Fault Induced Voltage Sag Mitigation using Dynamic Voltage Restorer

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Abstract: In this paper aim is to study the effectiveness of Dynamic Voltage Restorer (DVR) in mitigating the voltage sag due to different types of faults at every point of the power network under study. The comparative study is done with conventional DVR along with series insertion transformer and proposed DVR at the tertiary winding of already existing step down transformer in the system at the load point. The effectiveness of DVR is studied in terms of critical fault length. It is observed that there is reduction in critical fault length with DVR in the system. Further the study shows that the voltage sag compensation with transformer tertiary winding DVR is effective. But the conventional DVR are more effective to compensate fault induced voltage sag at the cost of additional insertion transformer. The system considered is simulated in PSCAD/EMTDC to do the required study.

Key-Words: - Voltage sag; faults; DVR; critical fault length.

1.INTRODUCTION:

Now a day electric industry including customers, utilities and electrical equipment manufacturers are more concerned about the power quality issues. Due to modernization and automation of industry involving increasing use of computers, microprocessors and power electronics systems such as adjustable speed drives are sensitive to different power quality problems. Voltage sag is important power quality problem as compared to harmonics, flicker, EMI, noise etc. Loads can suffer detrimental effects for voltage sag resulting in economic loss.

Voltage sag is a sudden drop in the root mean square (RMS) voltage and is usually characterized by the remaining (retained) voltage. The most severe sags are caused by faults in the power system at transmission and distribution level [1][2]. The characteristic of sag will depend on type and location of fault in the system. Out of three methods proposed for the assessment of voltage sags due to fault: method of critical distance, the method of fault position and the Monte Carlo method [2], the fault position is most suitable with electromagnetic Transient program [3]. As studied in [4] the simulation results matches well with field measurements, here well established package PSCAD/EMTDC is used to do simulation.

For proper designing of mitigating methodology the characteristic and frequency of voltage sag at sensitive load terminal must be known. In this paper the study system with transmission and distribution network [5] is simulated in PSCAD/ EMTDC environment [6] for different types of faults along all the line in the system. With simulated results and historical fault rate the no. of sags can be estimated [5] [7]. The transformer in the system is having impact on the propagation of voltage sag [8]. It is observed that with star-star grounded transformer the estimated number of sag at the load terminal are less [9]. So, further study is carried out with this transformer.

Custom Power device is the category of power electronics based devices to mitigate power quality problems. Out of different PQ mitigating devices [10][11], Dynamic Voltage Restorer(DVR) is used to mitigate voltage sag at the terminal of sensitive load. In different research papers DVR is used for balancing the voltage [12], against source side unbalancing and harmonics [13], to eliminate switching transients [14], designing of versatile switching scheme of DVR [15], minimize storage capacity of DVR [16].

Here aim is to study the effectiveness of DVR[17] on the sag magnitude at the sensitive load terminal with change in the type a well as location of fault along all lines in the system. The performance of the system with and without DVR is studied in terms of critical length[18]. Further it is proposed that DVR can be inserted in the system through the existing transformer with additional tertiary winding instead of separate series insertion transformer. This proposed DVR will be cost effective solution to mitigate voltage sag. The proposed DVR on the tertiary winding of the transformer can be as effective as traditional DVR with increased rating of converter of the DVR. As used in [19] , here PSCAD/EMTDC is used for modeling and simulation of the system under study with and without DVR.

2. Voltage sag due to fault

The voltage sag induced due to fault in the power system is studied in this paper. In general voltage sag is characterized by sag magnitude, phase angle jump, duration of sag and three phase balance. The sag magnitude is the lowest per unit rms remaining voltage during the event of sag i.e fault in this case. The Phase-angle jump manifests itself as a shift in zero crossing of the instantaneous voltage. Phase-angle jumps during three phase faults are due to the difference in X/R ratio between the source and the feeder. The duration of sag is mainly determined by the fault-clearing time. In the power system depending on the type of fault the sag in all the three phases can be balanced or unbalanced.

The basis of voltage sag determination is fault analysis. With accurate information of all impedances including the positive, negative and zero sequence resistances and reactances of the power components, and the fault impedances, the system can be simulated to predict the sag characteristic at the node where the sensitive load is connected. To quantify sag in a radial system, the voltage divider model is as shown in Fig.1. In this figure Z_s is source impedance at the point of common coupling (PCC) and Z_f is the impedance between PCC and the fault. The PCC is the point from which both the fault and the load is fed. In the voltage divider model the load current before as well as during fault is neglected. The voltage at the PCC which is voltage at the terminal of sensitive equipment will be as per (1)

$$\overrightarrow{V_{sag}} = \vec{E} * \overrightarrow{Z_f} / (\overrightarrow{Z_f} + \overrightarrow{Z_s}) \quad (1)$$

With the assumption that prefault voltage is 1 pu., E=1. Now the expression of sag will be as (2)

$$\overrightarrow{V_{sag}} = \overrightarrow{Z_f} / (\overrightarrow{Z_f} + \overrightarrow{Z_s}) \quad (2)$$

Here fault impedance is included in feeder impedance Z_f.

Equation (2) can be used to calculate the sag as a function of the distance to the fault. Let $Z_f = zl$, with z as the impedance of the feeder per unit length and l as the distance between the fault and the PCC. Equation (2) will be now,

$$\overrightarrow{V_{sag}} = \overrightarrow{zl} / (\overrightarrow{Z_s} + \overrightarrow{zl}) \quad (3)$$

In above equations V_{sag} , Z_f, Z_s. zl are complex quantities.

From equation (3) the magnitude of sag voltage at PCC will be,

$$\left|V_{sag}\right| = \left|Z_f\right| / (\left|Z_f\right| + \left|Z_s\right|) \quad (4)$$

And the phase-angle jump associated with voltage sag at PCC is given by

$$\Delta\Phi = \arctan(X_f/R_f) - \arctan((X_s+X_f)/(R_s+R_f)) \quad (5)$$

Where $Z_f = R_f + j X_f$ and $Z_s = R_s + jX_s$.

Thus the phase-angle jump will be present if the X/R ratio of the source and the feeder are different [2].

The network configuration of industrial power system often consists of parallel branches. The equivalent circuit for such system with sub-transmission loops is as shown in Fig.2.

The voltage sag at the load bus for the fault on one of the two parallel lines is [2],

$$\overrightarrow{V_{sag}} = \frac{\psi(1-\psi)Z_1^2}{Z_s(Z_1+Z_2)+\psi Z_1 Z_2+\psi(1-p)z_1^2} \quad (6)$$

Duration of sag is determined by fault clearing time which is considered as 0.05 seconds for this study. For three phase to ground fault i.e. balanced fault the voltage sag (during fault voltage) will be balanced in all the phases and its calculations can be carried out on single phase basis using positive sequence values of all the parameters. But for unbalanced faults the voltage divider model has to be split into its three components: a positive-sequence network, a negative-sequence network and a zero sequence network. The three component networks have to be connected into equivalent circuit at the fault position. The connection of the component networks depends on the fault type[2].

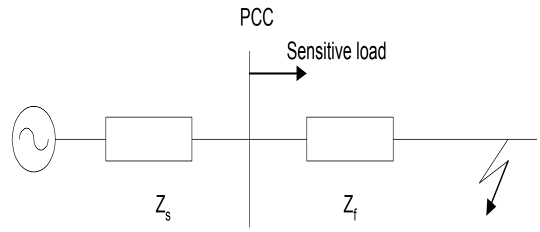

Fig. 1. Voltage divider model

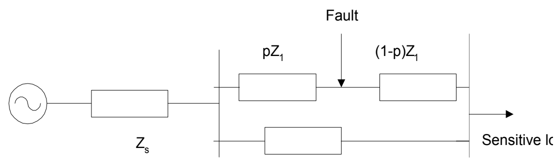

Fig.2.Equivalent circuit for sub-transmission loop

Faults along the lines length can be considered with fault position method. Certain numbers of discrete fault positions are selected along the system lines. Consider the transmission lime between buses k and j as shown in Fig.3.[6], the location at which fault occurs is identified by means of parameter ψ. This parameter varies from 0 to 1, as fault position moves from bus k to bus j, so ψ is defined as

$$\psi = \frac{L_{kp}}{L_{kj}} \quad (7)$$

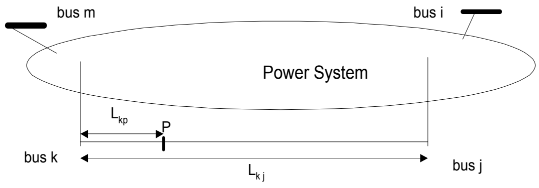

Fig.3. Electrical System

Where, L_{kp} distance between bus k and the location p where fault occurs;L_{kj} length of transmission line k-j.

When the fault takes place at a position p between k and j, the voltage at m will be given by

$$V_m^{012} = V_m^{012\,pf} - \left[Z_{mp}^{012}\right] I_p^{012} \tag{8}$$

Where

$V_m^{012} = \begin{bmatrix} V_m^0 \\ V_m^1 \\ V_m^2 \end{bmatrix}$ and the terms V_m^0, V_m^1, and V_m^2 are zero, positive and negative sequence voltage phasors at m, respectively.

$V_m^{012\,pf} = \begin{bmatrix} V_m^{0pf} \\ V_m^{1pf} \\ V_m^{2pf} \end{bmatrix}$ and the terms V_m^{0pf}, V_m^{1pf}, and V_m^{2pf} are zero, positive and negative sequence prefault voltage phasors at m, respectively.

$\left[Z_{mp}^{012}\right] = \begin{bmatrix} Z_{mp}^o & 0 & 0 \\ 0 & Z_{mp}^1 & 0 \\ 0 & 0 & Z_{mp}^2 \end{bmatrix}$ where the terms Z_{mp}^0, Z_{mp}^1, and Z_{mp}^2 are the transfer complex impedances between m and fictitious bus p in the Z matrix. The position of p is defined by a value of parameter ψ between 0 to 1.

$I_p^{012\,pf} = \begin{bmatrix} I_p^0 \\ I_p^1 \\ I_p^2 \end{bmatrix}$ and the terms I_p^0, I_p^1, and I_p^2 are zero, positive and negative sequence fault current phasors at p, respectively.

Expressions relating the transfer and driving point impedance of a location along the line to the transfer and driving point impedances of buses at the end of that line and the line impedances in generalized form are

$$\left[Z_{mp}^{012}\right] = (1-\psi)\left[Z_{mk}^{012}\right] + \psi\left[Z_{mj}^{012}\right] \tag{9}$$

$$\left[Z_{pp}^{012}\right] = (1-\psi)^2\left[Z_{kk}^{012}\right] + \psi^2\left[Z_{jj}^{012}\right] + 2\psi(1-\psi)\left[Z_{kj}^{012}\right] + \psi(1-\psi)\left[Z_{kj}^{012}\right] \tag{10}$$

Where $\left[Z_{mk}^{012}\right], \left[Z_{mj}^{012}\right], \left[Z_{kk}^{012}\right]$, and $\left[Z_{kj}^{012}\right]$ are diagonal 3x3 matrices whose diagonal elements are zero, positive, and negative sequence Z-bus impedances corresponding to buses indicated by the subscript.

For single line to ground fault

$$I_p^{012} = \begin{bmatrix} \dfrac{1}{Z_{pp}^o + Z_{pp}^1 + Z_{pp}^2} \\ \dfrac{1}{Z_{pp}^0 + Z_{pp}^1 + Z_{pp}^2} \\ \dfrac{1}{Z_{pp}^0 + Z_{pp}^1 + Z_{pp}^2} \end{bmatrix} \tag{11}$$

For Three Phase Fault

$$I_p^{012} = \begin{bmatrix} I_p^0 \\ I_p^1 \\ I_p^2 \end{bmatrix} = \begin{bmatrix} 0 \\ \dfrac{1}{Z_{pp}^1} \\ 0 \end{bmatrix} \tag{12}$$

For Line to Line Fault

$$I_p^{012} = \begin{bmatrix} I_p^0 \\ I_p^1 \\ I_p^2 \end{bmatrix} = \begin{bmatrix} 0 \\ \dfrac{1}{Z_{pp}^1 + Z_{pp}^2} \\ -I_p^1 \end{bmatrix} \quad (13)$$

For Double line to ground Fault

$$I_p^{012} = \begin{bmatrix} I_p^0 \\ I_p^1 \\ I_p^2 \end{bmatrix} = \begin{bmatrix} -I_p^1 \dfrac{Z_{pp}^2}{Z_{pp}^o + Z_{pp}^2} \\ \dfrac{1}{Z_{pp}^1 + \dfrac{Z_{pp}^{21} + Z_{pp}^0}{Z_{pp}^0 + Z_{pp}^2}} \\ -I_p^1 \dfrac{Z_{pp}^0}{Z_{pp}^0 + Z_{pp}^2} \end{bmatrix} \quad (14)$$

Z_{pp}^0, Z_{pp}^1, and Z_{pp}^2 must be calculated using(9).

Thus voltage at m during fault can be expressed in terms of parameter ψ. Then it is possible to express the remaining voltage (sag magnitude) for each phase as a function of ψ using symmetrical components matrix.

3. Dynamic Voltage Restorer

Power Electronics based devices installed at medium voltage level for mitigation of power quality phenomenon , known as "Custom Powers Devices", able to deliver customized solution to power quality problems. Voltage dip and interruption mitigating devices are normally connected between the supply and the load. For industrial customers, who do not normally have access to system or equipment improvement, the installation of additional mitigating equipment is often the only option left to achieve the desired quality of supply at the system-load interface [10].

The series device, traditionally known as static series compensator(SSC) is VSC connected in series on the line, which provides a controllable source , whose voltage adds to the source voltage to obtain the desired load voltage. Manufacturers that are pioneering this technology with the name of "dynamic voltage restorer"(DVR) have realized instillation, among others, at a yarn manufacturer, semiconductor plants, a utility feeder serving industrial and commercial customers in Canada, a large paper mill in Scotland[11]. The compensation system is installed at medium voltage level and protected loads have rating between 0.5 MVA and around 21 MVA. This solution although costly, is very attractive for large sensitive industrial customers, as it allows for protection of entire plant through installation of only one device.

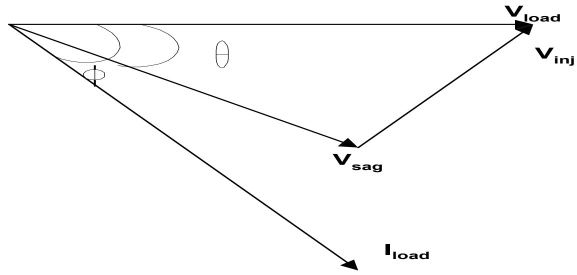

Fig.4. DVR phasor diagram.

The principle of series injection for voltage sag compensation is depicted in the phasor diagram, Fig.4. The Voltage at the load Terminal is 1pu along the positive real axis. And the load current is 1pu in magnitude, with lagging power factor angle Φ.

$$\overrightarrow{I_{load}} = Cos\phi - jSin\phi \quad (15)$$

The voltage at the system side of the compensator has magnitude V and phase angle jump θ

$$\overrightarrow{V_{load}} = 1 + j0 \quad (16)$$

$$\overrightarrow{V_{sag}} = VCos\theta + jVSin\theta \quad (17)$$

The complex power taken by the load is

$$P_{load} + Q_{load} = \vec{V}_{load}\vec{I}^{*}_{load} = Cos\phi + jSin\phi \quad (18)$$

The complex power taken from the system is

$$P_{sys} + Q_{sys} = \vec{V}_{sag}\vec{I}^{*}_{load} = VCos(\phi+\theta) + jVSin(\phi+\theta) \quad (19)$$

The active power need to be generated by the compensator is:

$$P_{cont} = P_{load} - P_{sys}$$

$$P_{cont} = \left[1 - \frac{V\cos(\phi+\theta)}{\cos\phi}\right]P_{load} \quad (20)$$

For zero phase angle jump active power requirement of the controller is

$$P_{cont} = [1 - V]P_{load} \quad (21)$$

For three phase balanced sag the same amount of power is injected in each phase. And for unbalanced fault the amount of power injected by compensator is different in each phase, but it is half of power injected during balanced sag [2].

The basic elements of DVR as shown in Fig.5 are DC-side energy source, Voltage source converter (VSC), Injection Transformer, Harmonic filter, Bypass and disconnection equipment [17].

Voltage Sourced Converter: Converter employed in the DVR is Voltage Sourced Converter controlled by PWM technique. The VSC under consideration here consists of a NPC three level converter, which allows the connection of the converter output voltage to ground

DC side Energy storage: As the action of keeping up the load voltage at its rated value turns out in providing a certain amount of the required load active power during voltage sag, an energy storage has to be installed on the DC-side of the VSC.

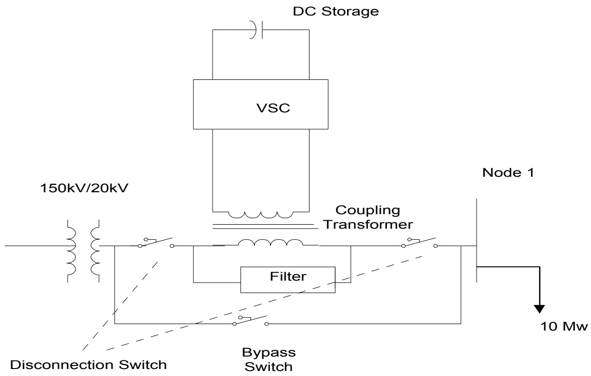

Fig.5. Basic circuit of DVR

Examples of energy storage devices are dc capacitors, batteries, super-capacitors, Superconducting Magnetic Energy Storage and flywheels. The capacity of energy storage device has a big impact on the compensation capability of the system, as it ultimately determines the ride-through time for the load.

Series Injection Transformer: The transformer used to insert a output voltage of VSC in series with the system.

Passive Filters: Can be placed either on the high voltage side or the converter side of the injection transformer. The advantages of the converter side filters are the converters are rated at lower voltage and higher order harmonic current do not flow through transformer winding. But the disadvantages are that the filter inductor causes voltage drop and phase angle shift in the voltage injected. Location of filter on high voltage side overcome this problem but results in higher rating of the transformer as high frequency currents can flow through the winding.

Bypass and Disconnection Equipment: The most critical disturbance for DVR are faults on the load side that causes high current flows through the series transformer and the conducting VSC valves. To prevent these devices from being thermally destroyed, a bypass equipment is used. Disconnection switch is used to isolate the DVR purposely for maintenance.

4. Study Case

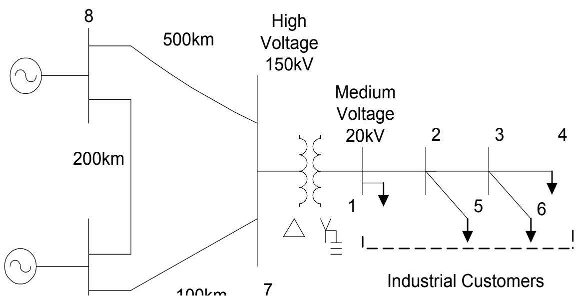

Fig.6. Study system.

The diagram of test system is shown in Fig.6.[5]. Six critical industrial customers are connected at six nodes of the same 20-kV distribution line(40-km total length) through a solidly grounded delta-wye transformer. It should be noted that this network represents a typical distribution network with several hundred nodes spread along the main feeder and lateral but only the node supplying the most critical customer need to be examined. The equivalent transmission system consists of three 150-kV lines and is relatively of large size(800-km total length) to take into account the fact that fault at 100 km away from the critical customer will cause severe sags. The data of the transmission and distribution lines is as given in Table 1. Here it is simulated using PSCAD/EMTDC software package by Fault position method [2]. PSCAD/EMTDC environment there is no need of complex programming. A system is simulated for different types of faults with fault positions at a distance of 5% of the length of the line for all the lines in the system. The voltage at critical node 1 is observed for different types of faults for different fault locations for the complete length of all the lines. And graphs are plotted for three phase rms voltages at the terminal of sensitive load versus length of lines.

Originally in the study system the transformer considered was delta-star i.e. type III [2]. Type of transformer in the power system is important parameter affecting propagation of sag [8]. It is observed that with star-star grounded transformer the number of estimated sags and corresponding financial losses are less [9], so here the transformer considered is star-star grounded. The study system with conventional DVR with series insertion transformer is as shown in Fig.7. The voltage at critical node 1 is observed for different types of faults for different fault locations for the complete length of all the lines with conventional DVR.

As it is stated in different research paper that the mitigation with DVR is effective but costly, here the proposed tertiary winding DVR is connected to the tertiary winding of existing transformer in the system as shown in Fig. 8. So now instead of two winding the power system transformer at the load terminal will be three winding transformer. The DVR of same rating is connected at the tertiary winding of the transformer. This will save the cost of additional insertion transformer required for conventional DVR. In case of conventional DVR the compensating voltage is inserted directly in series with the system. Whereas with proposed tertiary winding DVR the voltage will be inserted through system impedance and not directly. As a result of this the compensation will be less effective but economical. The performance of DVR can be assessed in terms of Critical length [18]. For l=0, i.e. fault near PCC (node 1 in this case), the sag is most severe in the respective phase depending on the type of fault.

Table.1.Transmission and distribution line impedances

Line(s)	Positive & Negative sequence impedances (ohm/km)	Zero sequence impedance (ohm/km)
1-2,2-3,3-4	0.22+j0.37	0.37+j1.56
2-5.3-6	1.26+j0.42	1.37_j1067
7-8,8-9,7-9	0.097+j0.39	0.497+j2.349

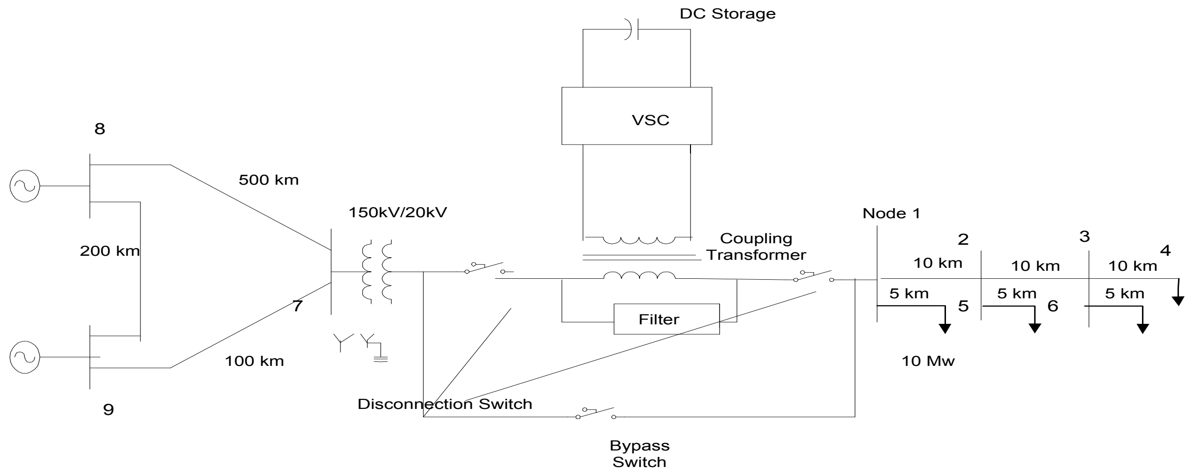

Fig.7 The study system with conventional DVR

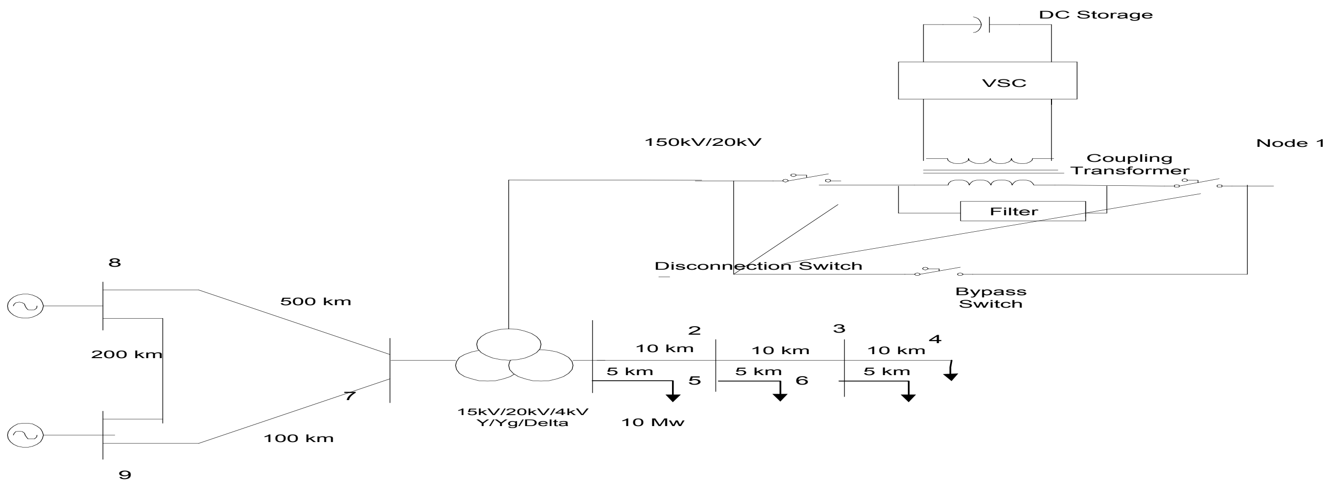

Fig.8. Proposed tertiary winding DVR implemented in the study system.

Then, for increasing the distance between the fault and the PCC, the sag become less severe. The length for which at least one out of three phases of the system voltage fall below the critical voltage (0.7 for sag duration of 0.05 s, as per CBEMA standard) is critical length (lcrit,fault) for that particular type of fault.

In this simulation a 4kV battery is used as energy storage device.To compensate the voltage of max depth Vs,max(Vgr/√3), the transformer power will be **At=√3 Vs,max VgrIlr,** where Vs,max <1 the maximum series injection voltage in pu, Vgr is the rated line-to-line voltage, Ilr is the rated load current.As voltage sags are short compared to the thermal time constant of the transformer, one with series insertion transformer can choose the rated power smaller than the above calculated value.

In the system under study, Vgr=20kV, as Pload =10 MW, Ilr=0.5kA and as the existing DVRs are usually sized for 50% maximum voltage injection, Vs,max=0.5. The power rating of the transformer used in simulation is At=0.5*(20√3)/*0.5=**5 MVA.** The RMS value of the fundamental-frequency component of the VSC output phase voltage can be expressed as a function of PWM modulation index ma and DC side voltage Vdc as ma*Vdc/2√2. Since DVR has to compensate a voltage sag of max depth Vs,max (Vgr/√3), the transformer turn ratio Kt is calculated as t=[Vs,max(Vgr/√3)]/[mar*Vdc/2√2)]

=5.77/1.13

mar is chosen as 0.8, in order to work in the linear region when the maximum series injection is required and to have still a compensation margin in the linear region for the voltage sags of larger depth or when, during the compensation process, the dc-side voltage falls below its rated value[17]. In different research papers, depending on the application, different control schemes are used to control the output voltage of VSC, like controller

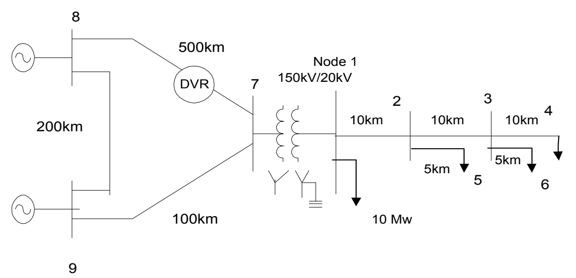

Fig.9. DVR implemented in sub-transmission loop

designed in the rotating dq-reference frame, controller implementing positive and negative sequence detection scheme, controller using back-calculation of voltage drop (missing voltage), controller by adding feedback of the capacitor voltage, controller by adding another loop that controls the current through the converter valves.

In this study, control scheme implemented consist of pu three phase rms voltage at the load terminal (which is sagged due to fault) as input to the control scheme and it is compared with desired value i.e. 1pu[16]. The difference between these two quantities is an error signal, which is passed through PI controller to produce a phase angle delta. Delta is input to the PWM firing scheme, to control the firing pulses of VSC in order to minimize the three phase voltage sag. Since the power transformer is at node 1, the proposed DVR can be located at the tertiary winding of this transformer.

The system under study is first implemented with convention DVR with above designed rating. Then the simulation is carried out with proposed tertiary winding DVR. The rating of proposed tertiary winding DVR is same as used in conventional DVR.

5. Simulation Results

Initially the system is simulated to study the effectiveness of conventional DVR when the fault takes place at different locations along the line lengths. To study the effectiveness of DVR in sub-transmission loop, firstly the conventional DVR is placed at the mid point of the line 8-7, with three 5 MVA, 43/1.13kV transformers as shown in Fig.9. The most severe ABC-G fault is created along the other parallel line 7-9. The result for faults in sub-transmission loop is as shown in Fig.10. It shows the effectiveness of conventional DVR in sub-transmission loop.

In order to compare the performance of the system without DVR, with conventional DVR and with proposed tertiary winding DVR, the magnitude of three phase rms voltage as sag magnitude at node 1, for all cases are plotted verses the distance of fault along all the lines in the system. Since power transformer is at node 1, the proposed DVR can be located at this location. The results for line 7-9 are as shown in fig.12. Similar graphs are plotted for remaining two transmission lines. As observed in the Fig.12, the system performance is improved with conventional DVR.

With proposed tertiary winding DVR there is improvement in the system performance as compared to without DVR in the system, but conventional is more effective than the proposed DVR. The effectiveness of DVR is studied in terms of critical fault length. For l=0, i.e. fault near PCC (node 1 in this case), the sag is most severe in the respective phase depending on the type of fault. Then, for increasing the distance between the fault and the PCC, the sag become less severe. The length for which at least one out of three phases of the system voltage fall below the critical voltage is critical length (lcrit,fault) for that particular type of fault. The performance of DVR can be assessed in terms of Critical length [18]. As per CBEMA standard [2], the critical voltage for the sag of duration 0.5 sec is 0.7 pu. The critical length for the fault of different types along all three transmission lines of the study system are as shown in Table.2.

The Conventional DVR is effective but its cost is more whereas the proposed tertiary winding DVR is cost effective solution but less effective. With proposed tertiary winding DVR the critical fault length is reduced as compared to without DVR. Thus by using three winding transformer instead of two winding transformer, with DVR at the third winding terminal will be cost effective solution to mitigate voltage sag at the terminal of sensitive load.

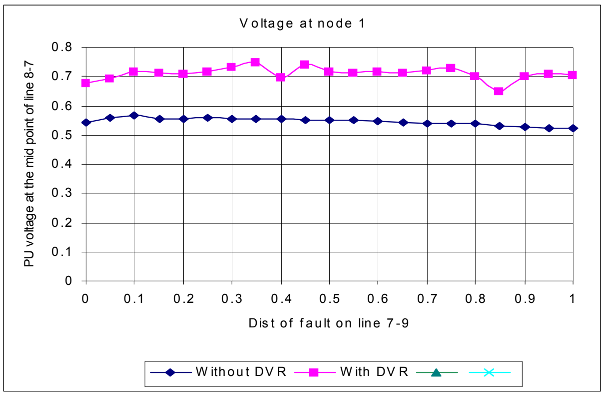

Fig10. Three phase rms sag voltage at node the mid point of line 8-7 in pu due to fault along the 150kV line 7-9 of length 100 km

Table.2. Critical fault length as percentage of full line

% Critical Length Line 7-8			
Type of Fault	**Without DVR**	**With Conventional DVR**	**With Proposed DVR**
ABC-G	100	33	61
AG	0	0	**0**
BC-G	38	0	**14**
BC	23	0	**3**
% Critical Length Line 8-9			
Type of Fault	**Without DVR**	**With Conventional DVR**	**With Proposed DVR**
ABC-G	100	13	**47**
AG	2	0	**0**
BC-G	24	3	**9**
BC	15	0	**0**
% Critical Length Line 7-9			
Type of Fault	**Without DVR**	**With Conventional DVR**	**With Proposed DVR**
ABC-G	100	100	**100**
AG	4	0	0
BC-G	100	7	100
BC	100	41	0

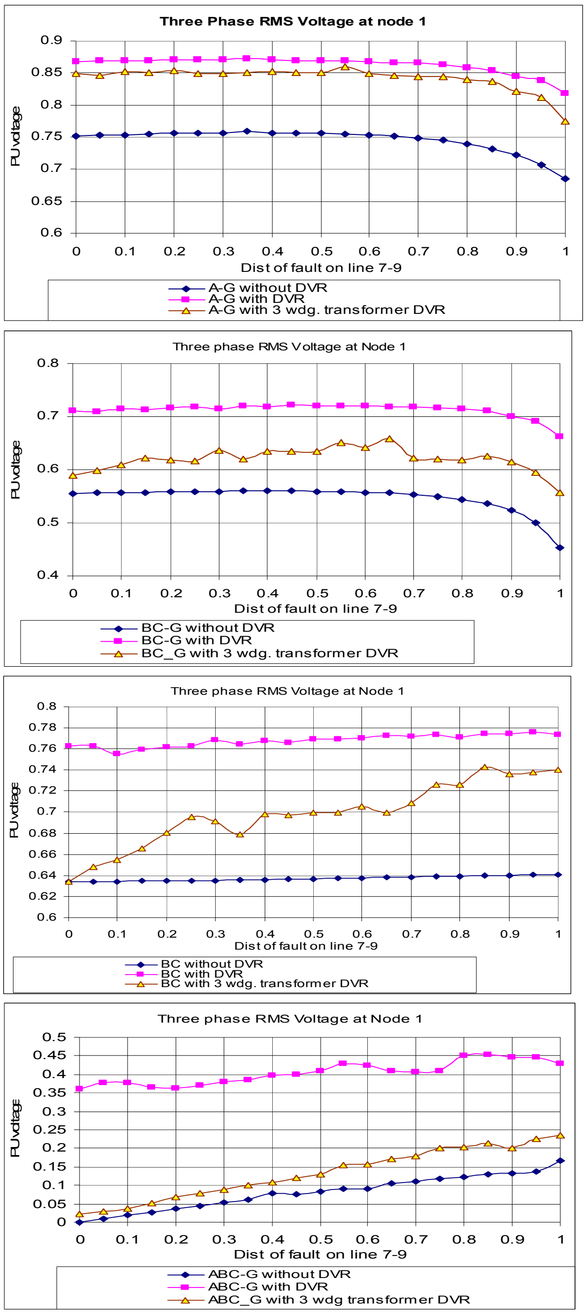

Fig.11. Three phase rms sag voltage at node 1 in pu due to fault along the 150kV line 7-9 of length 100 km

6. Conclusion

Financial loss due to voltage sag induced as a result of faults in the power system is large. Reduction in the critical length will cause reduction in the financial loss. As conventional DVR with series insertion transformer is costly solution, the proposed tertiary winding DVR is cost effective solution to mitigate voltage sag induced due to faults in the system. With proposed DVR the critical fault length is reduced as compared to no DVR in the system but conventional DVR is more effective. By proper designing of VSC, transformer rating and control scheme of proposed DVR; its effectiveness can be further improved as that of conventional DVR.

7. References

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