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The Effect of DVR in Voltage Sag Mitigation and Comparison with D-STATCOM in a Distribution Network

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Abstract

In this paper, the voltage sag mitigation was studied in IEEE 13-Nodes standard distribution system in the presence of different loads. By applying types of short circuit faults near one of the nodes of this network, the amount of voltage sag will be studied in other nodes. In order to decrease this sag, dynamic voltage restorer (DVR) was used and the results of which are observed. In order to survey the DVR effect on voltage optimization, the results from compensation via the distribution static compensator (D-STATCOM) will be presented and compared with each other. The control method used to compensate this system is the direct control method. Regarding the existence of a phase angle jump in asymmetric short circuit faults, and for a better compensation, the phase locked loop (PLL) is used to compensate this jump.

Keywords: voltage sag, dynamic voltage restorer, distribution static compensator, phase angle jump, phase locked loop.

1. Introduction

Voltage sag is a temporary drop in voltage that occurred due to short circuits, overload and starting of heavy motors. Compared with interruption voltage sag are more general and influencing more customers. According to IEEE Standard 1159-1995, voltage sag or dip is a decrease between 0.1 to 0.9 pu in rms voltage or current

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at power frequency for duration 0.5 cycles to 1 minute [1]. The most major cause of this occurrence is short circuit faults that asymmetric faults have a major contribution relative to isometric faults [2]. Different methods exist to reduce voltage sag in power systems. Relevant conventional methods include the by using of capacitor banks, introduction of new parallel feeders and by installation of uninterruptible power supplies (UPS) [3]. In distribution systems, DVR and D-STATCOM are highly used to reduce voltage sag. DVR is a series solid state device which injects voltage in distribution systems to regulate the load voltage. This device is usually installation in a distribution system between the source and the sensitive load. The DVR injects ac voltage series and synchronized with the distribution feeder voltages of the ac system [4-5]. Beside sag compensation and voltage swell DVRs can also express other capabilities such as voltage harmonic compensation, decrease the overshoots in voltage and delimit the fault current [6]. In most papers, DVR compensation has been surveyed where there are a limited number of loads in the network [8-7].

Also in some papers have only dealt with the faults which occur in parallel sources with DVR [9-10]. Research the efficiency of DVR in distribution standard is important for increase of knowledge from efficiency of compensator in distribution networks. For this purpose, 13-Nodes standard distribution system is studied in this paper. After the establishment of isometric and asymmetric short circuits in network, effect of DVR in mitigation of voltage sag will be shown by using simulation. The considerable point is improvement of voltage through reactive power injection without any batteries and dc charge source and it will have a more economic design. In Reference [11], mitigation of voltage sag in this network has been compensated using D-STATCOM. Therefore, the results by both of compensators will be compared together. Besides, by applying all types of short circuit, efficiency of DVR in compensation of them will be compared together.

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2. Dynamic voltage restorer

Dynamic voltage restorer is a series state compensator which generates active or reactive power for injection in the network. In power injection via DVR, the purpose is to produce the least required power. This purpose is fulfilled by selecting the amounts of voltage amplitude and phase. Fig. 1 shows the basic structure of DVR. It is consisting of two important parts: a power circuit and a control unit. Power circuit of DVR includes a voltage source converter (VSC), injection transformers, a harmonic filter and an energy storage unit connected to the dc link [12]. The control circuit in DVR is used to regulate the parameters of amplitude, frequency and phase by which to control the rate of injection voltage [13].

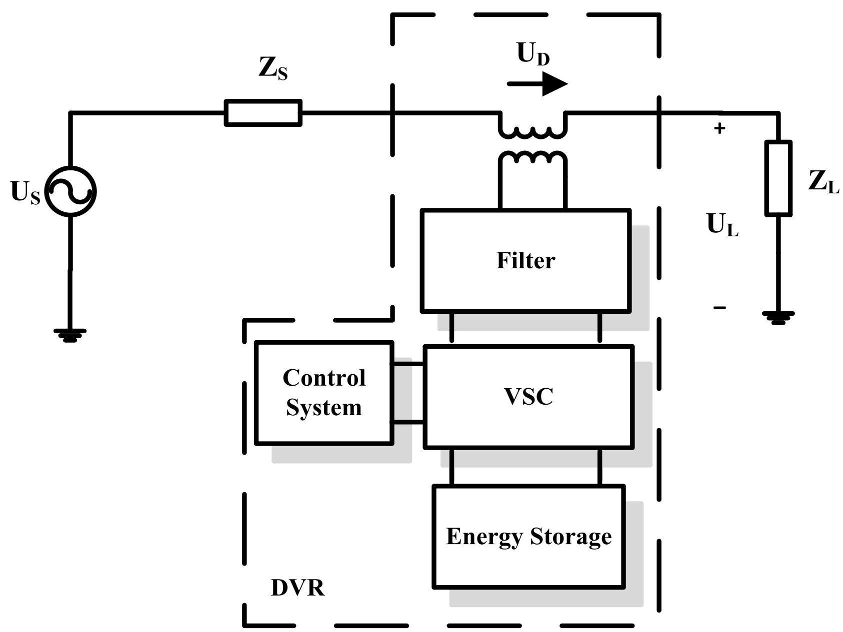

Figure 1: The basic structure of DVR

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3. Distribution Static Compensator

Like the DVR, this fitment includes a power circuit and a control unit. Power circuit consists of a VSC, injection transformers, a harmonic filter and an energy storage unit. Against the DVR, D-STATCOM is located in parallel with the distribution network. Correct adjustment of phase and amplitude will be caused about an effective control to exchange active and reactive powers between the D-STATCOM and the network [14]. Fig. 2 shows different components of this fitment.

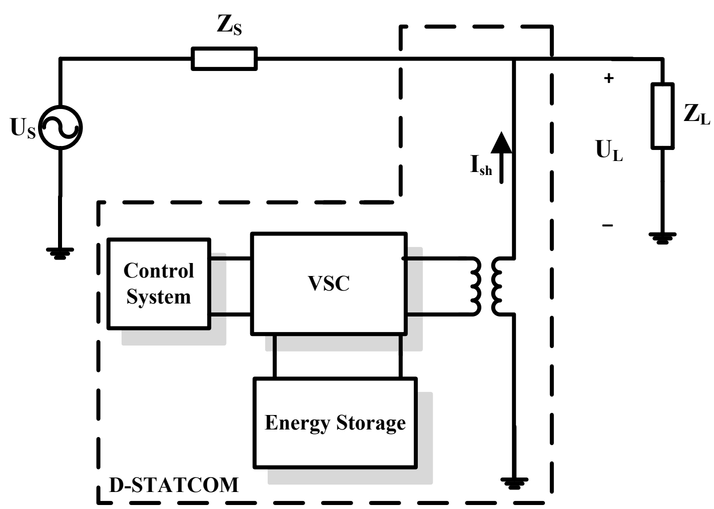

Figure2: The basic structure of D-STATCOM

4. Function of control system

In the applied control system, beside voltage amplitude compensation, there is also phase angle jump compensability. When a fault is applied in one of the nodes, the control system will diagnose the fault and compensation operations will be performed in all the nodes. Major operations which should be effected in DVR are fault diagnosis, reference voltage production and generation of pulses required for switching, whose details will

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follow [15]. Fig. 3 shows all the steps made to control and inject voltage via the DVR in this system. The control system used in the D-STATCOM is referenced in [11].

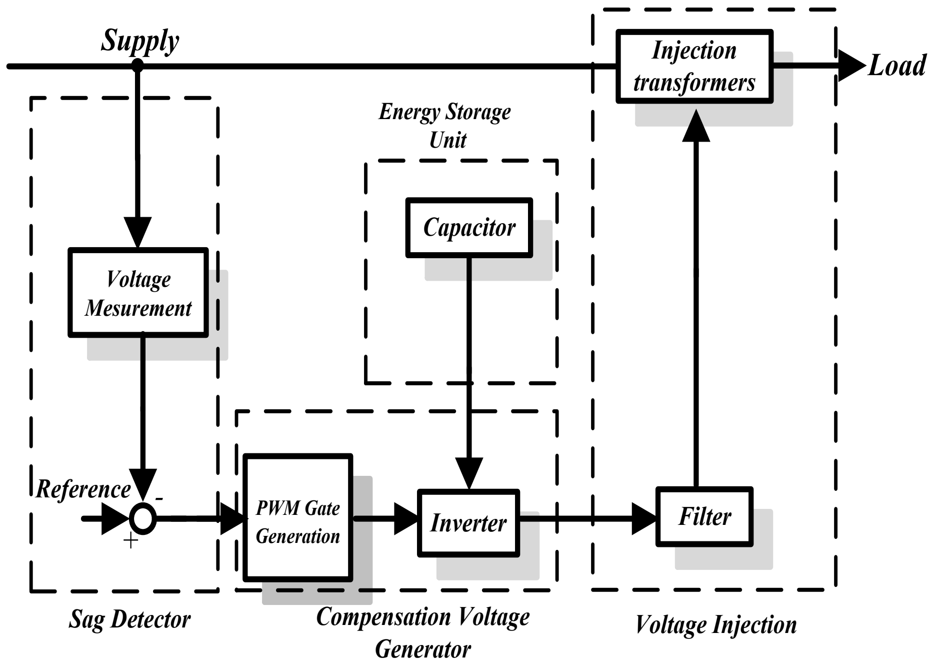

Figure 3: The function of control system from fault diagnosis until injection voltage

4.1. Fault diagnosis

When the voltage is in normal state, the DVR will be in the stand-by mode and should not inject any voltage. When there is a voltage drop or any disturbance, it will disturb the voltage curve quality. Therefore, DVR should be able to diagnose the fault quickly. Figure (4) shows the mode of fault diagnosis in this method. The purpose of this system is compensation with reactive power injection. The network voltage and reactive power in the terminal will be sampled instantaneously by a measurement block. The output of control loop is the difference between the system voltage and reference voltage. This difference determines the amount of the flowing reactive power.

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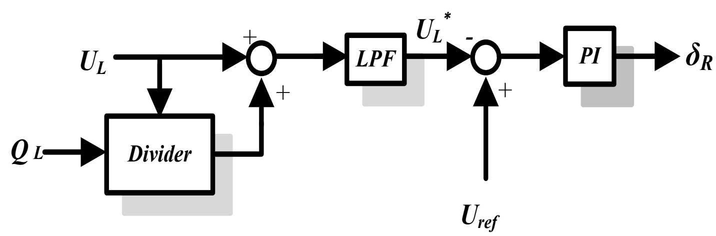

Figure 4: Fault diagnosis by reactive power control loop

4.2. Reference voltage generation

In this part, the alternative voltage curve synchronized with the system voltage is generated as the reference voltage for dispatch to the pulse width modulation (PWM) controller. In order to actualize this objective a PLL can be used. Fig. 5 shows the reference voltage generation mode.

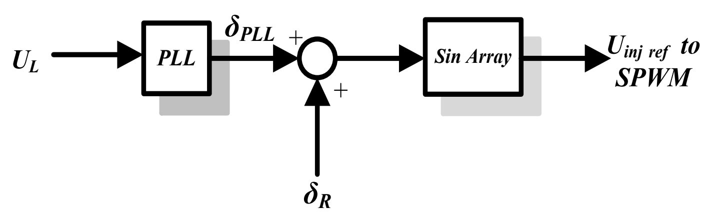

Figure 5: Generation of reference voltage

4.3. Pulses generation

Another part of the control system is the PWM signal regulation so that the system can exercise optimized control over the performance of semi-conductor switches. In order to generate the pulses required for the GTO a comparison should be made between the produced reference voltage and the carrier voltage. At the time at which the reference voltage is more than the carrier voltage, three of the switches will turn on and the other three switches are consequently off. In this manner switching operations are performed in

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the inverter and the output voltage will reach the desired value. This method is called PWM. This part of control includes two sections: triangular wave generation and fire control. In first part, the load voltage enters the PLL and making an angle synchronized with the network in the block output. The above mentioned angle will generate a triangular curve synchronized with the system sinusoidal voltage. Next Part of the PWM control system includes the block fire pulses for VSC. These are generated from the comparison of the reference sinusoidal signals with the triangular carrier wave. This method is thus called the sinusoidal pulse width modulation (SPWM) method. It is observed that the double groups of reference sinusoidal signals and the triangular carrier wave are the inputs of SPWM regulation system. They are thus used at any instant for the signal displacement process. As observed in Fig. 6, the block output will generate a signal fit for the control of semiconductor instruments.

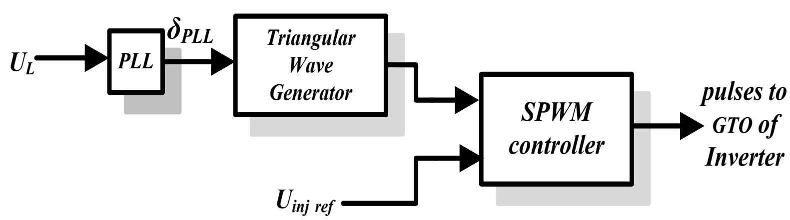

Figure 6: Generation the pulse of GTO

5. Capacitor sizing

The capacitor is needed for reactive power injection. Capacitor sizing is referred to the fault current in the system. The difference in current between the current before and after the fault is considered as current faults. In capacitor sizing a suitable range of DC capacitor is needed to store the energy to mitigate the voltage sag. The DC capacitor, C_{DC} is used to injected reactive power to the DVR when the voltage is in sag condition. The following equation is used to calculate C_{DC} [15].

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$$\frac{1}{2}C_{DC}[V_{CMAX}^2 - V_{DC}^2] = \frac{1}{2}V_{SM} \cdot \Delta I_L \cdot T \tag{1}$$

Equation (1) is used for harmonic mitigation in single phase system but for a three phase system the equation is given by:

$$C_{DC} = \frac{3.V_S \Delta I_L \cdot T}{V_{CMAX}^2 - V_{DC}^2} \tag{2}$$

where,

V_S = Peake phase voltage

I_L = step-drop of load current

T = period of one cycle of voltage and current

V_{CMAX} = pre-set upper limit of the energy storage C (pre-phase)

The value of ΔI_L can be found by measuring the load current before and during the voltage sag. The value of V_{DC} is given from by:

$$V_{DC} = \frac{3\sqrt{3}.V_S.\cos\alpha}{\pi} \tag{3}$$

where,

α = delay angle

If α = 0, the equation become,

$$V_{DC} = \frac{3\sqrt{3}.V_S}{\pi} \tag{4}$$

6. Results of simulation

The network under study is IEEE 13-Node standard distribution system that the general schema of witch shown in Fig (7). The more information about the network is

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referenced in [16]. By using the equations in last section, the capacitor sizing is measured in 300 µF.

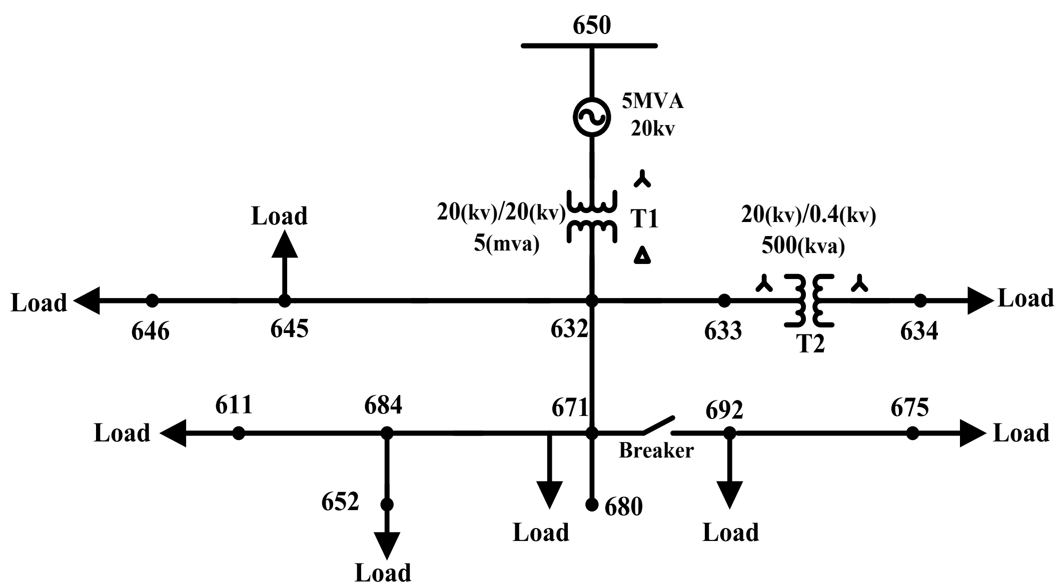

Figure 7: Schematic diagram of the IEEE 13-nodes standard distribution system

The presented network is simulated in the PSCAD software environment. In order to study the voltage sag in this network, single phase to ground, phase to phase, double phase to ground, three phase and three phase to ground short circuits are applied to node 671 and voltage outputs are recorded on other nodes. Regarding the network topology, the most sensitive node in this network is selected as node 671 and the short circuits are generated on this node. That fault resistance is 0.1 ohms. The time of the simulation is two seconds and the faults have been generated in first second for 100 milliseconds. This means the fault will be removed after 100 milliseconds by using circuit breakers and protective equipment. For beginning, types of short circuits are generated on node 671 and the voltages are measured on nodes 611, 634, 675 and 646. Figs. 8-10 show the network simulation results in some nodes.

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Table (1) shows voltage optimization percentage using DVR and D-STATCOM compensators. Results relevant to other mentioned nodes are listed in table (2) which shows voltage values in the network nodes before and after compensation. The results of simulation have been provided values the DVR and the D-STATCOM values regarding the obtained results are listed in [11]. By observing the results of simulation and the values mentioned in Tables (1) and (2) both compensators can be said to express optimal and of-course different performances to decrease voltage sag.

Regarding the intense drop made in the voltage of nodes 611 and 675 due to fault in [11], voltage optimization percentage is more in the D-STATCOM than in the DVR. In node 675, due to the three phase short circuit fault voltage value has had an intense drop to 141 V. It has been compensated to 15.14 KV after applying the D-STATCOM and showing an optimization of 74.94%.Whereas according to Fig. 8, voltage 15.08 KV has been compensated to 17.75 KV after applying the DVR and showing an optimization of 13.35%. As Table (2) shows, the DVR has had an effective performance in all the network nodes voltage compensation.

While the D-STATCOM in nodes 646 and 634, not only has not caused any voltage optimization, but has also caused a voltage drop after being applied. As an example in [11], the voltage of node 634 is decreased than 354 V to 347 V upon applying the three phase to ground short circuit fault using the D-STATCOM compensator and showing a voltage drop of 1.63%. Yet, as Fig. 9 has shown, applying the DVR has caused a voltage optimization of 5%, increasing the voltage from 346 V to 366 V.

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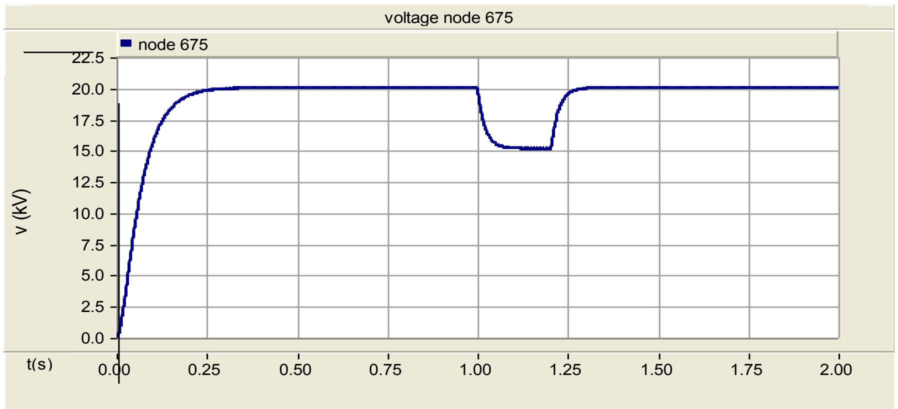

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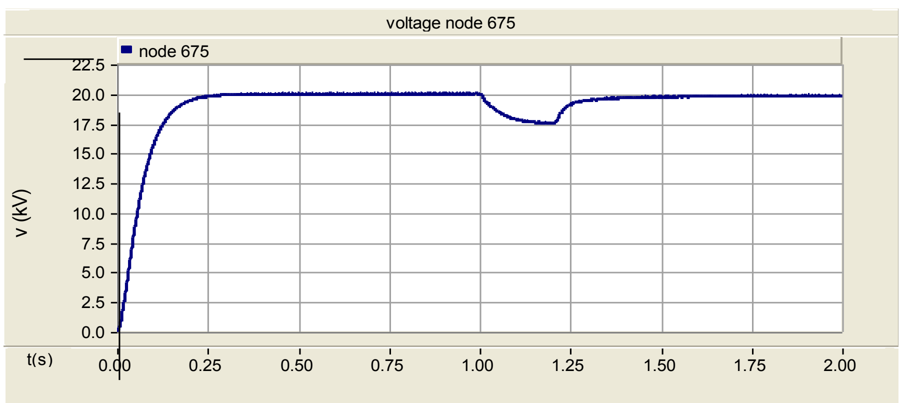

(b)

Figure 8: Voltage sag in node 675 due to three phases to ground short circuit
a) Before DVR,
b) After DVR

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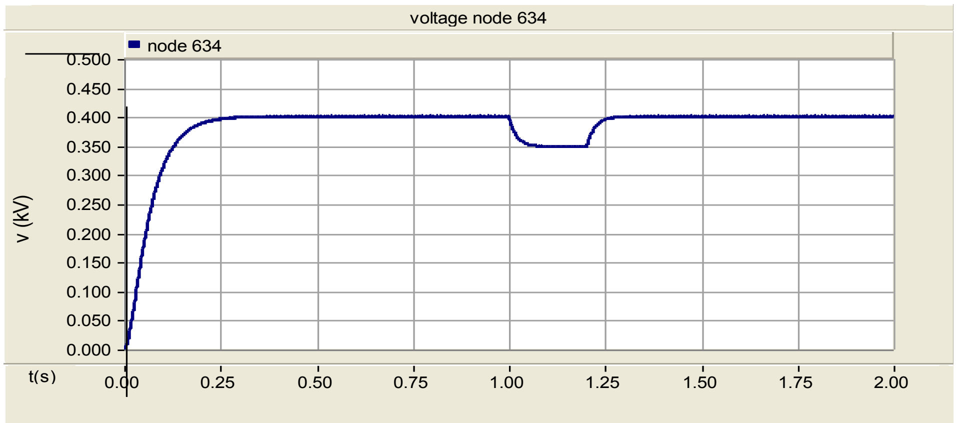

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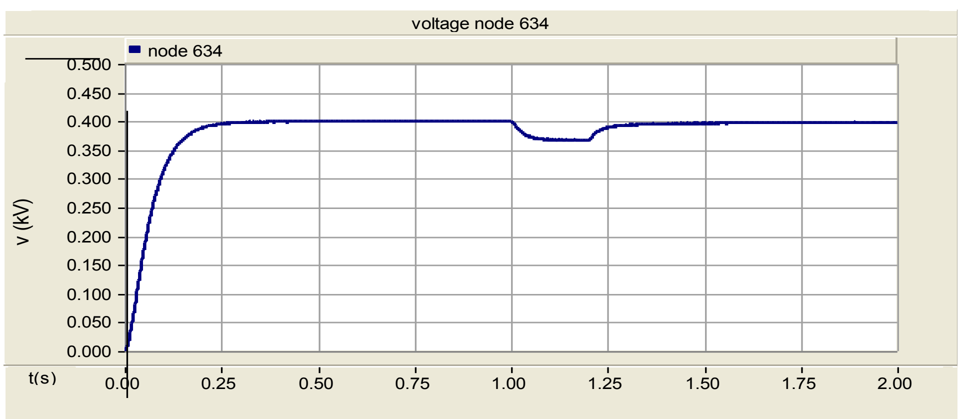

(b)

Figure 9: Voltage sag in node 634 due to three phases to ground short circuit

a) Before DVR,

b) After DVR

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Table 1: The percent of voltage improvement in nodes of network after use DVR/D-STATCOM

Kind of Fault	Percent of Improvement	675(%)	646(%)	611(%)	634(%)
Three Phase to Ground	DVR	12.55	5.9	12.55	**5**
	D-STATCOM	73.7	-1.9	74.98	**-1.75**
Three Phase	DVR	13.35	5.2	14.15	**4.75**
	D-STATCOM	74.94	-1.195	75	**7**
Single Phase to Ground	DVR	3.5	1	3.5	**0**
	D-STATCOM	5.85	-2.36	6.045	**-2.25**
Phase to Phase	DVR	7.5	5	4	**3.75**
	D-STATCOM	35.54	-0.2	36.07	**-0.25**
double Phase to Ground	DVR	5.5	3	2.5	**2.5**
	D-STATCOM	35.35	-1.63	35.95	**-1.5**

The D-STATCOM compensator has been able to bring about an optimization in node 646. For example, due to a three phase short circuit fault in this node voltage has decreased from 17.701 KV to 17.462 KV and showing a drop of 1.19%. Whereas according to Fig. 10, the DVR has been able to increase voltage from 17.46 KV to 18.54 KV that showing an optimization of 5.2%.

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Table 2: The magnitude of voltages in nods of simple network caused by short circuit in node 671 before and after DVR/D-STATCOM

Kind of Fault			675	646	611	634
Three Phase to Ground	DVR	Before	15.10	17.50	15.10	0.346
		After	17.60	18.70	17.60	0.366
	D-STATCOM	Before	0.385	17.830	0.1283	0.354
		After	15.125	17.450	15.125	0.347
Three Phase	DVR	Before	15.08	17.46	15.10	0.351
		After	17.70	18.54	17.90	0.370
	D-STATCOM	Before	0.141	17.701	0.126	0.319
		After	15.130	17.462	15.127	0.347
Single Phase to Ground	DVR	Before	19	19.70	19	0.390
		After	19.7	19.90	19.70	0.390
	D-STATCOM	Before	17.233	19.636	17.190	0.390
		After	18.403	19.164	18.399	0.381
Phase to Phase	DVR	Before	17.5	18.5	17.5	0.370
		After	19	19.5	18.3	0.385
	D-STATCOM	Before	10.579	18.791	10.470	0.373
		After	17.687	18.751	17.684	0.372
Two Phase to Ground	DVR	Before	17.5	18.5	17.5	0.370
		After	18.6	19.1	18	0.380
	D-STATCOM	Before	9.791	18.656	9.669	0.370
		After	16.862	18.333	16.859	0.364

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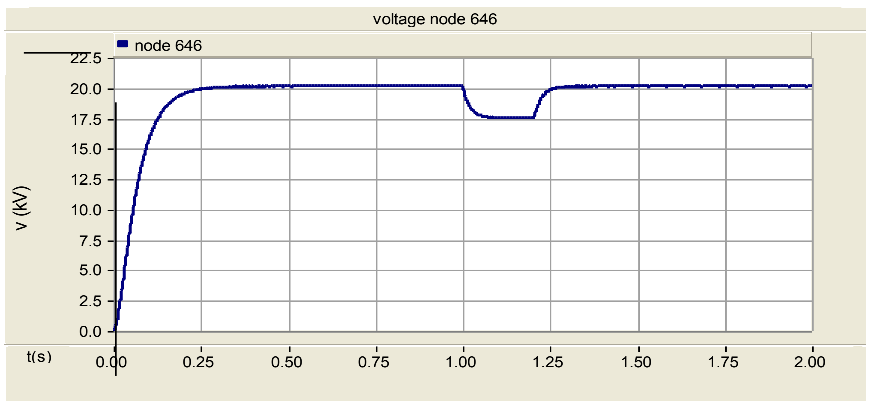
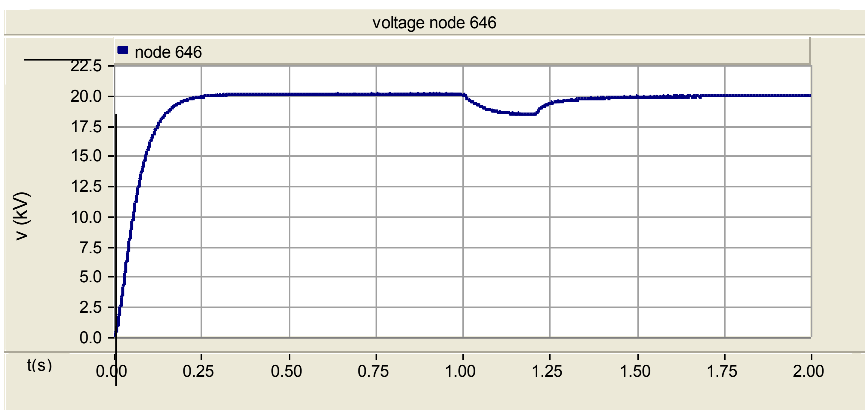


(a)



(b)

Fig.10. Voltage sag in node 646 due to three phase short circuit

a) Before DVR, b) After DVR

Conclusion

In this paper IEEE 13-Nodes standard was simulated using the PSCAD software. Then, different short circuits were applied in sensitive point of network for generating voltage sag. Regarding the results of Tables (1) and (2) and the comparison of DVR and D-STATCOM compensations, it is observed that voltage sag compensation in

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these was desired. The DVR has differently performed in kinds of short circuits. As an example, the performance of this fitment in voltage sags due to double phase short circuits is better than that double phase to ground. In single phase to ground short circuit, DVR has been able to compensate the voltage sag. But, this compensation is lower than the rest cases. Operation of DVR nearly was the same in three phases and three phases to ground. D-STATCOM has been able to compensate the voltage sag better than DVR. Yet oppositely, in some nodes voltage has not been optimized. It has rather dropped after the compensator application and this is one of the D-STATCOM drawbacks in this network. By comparing the results obtained in this paper and the difference which exists in the network loads sensitivity level, the best compensator for this standard network can be selected. Therefore, the D-STATCOM can be has an optimal performance. Yet, its performance will influence other nodes voltages, whereas the DVR has brought about a uniform optimization in all nodes of network.

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