Effect of Transmission Line Capacitance on Performance and Cost of Dynamic Voltage Restorer DVR

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Abstract- This paper analyzes the Effect of Transmission line Capacitance on Dynamic Voltage Restorer (DVR) Performance. The DVR is used to improve the system voltage profile for different types of faults. The DVR is modeled as three individual units controlled using PWM technique and conventional PI controllers. To approve the DVR effectiveness, symmetrical and unsymmetrical faults are applied at the load point of common coupling. three lengths of transmission line were used to study the effect of transmission line capacitances on DVR performance. Finally, total cost of proposed DVR model components are calculated. All simulations are performed using MATLAB/Simulink to approve the proposed system validity.

Keywords- capacitor, dynamic voltage restorer, voltage sag, swell, pi controller, pulse width modulation.

I. INTRODUCTION

Power quality is one of the main problems in power system. There are many problems of power quality such as voltage transient , harmonic, unbalance voltage, voltage sag and swell[1]. Voltage sag and swell are considered to be one of the most severe disturbances to industrial equipment's [2]. Voltage sags and swells caused by symmetrical three phase faults and unsymmetrical faults such as double line to ground, line to line and single line to ground fault [3].For some critical devices, a temporary disturbance can cause system crashes, scrambled data, equipment failure and interrupted communications [4].Voltage sag is defined as reduction in rms voltage to value from 0.1 to 0.9 p.u and for period from 0. 1 to 1 minute. Also voltage swell is defined as increase inrms current or voltage at power frequency to value between 1.1 and 1.8 p.u for time from 0.1 to 1 minute [5]. To solve voltage sag and swell problems, dynamic voltage restorer is a modern and important custom power device for mitigation voltage sags and swell in distribution systems[6]. DVR is one of the most efficient and effective custom power devices due to its smaller size and fast response lower cost [7]. DVR is a recently presented series connected solid state device which injects voltage into the system in order to regulate the load side voltage. It is installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC) [8]. The Effect of Transmission line Capacitance on Dynamic Voltage Restorer DVR Performance is studied. Transmission line classify to three type short, medium and long transmission line. Length in transmission line less than 80 km so Capacitance effect is negligible. For medium transmission line length of lines more than 80 km and below 250 km so shunt capacitance must be considered. In case the lines are more than 250 km long the lines are called long transmission line[9].

II. PRINCIPLEOPERATION OF DVR

DVR consists of Harmonic filter, Voltage Source Converter (VSC), Storage Devices, Injection transformer, DC charging circuit, and Control and Protection system[10].

The main function of the DVR is to inject a controlled voltage produced by a forced commuted converter in a series to the bus voltage by means of an injecting transformer [11]. A DC to AC inverter regulates this voltage by sinusoidal PWM technique. All through normal operating condition, the dynamic voltage restorer injects only a small voltage to mitigate for the voltage drop of thedevice lossesand injection transformer[12]. Note that the DVR capable of absorbing or generating reactive power but the active power injection of the device should be provided by an external energy source or energy storage system [12].

The contribution of this paper is that, it studies and analyzes the effect of transmission line Capacitance on Dynamic Voltage Restorer (DVR) Performance. Also total cost of proposed DVR model components are calculated.

III. MODELING OF DYNAMIC VOLTAGE RESTORER

Figure (1) shows modeling of DVR and studies the Effect of Transmission line Capacitance on DVR Performance when short circuit fault occurred on load bus . The DVR model is designed for each phase to measure single phase voltage. the introduced DVR consists of three blocks of PI Controller, and three blocks of single phase voltage source converter.

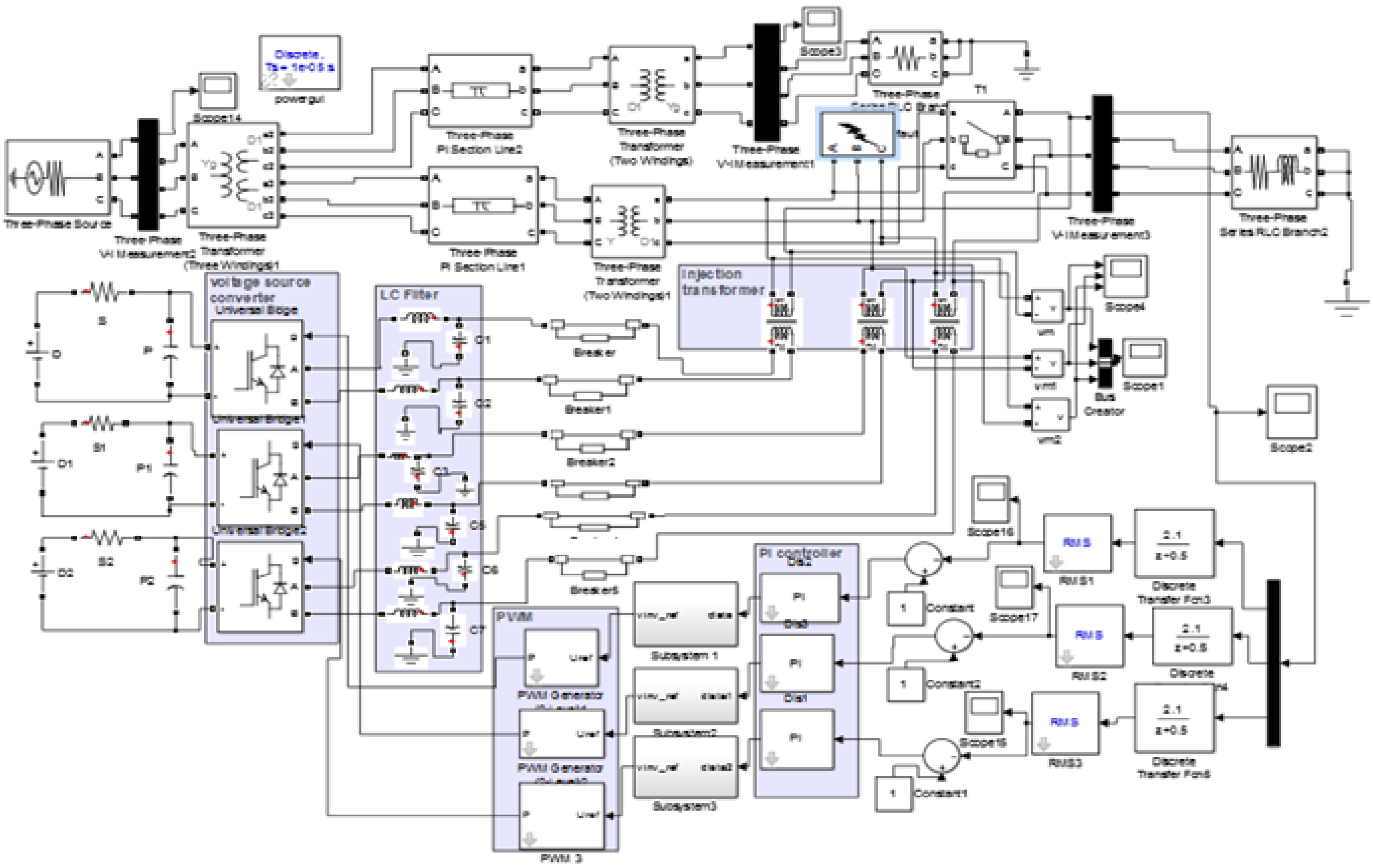

Figure (1):Simulation model with DVR

A. SIMULATION RESULTS AND DISCUSSIONS

Figure (2) presents single line diagram of test system used to study the performance of proposed dynamic voltage restorer. Test system of DVR is composed by 13 kV, 50 Hz generation system, supply two transmission lines through 3-winding transformer connected in Y ⁄ Δ ⁄ Δ, 13 ⁄ 115 ⁄ 115 kV. Such transmission lines supply two distributions networks through two transformers are connected in Δ ⁄ Y, 115 ⁄ 11 kV. The simulations are done as follows.

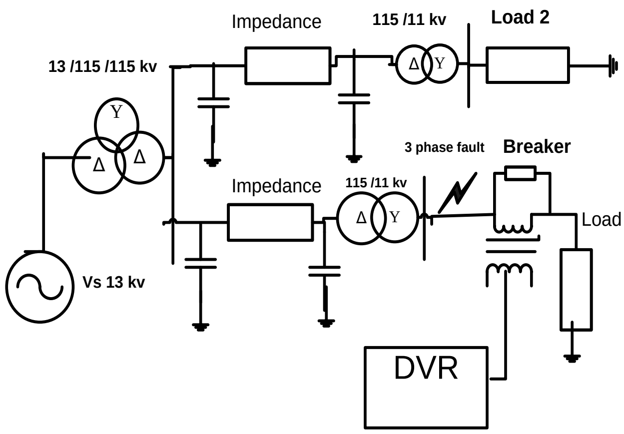

Figure (2): Single line diagram of test system

a) Three phase fault without DVR

In this model three phase short circuit fault is studied, three phase fault is applied at load point, and it has fault resistance of 0.33 ohms during the period 0.2 to 0.3 sec. It is found that voltage sag at phase A, B, C in Figure (3) are equal. as shown in table1.

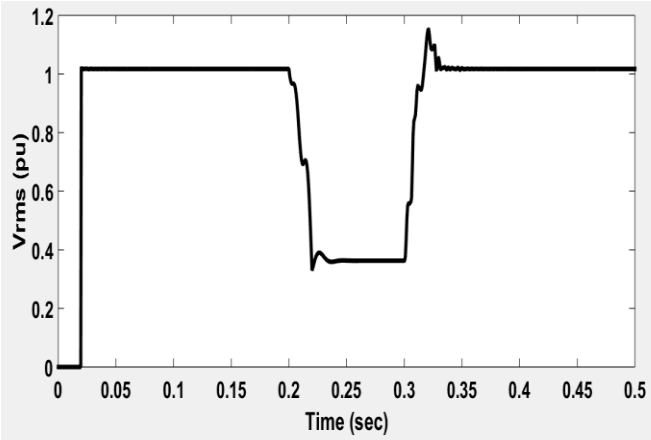

Figure (3): RMS load voltage at phase (A,B,C) with three phase fault without DVR, With L=200km

Table 1: The different length of line in case of *3-Φ fault without DVR*

The Length of line (km)	Out DVR sag magnitude %
100	50%
200	64%
230	67%

b) <u>Three phase fault with DVR</u>

The voltage sag is mitigated as shown in Figure (4) when DVR is connected to model. Also the required DC voltage increase with increasing the length of the line as shown in Table 2.

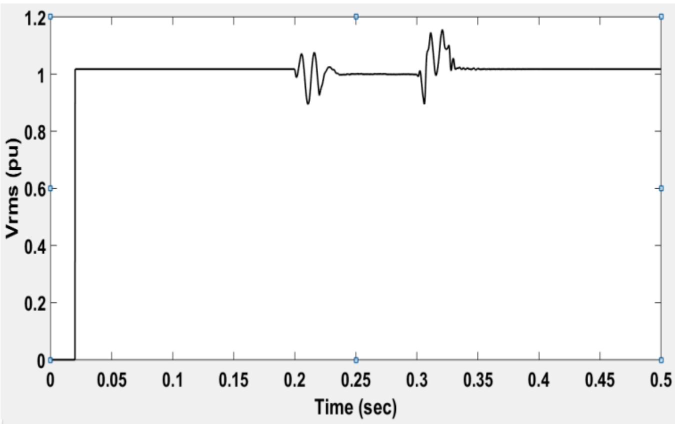

Figure (4): RMS voltage at phase (A,B,C) with three phase fault with DVR, with L=200km

Table 2: The different length of line with 3-Φ fault, with DVR

The length of line (km)	Required DC $_{new}$ Voltage	With DVR sag magnitude %
100	5kv	100
200	5.6kv	99
230	5.8kv	99

c) <u>single line to ground fault without DVR</u>

Single line to ground fault is applied at load point. It has fault resistance of 0.77 ohms during the period 0.2 to 0.3 sec , the voltage sag and swell occur when DVR is not connected as shown in Figure (5,6,7) and table 3. Voltage profile increases with increasing the length of linephases.

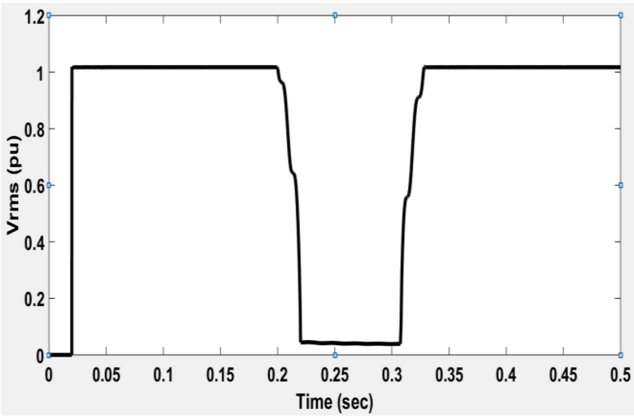

Figure (5): RMS load voltage at phase A with single line to ground without DVR, with L=200km

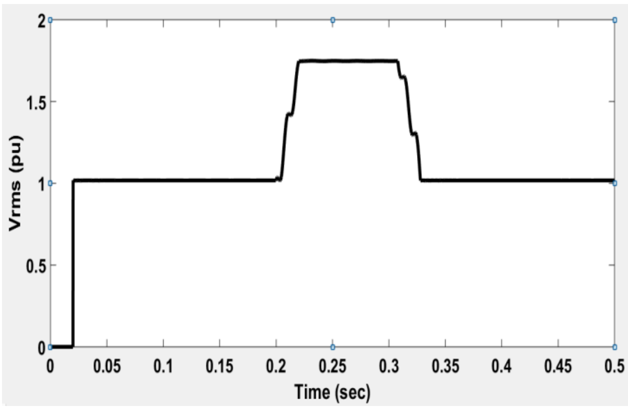

Figure (6): RMS load voltage at phase B with single line to ground fault without DVR, with L=200km

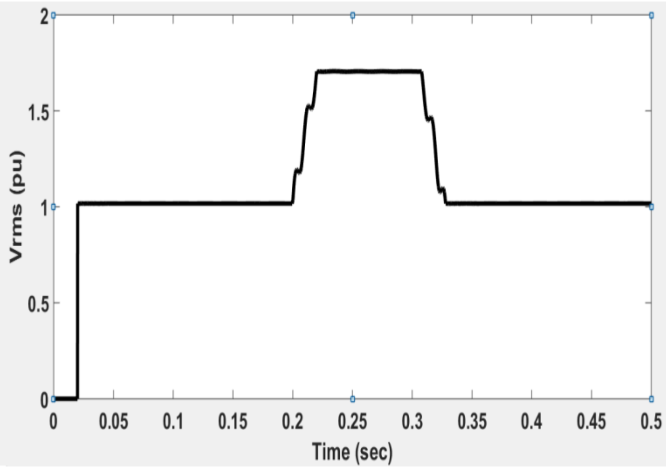

Figure (7): RMS load voltage at phase C, with single line to ground fault without DVR, with L =200km

Table 3: The different lengths of line with single line to ground fault, without DVR

The length of line (km)	Sag in Phase A %	Swell in Phase B %	Swell in Phase C %
100	96	71	68
200	96	75	70
230	96	78	72

d) Single line to ground fault with DVR

The voltage sag and swell are eliminated When DVR is connected to model, as shown in Figure (8,9,10). The value of required DC voltage not change with increasing the length of line because the increasing in voltage swell is small. And voltage sag value not change as shown in table 4.

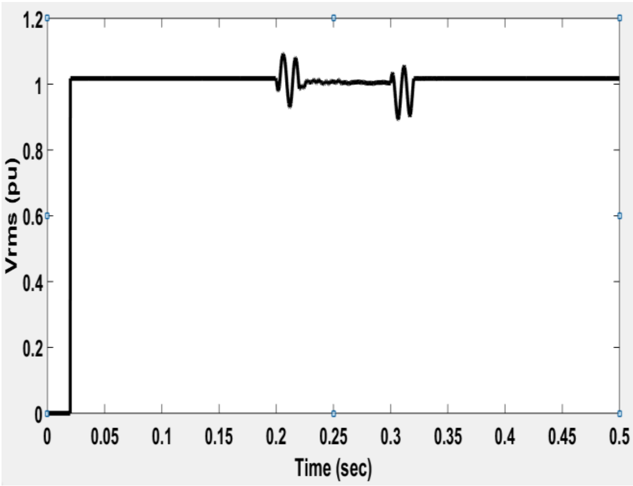

Figure (8): RMS load voltage at phase A, with single line to ground fault with DVR, with L =200km

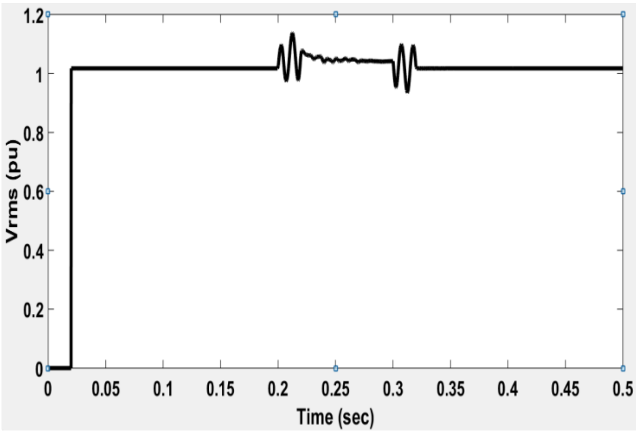

Figure (9): RMS load voltage at phase B, with single line to ground fault with DVR, with L=200km

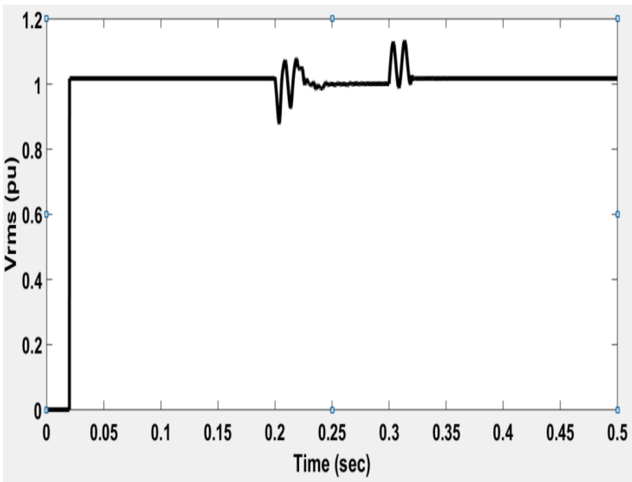

Figure (10): RMS load voltage at phase C, with single line to ground fault with DVR, with L=200km

Table 4 The different lengths of line with single line to ground fault, with DVR

The length of line	Sag in Phase A %	Swell in phase B%	Swell in phase C %	Required DC voltage
100	100	100	100	VdcA =7.8KV vdcB=12kv vdcC=17kv
200	100	100	99	
230	98	100	99	

e) Line to line fault (A, B) without DVR

A Line to line fault is applied at load point.it has fault resistance with 0.77 ohms during the period 0.2 to 0.3 sec. the voltage sag takes place when dynamic voltage restorer is not connected.the voltage sag takes place at phase B in Figure (12) as shown in table 5 . But load voltage at phase (A, C) in Figure (11,13) is equal to reference voltage. also voltage profile increases.

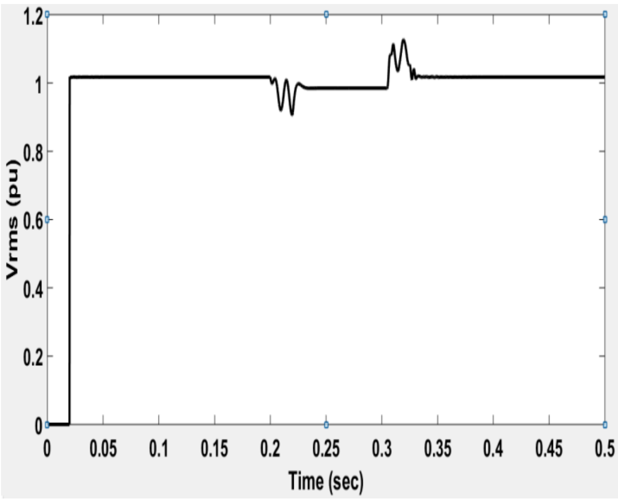

Figure (11): RMS load voltage at phase A, with line to line fault without DVR, with L=200km

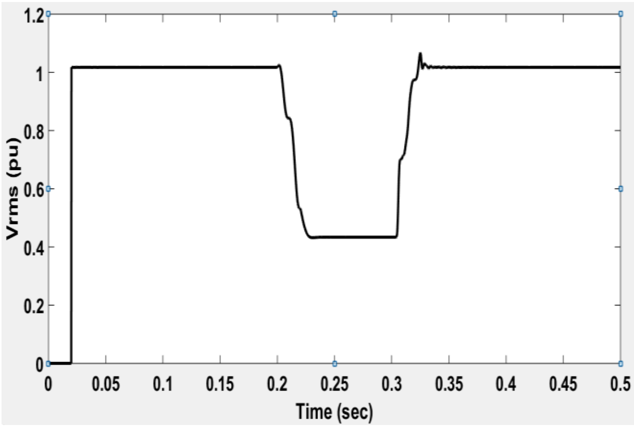

Figure (12): RMS load voltage at phase B, with line to line fault without DVR, with L=200km

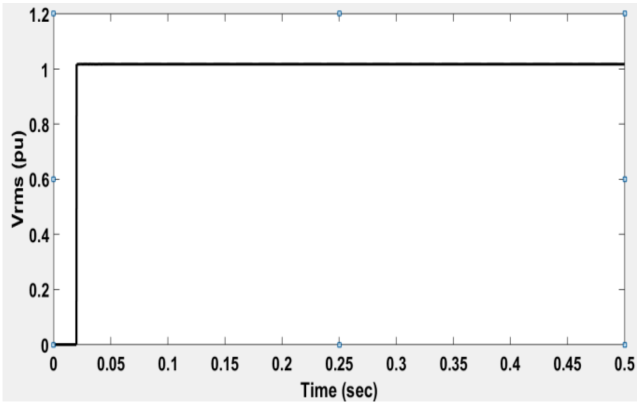

Figure (13): RMS load voltage at phase C, with line to line fault without DVR, with L=200km

Table 5: The different lengths of line with line to line fault, without DVR

The length of line (km)	Out DVR Sag in phase B %
100	42%
200	53%
230	55%

f) Line to line fault (A, B) with DVR

The voltage sag at phase B in Figure (14) is mitigated when DVR is connected to model as shown in table 6. when the length of line increases the required DC voltage of DVR reduce.

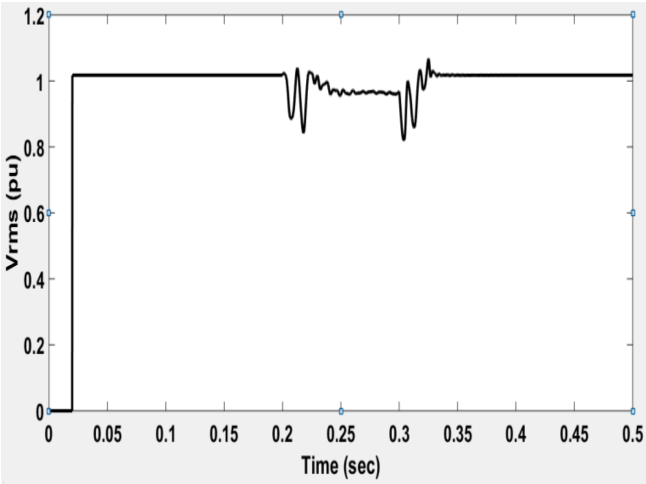

Fig (14) RMS load voltage at phase B, with line to line fault with DVR, with L=200km

Table 6 : The different lengths of line with line to line fault, with DVR

The length of line (km)	Phase A%	Sag in Phase B%	Phase C%	Required DC $_{new}$ Voltage (kv)
100	100%	99%	100%	V_{dcA}=3kv, V_{dcB}=10.8kv, V_{dcC}=16.5kv
200	100%	97%	99%	V_{dcA}=1.6kv, V_{dcB}=10.5kv, V_{dcC}=16.8KV
230	99%	96%	98%	V_{dcA}=1.5kv, V_{dcB}=10.2kv, V_{dcC}=17kv

g) <u>Double line to ground without DVR</u>

A double line to ground fault is applied at load point. it has fault resistance with 0.77 ohms during the period 0.2 to 0.3 sec. the voltage sag and swell occur in Fig (15,16,17) when DVR is not connected. as shown in table 7.

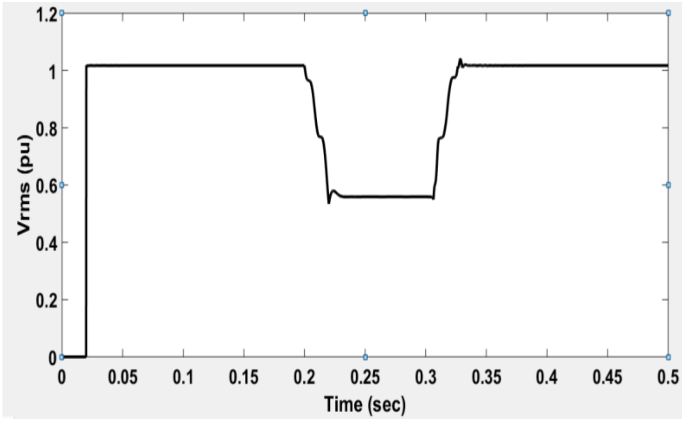

Fig (15) RMS load voltage at phase A, with double line to ground fault without DVR, with L=200km

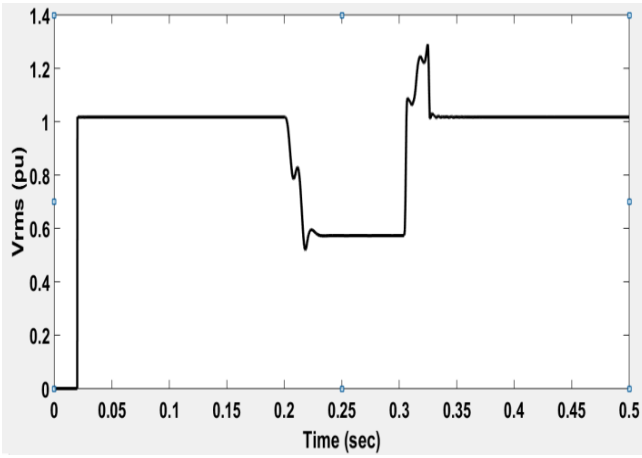

Fig (16) RMS load voltage at phase B, with double line to ground fault without DVR, with L =200km

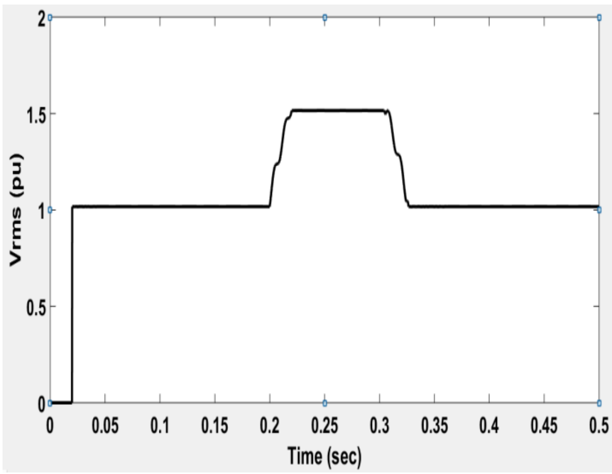

Fig (17) RMS load voltage at phase C, with double line to ground fault without DVR, with L=200km

Table 7: The different lengths of line with double line to ground fault, without DVR

The length of line(km)	Sag in phase A %	Sag in phase B%	Swell in phase C %
100	35%	35%	48%
200	45%	43%	51%
230	47%	47%	53%

h) <u>Double line to ground without DVR</u>

The voltage sag and swell are eliminated When DVR is connected to model as shown in Figure (18,19,20). the required DC voltage of DVR reduce with increasing the length of line as shown in table 8.

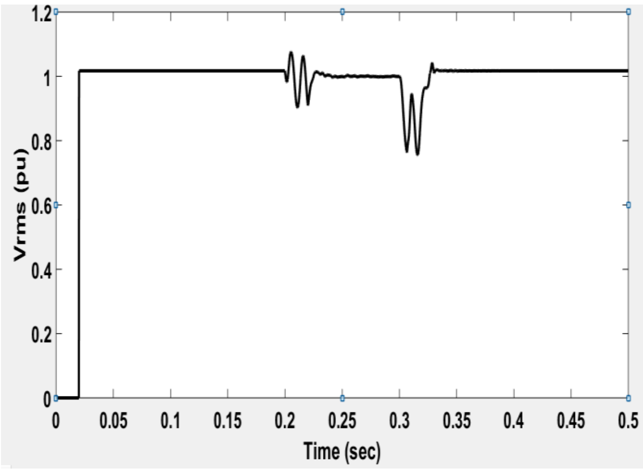

Figure (18): RMS load voltage at phase A, with double line to ground fault with DVR, with L=200km

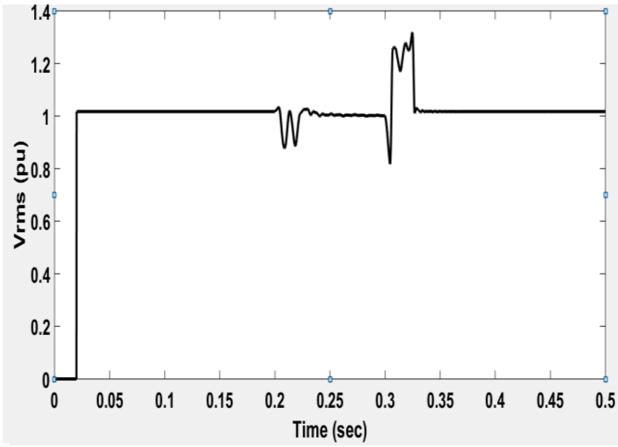

Figure (19):RMS load voltage at phase B, with double line to ground fault with DVR, with L=200km

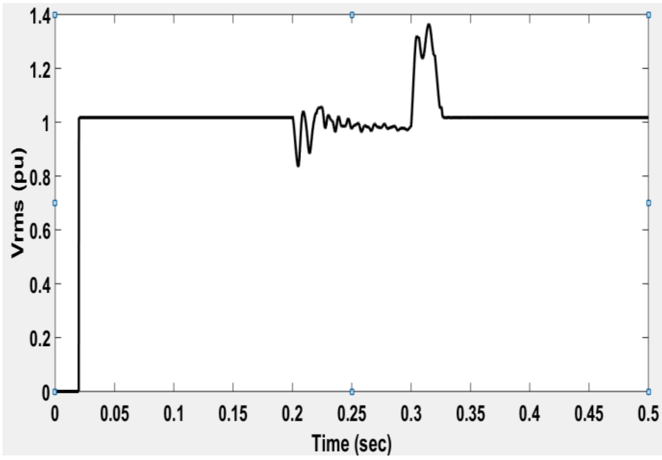

Figure (20): RMS load voltage at phase C, with double line to ground fault with DVR, with L=200km

Table 8: The different lengths of line with double line to ground fault, with DVR

The length of line(km)	Phase A%	Sag in Phase B%	Phase C%	Required DC $_{new}$ Voltage (kv)
100	100%	100%	100%	V_{dcA}=9.2kv, V_{dcB}=7.5kv, V_{dcC}=16.5kv
200	100%	100%	99%	V_{dcA}=8.4kv,V_{dcB}=7kv, V_{dcC}=16.5KV
230	98%	98%	99%	V_{dcA}=8.2kv, V_{dcB}=6.8kv, V_{dcC}=16.5kv

VI. CALCULATIONS OF DVR COST

Assume compensation level for the single-phase load is 50%**.** the coupling transformer power used in the classical dynamic voltage restorer is calculated as: .

$$S_{ta} = S * \frac{N_C}{\square} 3 \quad (1)$$

Where (*S*) is the load apparent power, (*Nc*) is the compensation level of voltage sag and (*Sta*) is the apparent power of the single-phase coupling transformer.

from simulation: three phase load apparent power is calculated

$$S_1 3(= \sqrt{3}\, V_1(L)\, I_1(L)) = 1399982.027 = 1.4 Mva \quad (2)$$

$$S_1 ta = 0.5 * 1399982.027(3 = 233.33\ KVA \quad (3)$$

The coupling transformer secondary voltage could be calculated by multiplying the load single-phase voltage by the required compensation level.

$$V_s = N_C * V_L = 0.5 * \frac{11}{\sqrt{3}} = 3175\ V \quad (4)$$

The minimal dc link voltage could be calculated as:

$$V_{mdc} = V_s * \sqrt{3}\sqrt{2} * \frac{V_1}{V_2} = 9503.65\ V \quad (5)$$

The lowest possible remaining energy would be the logical choice since it limits the capacitor value, but this would result in a high steady state voltage (voltage in which the dynamic voltage restorer does not inject neither absorb energy), effect directly in the cost of the switches and rated voltage. the minimal dc link voltage is known, it is possible to calculate the capacitor value by defining the remaining energy available in the dc link. The remaining energy of 1 MJ was chosen [13].The capacitor value is calculated as:

(6)

The maximum dc link voltages and the steady state can be calculated by using

$$V = \sqrt{\frac{2E}{C}} \quad (7)$$

As the capacitor absorbs 350 kJ until reaching the maximal voltage and injects 350 kJ until reaching the minimal voltage, the steady state and the maximum dc link voltages are, respectively: [11]

$$V_t = \sqrt{\frac{2 * 1350000}{0.0221}} = 11078.23 \quad (8)$$

$$V_{mdc} = \sqrt{\frac{2 * 1700000}{0.0221}} = 12431.63 \quad (9)$$

Considering the rated voltage of the switches in function of the market available and price, IGBTs of 1200 V are chosen[14]. Therefore, it is necessary to decrease the maximum dc link voltage, fitting the switches voltages. Adopting a safety margin of 33%, the same margin used in commercial inverters, the maximum dc link voltage has to be decreased to 1,139 V.
To obtain the required decrease, the turns-ratio of the coupling transformer is 1:2 and its primary voltage is calculated as:

$$V_p = V_s * 0.5 = \frac{3175}{\square} 2 = 1587.5 \quad (10)$$

To calculate the current through the IGBTs, the primary current is multiplied by the turns-ratio, obtaining 146.96A.
The coupling transformer has secondary voltage of 3175 V, primary voltage of 1587.5 V and rated power of 466.6 kVA. The power is defined as a double of the power that will be injected by the transformer. This is a safety margin used by the industry to avoid saturation in transient situations that could cause destroy to the dynamic voltage restorer [13]. Note that this transformer introduces special characteristics and it is designed to attend the application requirements, resulting in high cost. Another important characteristic is the low resistance in the windings to reduce losses. The price of the coupling transformer in relation to the conventional transformer is increased in 10% due to impossibility of obtaining the exact cost . The cost includes the filter that constitutes other element in which the characteristics depend on the place where it would be used [13]. Table 9 was built by using the prices obtained in [14].

Table .9 Calculated cost of the DVR

Item	Price (US$)
H-bridge (3unit)	374.04
Three phase rectifier	1,549.48
Coupling transformer	41,976

Capacitor bank (3 unit)	20,010
Total	63,909.52

VII. CONCLUSION

This paper studies the performance analysis of DVR in presence of transmission line capacitance. Presence of transmission line capacitance increases voltage profile. Different fault types three phase, single line to ground fault and double line to ground are applied at the load bus to examine the powerful of the proposed DVR. In case of three phase fault, The required DC voltage of DVR increases with increasing the length of line while in case of double line to ground fault and line to line fault with DVR the required DC voltage of DVR reduce with increasing the length of line. Also, the total cost of proposed DVR model components are calculated .

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