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# INTERLINE DYNAMIC VOLTAGE RESTORER CONVERTERS AND GATING CIRCUITS USED IN IDVR

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**Abstract**

Background And State of Art With the widespread use of electronic equipment, loads are becoming more sensitive and less tolerant of short-term voltage disturbances in the form of voltage sag.Custom power is a technology-driven product and service solution which embraces a family of devices to provide power-quality enhancement functions. Among the several novel custom-power devices, the dynamic voltage restorer (DVR) is the most technically advanced and economical device for voltage-sag mitigation in distribution systems. The conventional DVR functions by injecting AC voltages in series with the incoming three-phase network, the purpose of which is to improve voltage quality by the way of adjustment in voltage magnitude, wave shape, and phase shift. These attributes of the load voltage are very important as they can affect the performance of the protected load. The voltage-sag compensation involves injection of real and reactive power to the distribution system, and this determines the capacity of the energy storage device required in the restoration scheme. The reactivepower 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 ofa DVR, especially for mitigating long-duration voltage sag. Voltage injection with anappropriate phase advance with respect to source side voltage can reduce the energy consumption. However, the energy requirement cannot be met by the application of such phase-advance technique alone for mitigating deep sag of long duration, as it is merely a way of optimizing existing energy storage. If the DC link of the DVR canbe replenished dynamically by some means, the DVR will be capable of mitigating deep sag with long durations.

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

**FACTS AND CLASSIFICATION**

The interline IDVR provides a way to replenish the energy in the common DC-link energy storage device dynamically. The IDVR system consists of two DVRs protecting sensitive loads in different distribution feeders emanating from different grid substations and these DVRs shares a common DC link. The interline power-flowcontroller addresses the problem of compensating a number of transmission lines at a given substation. The IPFC scheme provides a capability to transfer real power directly between the compensated lines, while the reactive power is controllable within each individual line. The IDVR scheme provides a way to transfer real power between sensitive loads in individual line through the common DC link of the DVRs,as it does in the IPFC. However, the lines in the IPFC originate from a single grid substation while the lines in the IDVR system originate from different grid substations. When one of the DVRs in IDVR system compensates for voltage sag by imports, real power from the DC link, the other DVRs replenish the DC-link energy to maintain the DC-link voltage at a specific level. The control system of a DVR plays an important role, with the requirements of fast response in the face of voltage sags and variations in the connected load. Generally, there are two control schemes, open loop and closed loop, which are used in the DVR applications. The classification of Flexible Alternating Current Transmission System (FACTS), the basic principle and operation of the DVR and IDVR, voltage source converter and gating circuits used in IDVR.

FACTS is widely used in the transmission and distribution of AC networks to improve the power transmission capability and controllability of the network. All FACTS devices are power electronics-based system and are classified into four basic type controllers which are highlighted in Fig 1.

(i) Series FACTS controllers

(ii) Shunt FACTS controllers

(iii) Combined series-series FACTS controllers

(iv) Combined series-shunt FACTS controller

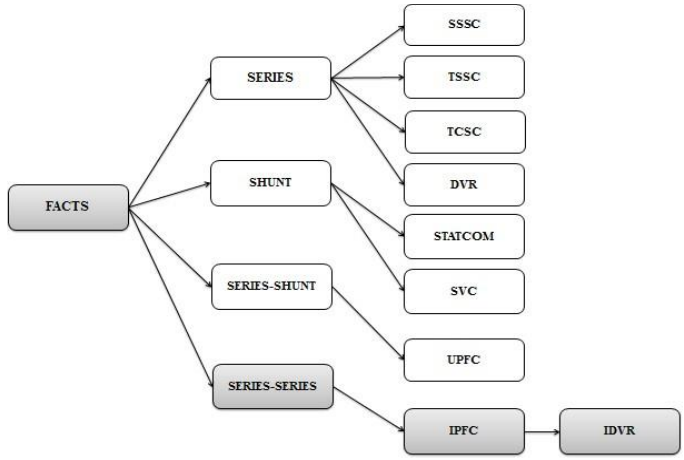


**Fig 1: Classification of FACTS**

## 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 2 shows the complete classification of custom power devices.

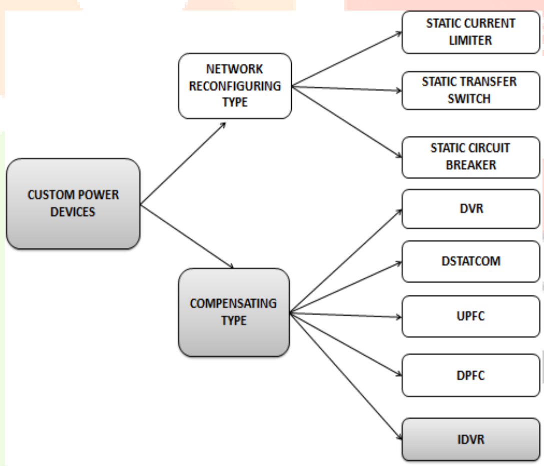


**Fig 2: Classification of Custom Power Devices**

Compensating type devices are classified into DVR, DSTATCOM, UPFC, DPFCand IDVR.

### Dynamic Voltage Restorer (DVR)

DVR is a series compensating device used in the distributed feeder to control theload voltage by supplying the inverter AC voltage from the DC source. The block diagram of VSI controlled DVR is illustrated in

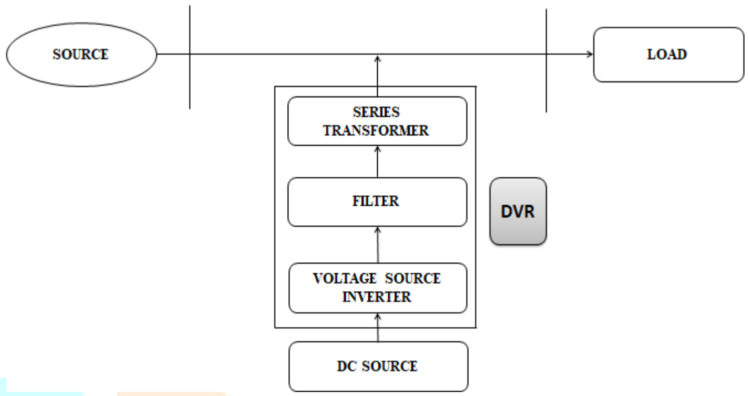


**Fig 3. Block Diagram of Dynamic Voltage Restorer**

### Distributed Static Var Compensator (DSTATCOM)

DSTATCOM is a shunt compensation device which is used to control the level ofbus voltage by injecting or absorbing the reactive power in the distributed power network. Fig 4 shows the VSI based STATCOM.

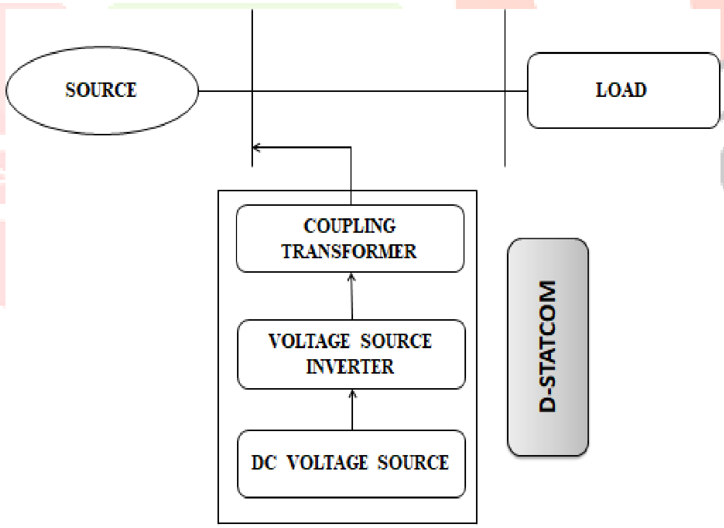


**Fig 4. Block Diagram of DSTATCOM**

## 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 providesthe bidirectional flow of real power between SSSC and STATCOM. Fig 5 shows the block diagram of UPFC.

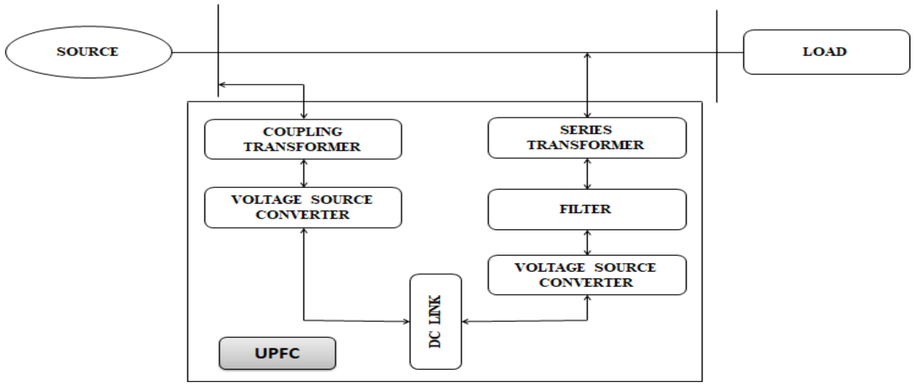


**Fig 5. Block Diagram of Unified Power Flow Controller**

## Distributed Power Flow Controller (DPFC)

DPFC is one of the FACTS devices, which consists of n number of DVR with one DSTATCOM connected in a distributed system to eliminate 3rd harmonic component. It transfers real power between the shunt and series converters without using the common DC link. Fig 6 shows the block diagram of DPFC.

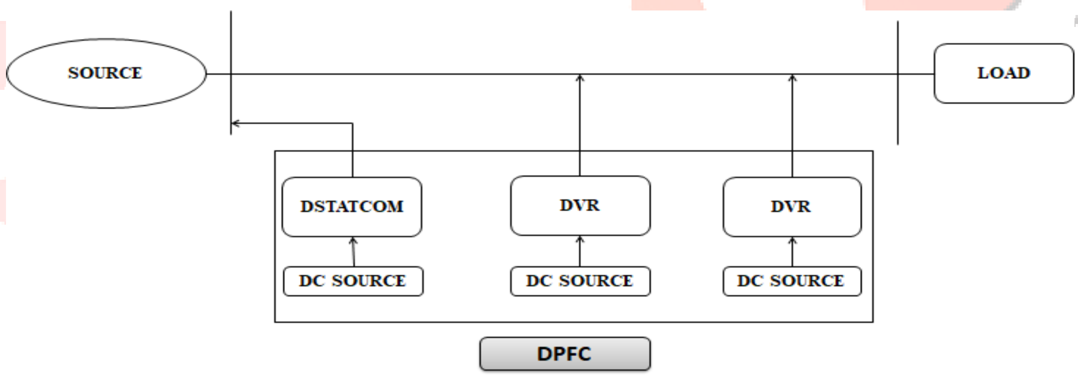


**Fig 6. Block diagram of distributed power flow controller**

## Interline Dynamic Voltage Restorer (IDVR)

IDVR system is used 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.

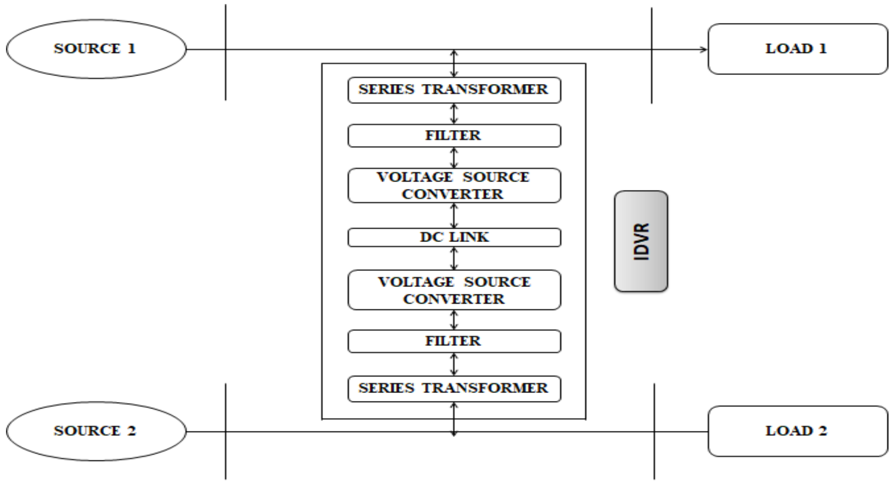


**Fig 7. Block Diagram of Interline Dynamic Voltage Restorer**

**BASIC CONFIGURATION OF DVR AND ITS SCHEMATIC CIRCUIT** DVR is a series compensating device used in the distribution system to control thevoltage sag in load side. The basic configuration of DVR consists of

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

Schematic diagram of the DVR is shown in Fig 3.8.

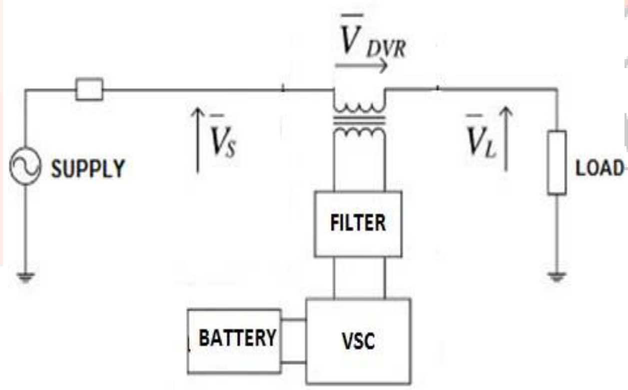


**Fig 8. Schematic diagram of DVR**

**PRINCIPLE AND OPERATION INVOLVED IN COMPENSATINGVOLTAGE SAG/SWELL**

The principle and operation of a DVR is that it injects the variable controlled voltagegenerated 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 converter circuit. Sinusoidal pulse width modulation technique is employed for triggering the VSC circuit in the proposed work.

## VOLTAGE SAG COMPENSATION USING DVR

A DVR is basically controlled by "voltage source converter" in series with thedistributed 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 conditionvoltage sag occur in load side which is compensated using the real power supplied by an energy storage device like a capacitor/ battery.

## MODIFICATIONS MADE WITH CONVENTIONAL DVR INTRANSFORMING 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 theDC link capacitor.

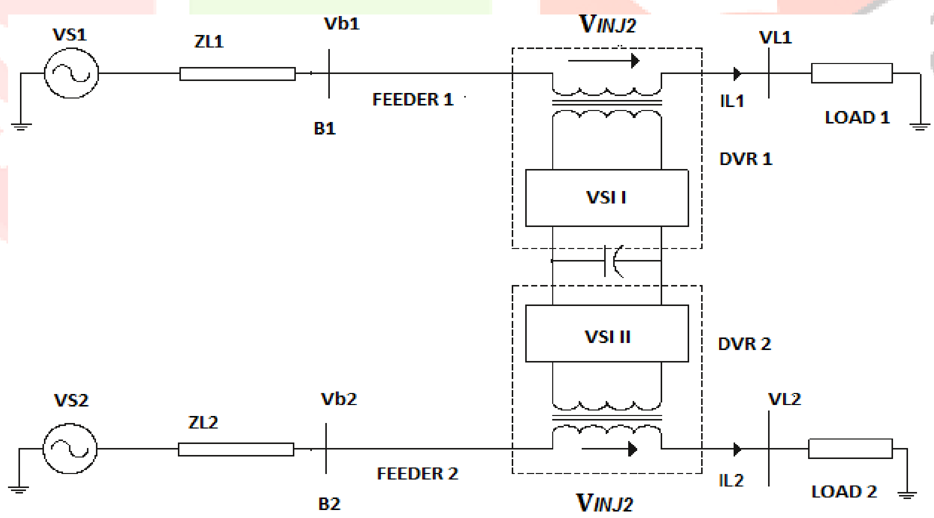


**Fig 9. Schematic Diagram of two-line IDVR system**

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

## IDVR USED AS REAL AND REACTIVE POWER ENHANCEMENT OFFEEDER

Fig. 10 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.

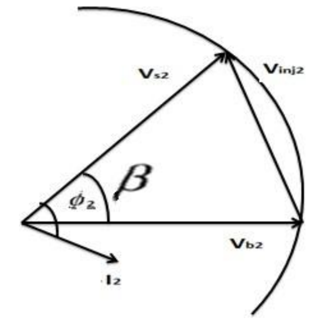


**Fig.10. Phasor Diagram of Feeder 2 for Real-Power Transfer**

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

**Case 1**

Real power exchange between two feedersFeeder 2,

$Pex2=3Vl2Il2\ [\cos(\Phi2-\beta)-\cos(\Phi2)]$ (1)

Let, $Sl2= 3Vl2Il2$

Sl2-Apparent power

β –Advance phase angle

Vl2- load voltage that is coupled in line2For maximum real power

$\beta= \Phi2$

$Pex2=3Vl2Il2\ [\cos(\Phi2- \Phi2)-\cos(\Phi2)]$

$Pex2=3Vl2Il2\ [\cos(0)-\cos(\Phi2)]$ (2)

$Pex2\ (max) =Sl2\ [1-pf2]$

$\beta max= \Phi2$ & $pf2= \cos(\Phi2)$

Feeder 1,

$Pex1= PDVR1+Plosses$ (3)

From (1) & (3), we get

$Pex=Sl2\ [\cos(\Phi2-\beta)-\cos(\Phi2)]$ $Pex/Sl2= [\cos(\Phi2-\beta)-\cos(\Phi2)]$

$Pex/Sl2+pf2= \cos(\Phi2-\beta)$

$\Phi2-\beta= \cos^{-1}[Pex/Sl2+pf2]$ $\beta= \Phi2 -\cos^{-1}[Pex/Sl2+pf2]$

$\beta= \Phi2 -\cos^{-1}[PDVR1+Plosses\ /Sl2+pf2]$ (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

$P_{DVR1pr}=S_{l1}$ [pf1-R/3(cos ($\Phi$1+$\theta$))] (5)

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

The sag factor

aj = Vb1j / Vl1

$\beta= \Phi_2 - \cos^{-1}$ [[Sl1*(pf1 –a*cos ($\delta + \theta$)) +Plosses]/Sl2+pf2] (6)

For maximum real power transfer,

a= [Sl1pf1 + Plosses- Sl2 (1-pf2)]/ [Sl1cos ($\Phi$1+ $\delta$) (7)

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

PDVR1>0

PDVR1opt=Sl1 [pf1-R/3],Where $\alpha_{opt} = \Phi_1+ \theta$

For a balanced 3 $\Phi$ voltage sag with sag factor

R=3*a,

$\beta= \Phi_2 - \cos^{-1}$[ [Sl1*(pf1 –a*) +Plosses]/Sl2+pf2] (8)

## CONVERTERS AND GATING CIRCUITS USED IN IDVR

### Voltage Source Converter

Fig 11 shows the single-phase converter circuit. It consists of four anti parallel diodes D1 to D4, four switching elements S1 to S4 and a DC bus voltage $V_{dc}$. The output voltage $V_O$ is obtained between two points A and B.

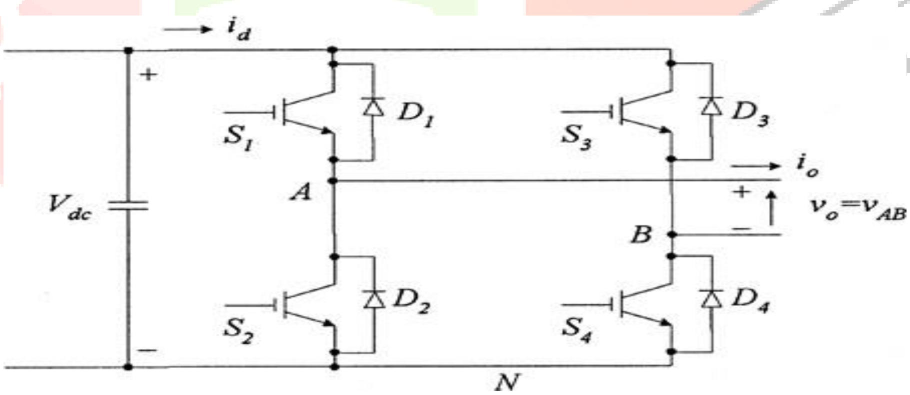


**Fig 11. Circuit Diagram of Single-Phase Converter**

The single-phase converter has two control modes. The switches S1&S4 and S2&S3 are 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, switches S2&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.

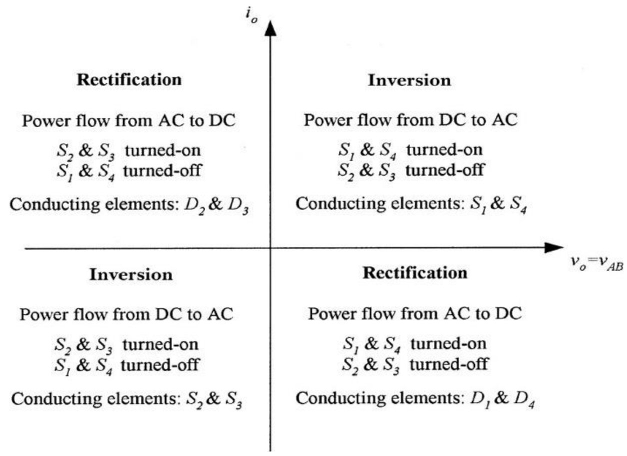


**Fig 12. Four Quadrant Operation of Single-Phase Converter**

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 &S2 turned on with remaining switches in the off condition through conducting element D2 & 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 carrierand 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 a square wave/sinusoidal wave, while the carrier signal output may betriangular/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 reactivepower 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 ofa DVR, especially for mitigating long-duration voltage sag. Voltage injection with anappropriate phase advance with respect to source side 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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