control scheme of DVR. The location of the filter o the high voltage side overcomes the drawbacks, but results in higher ratings of the transformers as high frequency currents can flow through the windings.

ENERGY STORAGE

This is required to provide active power to the load during deep voltage sags. Lead-acid batteries, °wheels or SMES can be used for energy storage. It is also possible to provide the required power on the DC side of the VSC by an auxiliary bridge converter that is fed from an auxiliary AC supply.

2.BASIC OPERATIONAL PRINCIPLE OF DVR

The DVR system controls the load voltage by injecting an appropriate voltage phasor in series with the system using the injection series transformer. In most of the sag compensation techniques, it is necessary that during compensation, the DVR injects some active power to the system. Therefore, the capacity of the storage unit can be a limiting factor in compensation, especially during long-term voltage sags.

One of the advantages of this method over the in-phase method is that less active power should be transferred from the storage unit to the distribution system. This results in compensation for deeper sags or sags with longer durations. Due to the existence of semiconductor switches in the DVR inverter,

This piece of equipment is nonlinear. However, the state equations can be linearized using linearization techniques. The dynamic characteristic of the DVR is influenced by the filter and the load. Although the modeling of the filter (that usually is a simple LC circuit) is easy to do, the load modeling is not as simple because the load can vary from a linear time invariant one to a nonlinear time-variant one. In this paper, the simulations are performed with two types of loads: 1) a constant power load and 2) a motor load. As the load voltage is regulated by the DVR through injecting Vdvr.

The DVR harmonic filter has an inductance of Lf, a resistance of R_f , and a capacitance of C_f . The Posicast controller is used in order to improve the transient response. Note that because in real situations, we are dealing with multiple feeders connected to a common bus, namely “the Point of Common Coupling (PCC),” from now on V1 and V2 will be replaced with Vpcc and Vl, respectively, to make a generalized sense. A simple method to continue is to feed the error signal into the PWM inverter of the DVR. But the problem with this is that the transient oscillations initiated at the start instant from the voltage sag could not be damped sufficiently. To improve the damping, as shown in Fig. 4, the Posicast controller can be used just before transferring the signal to the PWM inverter of the DVR.

In this paper, the PCC voltage is used as the main reference signal and the DVR acts like variable impedance. For this reason, the absorption of real power is harmful for the battery and dc-link capacitor. To solve this problem, impedance including a resistance and an inductance will be connected in parallel with the dc-link capacitor. This capacitor will be separated from the circuit, and the battery will be connected in series with a diode just when the downstream fault occurs so that the power

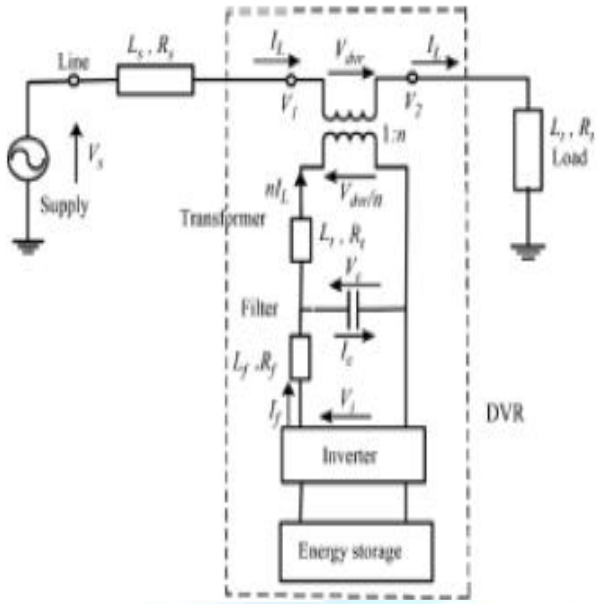

Fig.2 Distribution system with the DVR

does not enter the battery and the dc-link capacitor. It should be noted here that the inductance is used mainly to prevent large oscillations in the current. The active power mentioned is, therefore, absorbed by the impedance.

2.1 Proposed Multifunctioal Dvr

In this paper, the PCC voltage is used as the main reference signal and the DVR acts like variable impedance. For this reason, the absorption of real power is harmful for the battery and dc-link capacitor. To solve this problem, impedance including a resistance and an inductance will be connected in parallel with the dc-link capacitor. This capacitor will be separated from the circuit, and the battery will be connected in series with a diode just when the downstream fault occurs so that the power does not enter the battery and the dc-link capacitor. The active power mentioned is, therefore, absorbed by the impedance.

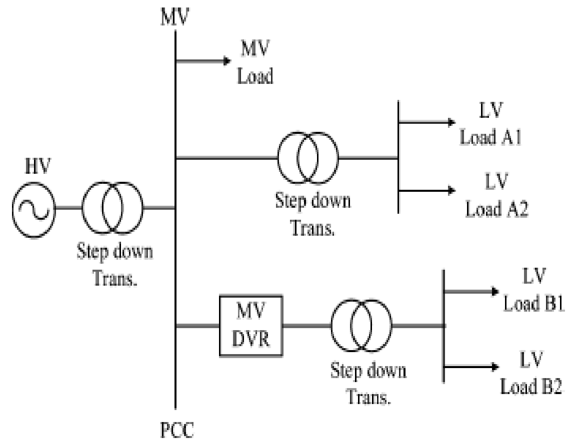

Fig.3 (a) DVR connect in a medium-voltage level power system

2.2 Proposed Method For Using The Flux-Charge Model

In this part, an algorithm is proposed for the DVR to restore the PCC voltage, limit the fault current and therefore, protect the DVR components. The flux-charge model here is used in a way so that the DVR acts as a virtual inductance with a variable value in series with the distribution feeder. To do this, the DVR must be controlled in a way to inject a proper voltage having the opposite polarity with respect to usual cases.

It should be noted that over current tripping is not possible in this case, unless additional communication between the DVR and the downstream side over current circuit breaker (CB) is available. If it is necessary to operate the over current CB at PCC, communication between the DVR and the PCC breaker might have to be made and this can be easily done by sending a signal to the breaker when the DVR is in the fault-current limiting mode as the DVR is just located after PCC. It should also be noted that the reference flux is derived by integration of the subtraction of the PCC reference voltage and the DVR load-side voltage.

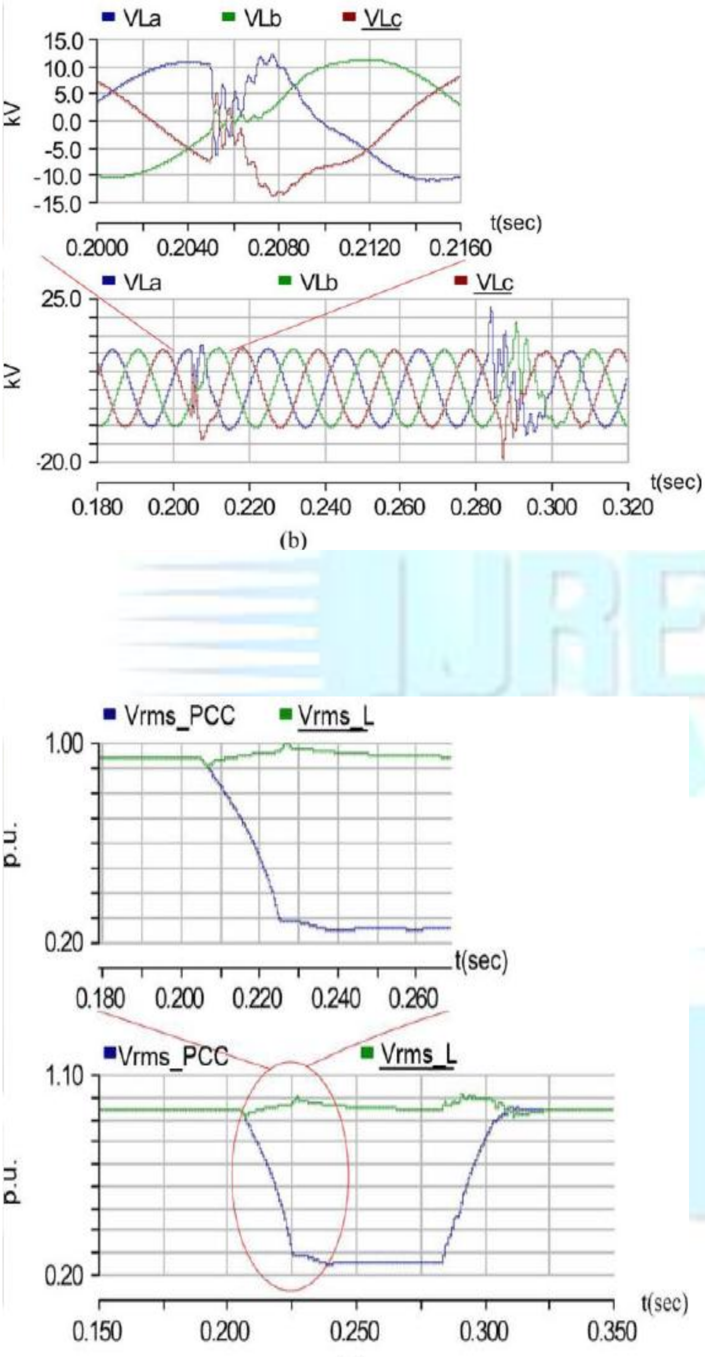

Fig.3 Three-phase fault compensation by DVR
(b)Three-phase load voltages
(c)RMS voltages of PCC and load

3.Three-Phase Short Circuit

In this part, the three-phase short circuit is applied on bus "26:FDR G," and the capability of the DVR in protecting the voltage on bus "05:FDR F" will be studied. The DVR parameters and the control system specifications are provided in Appendices A and B. At 305 ms, the fault will be recovered and, finally, at 310 ms, the separated line will be rejoined to the system by the breaker. The DVR will start the compensation just after the detection of sag. As can be seen in the enlarged figure, the DVR has restored the voltage to normal form with attenuation of the oscillations at the start of the compensation in less than half a cycle. It is worth noting that the amount and shape of the oscillations depends also on the time of applying the fault.

4. Starting The Induction Motor

A large induction motor is started on bus "03: MILL-1." The motor specifications are provided in Appendix C. The large motor starting current will cause the PCC voltage to drop. The simulation results in the case of using the DVR are shown. In this simulation, the motor is started at 405ms. as can be seen, at this time, the PCC rms voltage drops to about 0.8p.u. The motor speed reaches the nominal value in about 1 s. During this period, the PCC bus is under voltage sag. From 1.4 s, as the speed approaches nominal, the voltage also approaches the normal condition. However, during all of these events, the DVR keeps the load bus voltage at the normal condition. Also, as can be seen in the enlarged version, the DVR has succeeded in restoring the load voltage in half a cycle from the instant of the motor starting.

5.Conclusion

A multifunctional DVR is proposed, and a closed-loop control system is used for its control to improve the damping of the DVR response. Also, for further improving the transient response and eliminating the steady-state error, the Posicast and P+Resonant controllers are used. As the second function of this DVR, using the flux-charge model, the equipment is controlled so that it limits the downstream fault currents and protects the PCC voltage during these faults by acting as a variable impedance. The simulation results verify the effectiveness and capability of the proposed DVR in compensating for the voltage sags caused by short circuits and the large induction motor starting and limiting the downstream fault currents and protecting the PCC voltage.

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