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Original Article

IDVR Uses Interline Dynamic Voltage Restorer Converters and Gating Circuits

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Abstract: *Context and Current Status of Art Due to the increasing use of electronic devices, loads are growing less resilient to transient voltage fluctuations, called voltage sag. A range of devices called Custom Power is a technology-driven product and service solution that offers functionalities for improving power quality. The dynamic voltage restorer (DVR) is the most technologically sophisticated and cost-effective device for mitigating voltage-sag in distribution systems among the various innovative custom-power devices. In order to increase voltage quality by adjusting voltage magnitude, wave form, and phase shift, the standard DVR works by injecting AC voltages in series with the incoming three-phase network. These load voltage characteristics are crucial since they have the potential to the protected load's performance. Real and reactive powers are injected into the distribution system as part of the voltage-sag adjustment, which establishes the energy storage device's capacity needed for the restoration plan. The voltage source inverter of the DVR has the ability to electrically create the reactive power needed. To achieve the real-power need, an external energy storage device is required. Therefore, while evaluating a DVR's capabilities, particularly for mitigating long-duration voltage sag, the highest amount of real power that can be delivered to the load during voltage-sag correction is a determining factor. Energy consumption can be decreased by using voltage injection with a suitable phase advance relative to the source side voltage. However, using will not be sufficient to meet the energy need.*

Keywords: *DVR, IDVR, FACTS, DSTATCOM,UPFC,DPFC, PWM*

FACTS AND CLASSIFICATION

The common DC-link energy storage device's energy can be dynamically replenished thanks to the interline IDVR. Two DVRs that protect critical loads in separate distribution feeders that originate from separate grid substations make up the IDVR system. These DVRs share a common DC link. At a particular substation, the issue of compensating several transmission lines is handled by the interline power-flow controller. While reactive power is adjustable within each individual line, the IPFC scheme allows for the direct transmission of real power between the compensated lines. Similar to the IPFC, the IDVR scheme offers a means of transferring actual power between sensitive loads in separate lines via the DVRs' shared DC link. Still, the IPFC's lines come from while the lines in the IDVR system come from many grid substations; they originate from a single grid substation. The other DVRs in the IDVR system replenish the DC-link energy to maintain the DC-link voltage at a predetermined level when one of the DVRs makes up for voltage sag by importing actual power from the DC link. With the need for quick reaction in the event of voltage dips and changes in the attached load, a DVR's control system is crucial. In DVR applications, two control techniques are typically utilized: open loop and closed loop. Voltage source converters, gating circuits, the classification of Flexible Alternating Current Transmission System (FACTS), and the fundamentals of DVR and IDVR operation

CUSTOM POWER DEVICES

The custom power devices are widely used to enhance the power quality during voltage sag, voltage swell, active filtering and load balancing. The custom power devices are divided into two types, one is compensating type and another is network reconfiguration type. Fig 1 shows the complete classification of custom power devices.

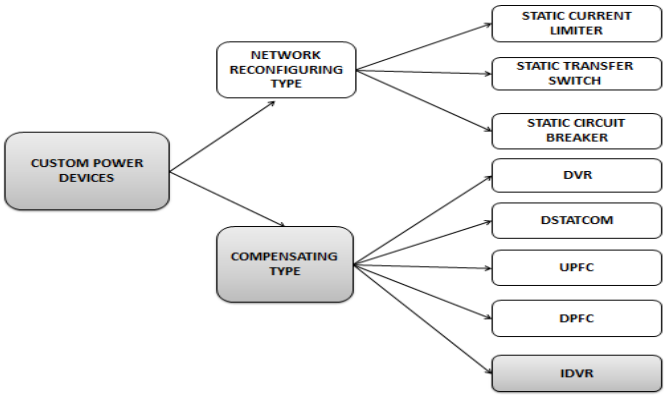

Fig 1 Classification of Custom Power Devices

CompensatingtypedevicesareclassifiedintoDVR,DSTATCOM,UPFC,DPFCand IDVR.

Dynamic Voltage Restorer (DVR)

DVRisaseriescompensatingdeviceusedinthedistributedfeedertocontrolthe load voltage by supplying the inverter AC voltage from the DC source. The block diagram of VSI controlled DVR is illustrated in Distributed Static Var Compensator (DSTATCOM)

DSTATCOM is a shunt compensation device which is used to control the level of bus voltage by injecting or absorbing the reactive power in the distributed power network..

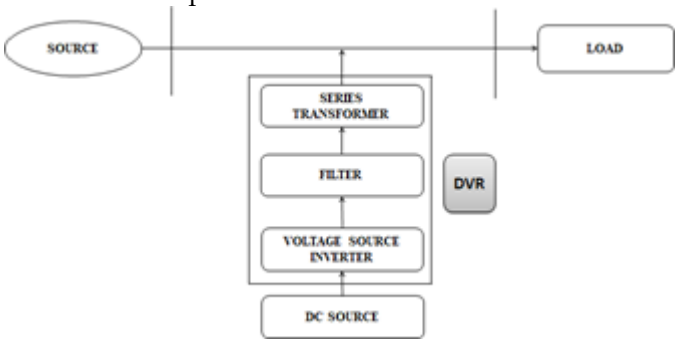

Fig 3 Block Diagram of DSTATCOM

Unified Power Flow Controller (UPFC)

UPFC is a combination of static synchronous series compensator(SSSC) and STATCOM, which are coupled through a common DC link. The DC link provides the bi-directional flow of real power between SSSC and STATCOM. Fig 5 shows the block diagram of UPFC.

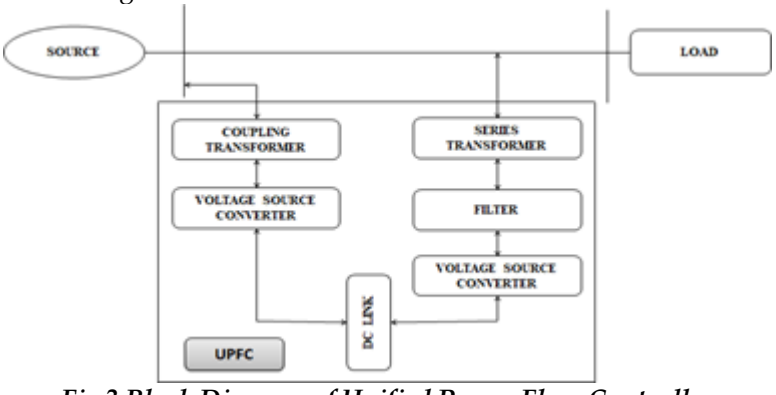

Fig 3 Block Diagram of Unified Power Flow Controller

DISTRIBUTED POWER FLOW CONTROLLER (DPFC)

DPFC is one of the FACTS devices, which consists of number of DVR with one DSTATCOM connected in a distributed system to eliminate 3rd harmonic component. It transfersreal power between the shunt and series converters without using the common DC link. Shows the block diagram of DPFC.

INTERLINE DYNAMIC VOLTAGE RESTORER (IDVR)

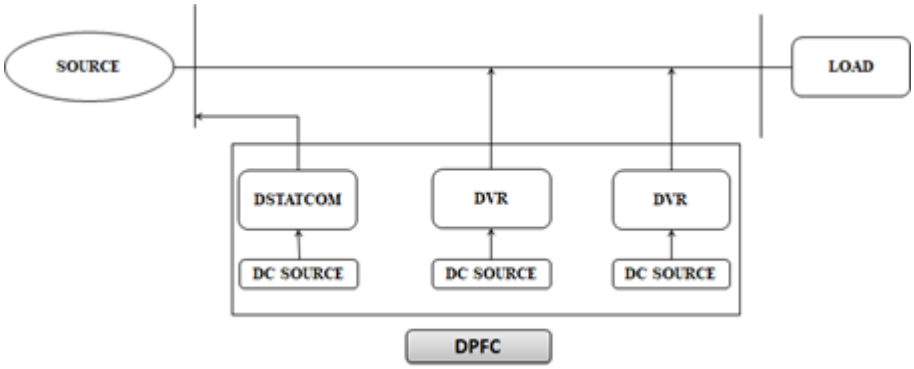

Fig 4 Block diagram of distributed power flow controller

IDVR system isused to compensate the voltage sag in two line distributed system using the common DC link. Fig 7 shows the block diagram of VSI controlled IDVR system.

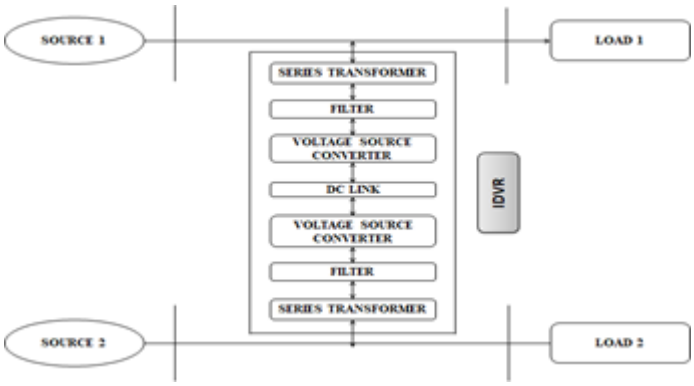

Fig 5 Block Diagram of Interline Dynamic Voltage Restorer

BASIC CONFIGURATION OF DVR AND ITS SCHEMATIC CIRCUIT

DVR is a series compensating device used in the distribution system to control the voltage sag in load side. The basic configuration of DVR consists of

(i)Series transformer
(ii)Harmonic filter
(iii)Energy storage device
(iv)Voltage Source Converter (VSC)

Schematic Diagram Of The DVR Is Shown In Fig

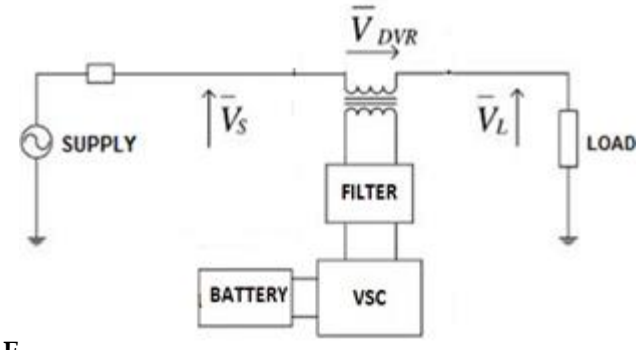

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Fig 6 Schematic diagram of DVR

PRINCIPLEANDOPERATIONINVOLVEDINCOMPENSATINGVOLTAGE SAG/SWELL

The principle and operation of a DVR is that, it injects the variable controlled voltage generated by converter in series to the bus voltage. There are different methods available for operating the DVR, which primarily differs based on triggering pulses applied for the convertercircuit.Sinusoidalpulsewidthmodulationtechniqueisemployed for triggering the VSC circuit in the proposed work.

VOLTAGE SAG COMPENSATION USING DVR

ADVR is basically controlled by "voltage source converter" in series with the distributed network. If any disturbance occurs in load side, the DVR injects a voltage to compensate the drop. The efficiency of DVR depends upon the following factors:

1. Real power supplied
2. Maximum voltage injection.

At abnormal condition voltage sag occur in load side which is compensated using the real power supplied by an energy storage device like a capacitor/ battery.

MODIFICATIONS MADE WITHCONVENTIONALDVRINTRANSFORMING IT TO IDVR

In the conventional method, only one DVR is used to compensate the voltage sag in distribution feeder, but in proposed method two DVR is employed for protecting sensitive loads in different distribution feeders. These DVR's shares a common DC link. It provides a capability to transfer real power, directly between the two feeder lines

TOPOLOGY AND OPEARTION OF IDVR

IDVR system consists of two DVR connected back to back with a common DC link. Fig 9 shows the schematic diagram of two line IDVR system. Two DVRs of IDVR are connected to two various feeders which are fed from two grids with different sources. These two feeder voltage levels could be equal or different. Whenever the voltage sags occur in any one of the load, one of the DVR mitigates the voltage sag, the other DVR in IDVR system is operated in power flow control mode to restore the DC link capacitor.

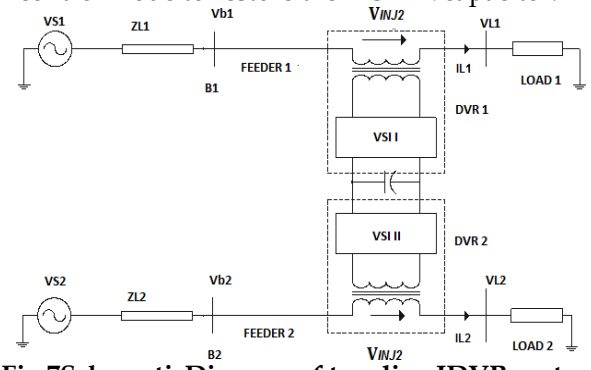


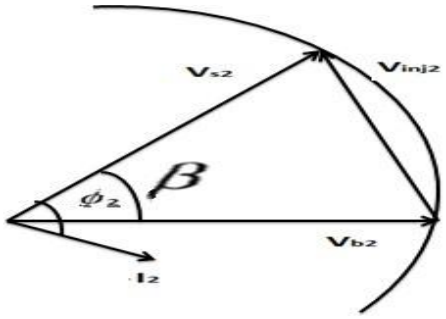
Fig 7SchematicDiagram of two line IDVR system

The voltage sag in the power system occurs due to fault, which depends on many factors like fault current, different voltage level and transformer connecting arrangement. To overcome the above factors, the IDVR system should be connected in two feeders and each feeder is connected to two different grid sources

IDVRUSEDASREALANDREACTIVEPOWERENHANCEMENTOFFEEDER

Fig. 8 shows a Phasor diagram of real-power transfer between the two feeders, $V_{s2}$is the source voltage from feeder 2 and $V_{b2}$is the bus voltage from feeder 2. V_{s2} and V_{b2} injects the voltage V_{inj2}in feeder 2.

Fig.8 Phasor Diagram of Feeder 2 for Real-Power Transfer



IDVR system is operated dynamically with voltage source inverter. Mathematical Equation for real power exchange between the two feeders is shown as follows with two cases.

Case 1

Real power exchange between two feeders Feeder 2,

$P_{ex2}=3V_{l2}I_{l2}[\cos(\Phi2-\beta)-\cos(\Phi2)]$

(1)Let, $S_{l2}= 3V_{l2}I_{l2}$

S_{l2}-Apparent power

β –Advance phase angle

V_{l2}- load voltage that is coupled inline2For maximum real power

$\beta= \Phi2$

$P_{ex2}=3V_{l2}I_{l2}[\cos(\Phi2-\Phi2)-\cos(\Phi2)]$

$P_{ex2}=3V_{l2}I_{l2}[\cos(0)-\cos(\Phi2)]$

(2)$P_{ex2(max)} =S_{l2}[1-pf2]$

$\beta_{max}= \Phi2$&$pf2= \cos(\Phi2)$

Feeder 1,

$$P_{ex1}= P_{DVR1}+P_{losses} \quad (3)$$

From (1) & (3), we get

$P_{ex}=S_{l2}[\cos(\Phi2-\beta)-\cos(\Phi2)]P_{ex}/S_{l2}= [\cos(\Phi2-\beta)-\cos(\Phi2)]P_{ex}/S_{l2}+pf2= \cos(\Phi2-\beta)$

$\Phi2-\beta= \cos^{-1}[P_{ex}/S_{l2}+pf2]\beta=\Phi2-\cos^{-1}[P_{ex}/S_{l2}+pf2]$

$$\beta= \Phi2-\cos^{-1}[P_{DVR1}+P_{losses}/S_{l2}+pf2] \quad (4)$$

Case 2

In this case, the voltage is fed from common DC-link at dynamic storage, DVR operates on pre-sag voltage

injection between the two feeders. Then feeder 1 is generating sag factor and its mitigating voltage sag can be optimized using equation(4).The real power requirements is given below using the equation .5
DVR1 operating pre-sag voltage injection

$$P_{DVR1pr}=Sl1[pf1-R/3(\cos(\Phi1+\theta))] \quad (5)$$

$$Y=\Sigma^{3}j=1ajsin(\delta j),\ \&\ \theta=\tan^{-1}[Y/X]$$

The sag factor

$$aj = Vb1j/\ Vl1$$

$$\beta= \Phi2-\cos^{-1}[[Sl1*(pf1-a*\cos(\delta+\theta))+P_{losses}]/Sl2+pf2] \quad (6)$$

For maximum real power transfer,

$$a= [Sl1pf1+ P_{losses}- Sl2(1-pf2)]/\ [Sl1\cos(\Phi1+\delta)] \quad (7)$$

For optimum real power required to mitigate voltage sag can be,

$$P_{DVR1}>0$$

$$P_{DVR1opt}=Sl1[pf1-R/3],\text{Where } \alpha_{opt}=\Phi1+\theta$$

For a balanced 3 Φ voltage sag with sag factor

$$R=3*a,$$

$$\beta= \Phi2-\cos^{-1}[\ [Sl1*(pf1-a*)+P_{losses}]/Sl2+pf2] \quad (8)$$

CONVERTERS AND GATING CIRCUITS USED IN IDVR

Voltage Source Converter

Fig shows the single phase converter circuit. It consists of four anti parallel diodes D1to D4, fours witching elements S1toS4andaDCbusvoltageV_{dc}.The output voltage $V_O$is obtained between two points A and B.

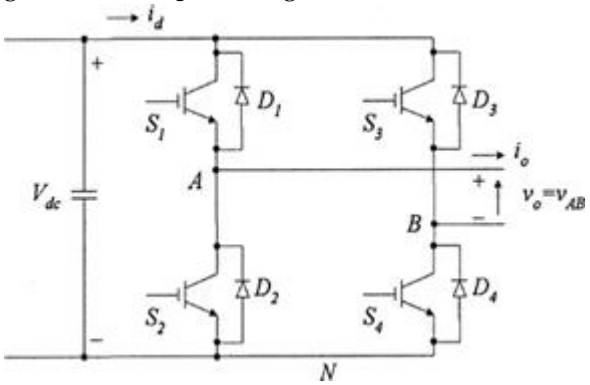


Fig9 Circuit Diagram of Single Phase Converter

The single phase converter has two control modes. The switches S1&S4 and S2&S3are used as a switch pair. Usually one pair of switches are turned on and turned off at the same time and at same duration. For the positive cycle, switches S1&S4 are turned on and output voltage is equal to the V_{dc}. For the negative cycle, switchesS2&S3 is turned on and the output voltage is equal to the -V_{dc}. The four quadrant operation of the single phase converter is shown in Fig 12.

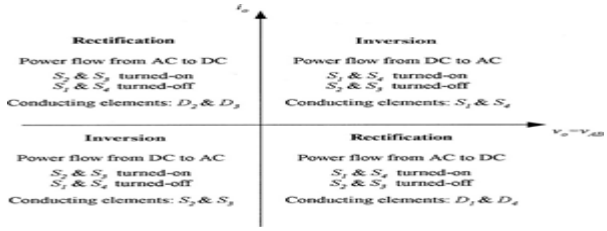


Fig10 Four Quadrant Operation of Single Phase Converter

Rectification process is carried out by turning on switches S1&S4 with remaining switches in off condition through conducting element D1& D4 or switches S3 &S2turned on with remaining switches in the off condition through conducting elementD2 & D3. Inversion process is carried out by turning on switches S1 & S4 with remaining' switches in off condition or switches S3 &S2 turned on with remaining switches in off condition

Pulse Width Modulation

The Pulse Width Modulation (PWM) is a technique which is characterized by the generation of constant amplitude pulse by modulating the pulse duration by modulating the duty cycle. PWM control techniques needs the development of carrier and reference signals that are fed to the comparator and logical conditions are implemented to get a final output. The reference signal is the fixed signal and output may be as quare wave/sinusoidal wave ,while the carrier signal output may be triangular/saw tooth wave, carrier signal frequency value is much greater than the reference signal value. There are different types of PWM technique that are used for inverter to get a different output and the performance of inverter depends on noise, efficiency and cost.

Three basic PWM techniques that are normally preferred are

(i)Single Pulse Width Modulation

(ii)Multiple Pulse Width Modulation

(iii)Sinusoidal Pulse Width Modulation

CONCLUSION

The reactive power requirement can be generated electronically within the voltage source inverter of the DVR. An external energy storage is necessary to meet the real-power requirement. Thus, the maximum amount of real power that can be supplied to the load during voltage-sag compensation is a deciding factor to analyze the capability of a DVR, especially for mitigating long-duration voltage sag. Voltage injection with an appropriate phase advance with respect to sources ide voltage can reduce the energy, FACTS classification ,basic principle and operation of the DVR and IDVR, converters and gating circuits used in IDVR were discussed.

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