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The Effect of Series-Connected Transformer in DVR Applications

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Abstract

This paper presents the effect of Series-Connected Transformer in DVR Applications. Sizes of DVR are 10 kVA, 380 Volt and frequency 50 Hz. According to the DVR operation, the comparison of with and without series-connected transformer is studied. To shows that without transformer can be operated better than with transformer. Operation of with transformer will have an impact on the phase shift and voltage drop. The simulation results show that the magnitude of load voltage without the transformer about 1.0 p.u. (per unit) more than with transformer. Moreover, it has not effect of phase shift and no voltage drop. Therefore, it can be ensured that the effect of transformer, that occurred on results has to consider for DVR applications. In addition if build the prototype can be reduced cost of transformer.

Keywords: Dynamic Voltage Restorer; Transformer; Voltage Sag

1. Introduction

Voltage sag is the one of power quality problems that will damage production process, especially; the industry is controlled by power electronics equipments. The voltage sags in power system under IEEE 1159-1995 standard [1] is the reduction of the magnitude of voltage supply in a short time, since 0.5 cycles until a minute and return to normal conditions as shown in Fig. 1. The rms value of voltage between 0.1 p.u. and 0.9 p.u. compared with the voltage of the system is 1.0 p.u. There are two important variables, the magnitude and duration of voltage sag.

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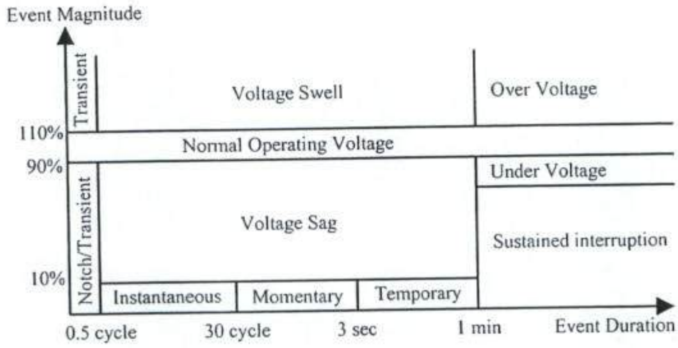


Fig. 1. IEEE 1159-1995 standard.

Dynamic Voltage Restorer (DVR) is the electrical equipment, installed to compensate for the lost voltage when voltage sag occurred. There are many researchers studied and developed the DVR technique. Single control loop technique is one of DVR technique which can control the peak of voltage but it has problem in control sensitivity and the presentation of control information [2]. Thus, DVR is not used injection voltage transformers and capacitors DC-link can be self-recharged in normal condition are developed. So if there is not transformer, then the DVR has been reducing the size and costs [3]. After that a multi-functional DVR presented that in addition to compensating voltage sag and voltage swell can limit fault current and keep constant large variation of the system frequency. But results showed that the efficiency of compensation is not clear [4]. Although the results of research are able to compensate for the voltage sag but the control of the DVR is still unclear. Therefore, an attempt to reduce the complexity of the algorithm in the control DVR and don't use transformers for Voltage injection [5].

The study of the DVR, mainly will not mentioned about the effect of the transformer. Knowledge, Transformers has flaw is incur phase shift and voltage drop. Moreover, the saturation of the transformer and inrush current is cause need to use is the transformer with rated 2 times the rated DVR [5]. Then this paper presents the analysis of DVR and comparison between with and without transformers. In addition, show that compensation method is not using transformers. It has effective more than with transformer. The presentation is the following steps.

This paper is organized as follows. The analysis of main performance of the DVR is described in Section II. Simulation and results using the Matlab/Simulink program is presented in Section III. And finally, conclusion of the DVR is presented in Section IV.

Nomenclature

DVR	Dynamic Voltage Restorer
p.u.	Per Unit
rms	Root Mean Square
AC	Alternating Current
DC	Direct Current
IEEE	Institute of Electrical and Electronics Engineers

PWM	Pulse-width modulation
mmf	Magnetomotive force
N	Number of turns in the coil
E	Voltage induced in the coil
I	Current in amperes
Z	Impedance of transformer
R	Resistance of transformer
X	Inductance of transformer
V	Voltage input/output of transformer
a	Ratio of transformer
U_i	the source and supply line impedance
t	Time of inrush current
C_i	Capacitance of the power supply
kHz	Kilohertz
μF	Microfarad
mH	Millihenry
Ω	Ohm

2. Analysis of main performance of DVR

All DVR generally consists of 3 main parts: energy conversion, energy storage, and controller as shown in Fig. 2. Compensate method for the voltage of the DVR can be classified into 3 methods [6];

1) Pre-Sag Compensation
2) in-Phase Compensation
3) Energy Optimization Technique

In this present work, Pre-Sag Compensation method is selected because can compensate both the size and voltage phase angle.

2.1. Control of DVR

Operation of control systems starting in occurred voltage sag. Detector will verify it. When there are signs it, the reference voltage generator part is created reference voltage for comparison with the actual voltage in the system. After, the voltage in this comparison will sent to PWM in the compensating voltage generator & voltage injection part for drive the converter, so it will inject voltage into the system. Block diagram of the control as show in Fig. 3.

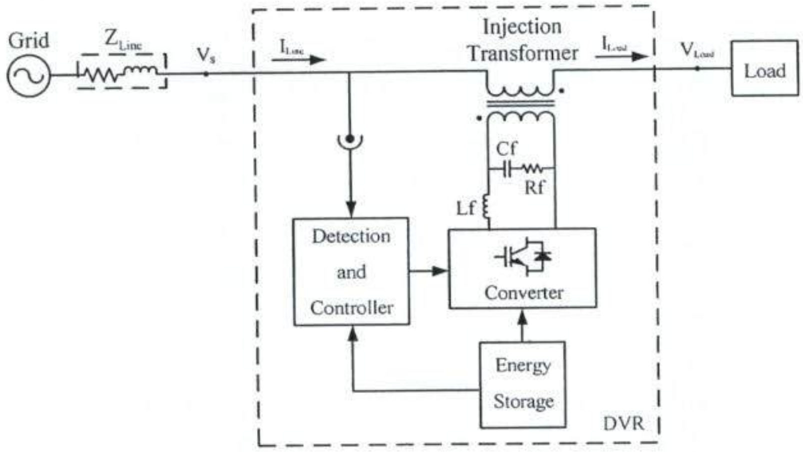


Fig. 2. Components of the DVR.

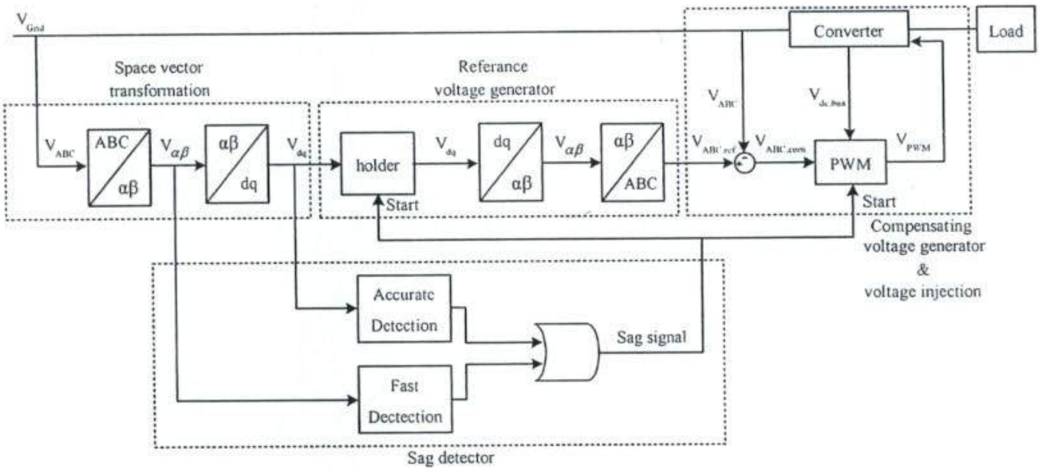


Fig. 3. Block diagram of the control of the DVR.

2.2. Series-connected transformer

Transformer acts as a power transfer from the DVR to the load. Transformer consists of 2 sets of windings around the core, which can be written in the equivalent circuit as shown in Fig. 4 [7]. For the equivalent circuit will be

$$X_0 = E_1 / I_\mu \qquad (1)$$

$$R_0 = E_1 / I_\omega \quad (2)$$

$$Z_m = R_0 // X_0 \quad (3)$$

$$Z_1 = R_1 + X_1 \quad (4)$$

From $E_2 / E_1 = N_2 / N_1 = a$ we can move values from one side to the other side. In Fig. 4 when the secondary winding moved toward primary winding. We can write the complete equivalent circuit of a transformer as shown in Fig. 5. Parameters move from the secondary winding toward the primary winding can be obtained from the following equation.

$$I_2' = aI_2 \quad (5)$$

$$V_2' = V_2 / a \quad (6)$$

$$R_2' = R_2 / a^2 \quad (7)$$

$$X_2' = X_2 / a^2 \quad (8)$$

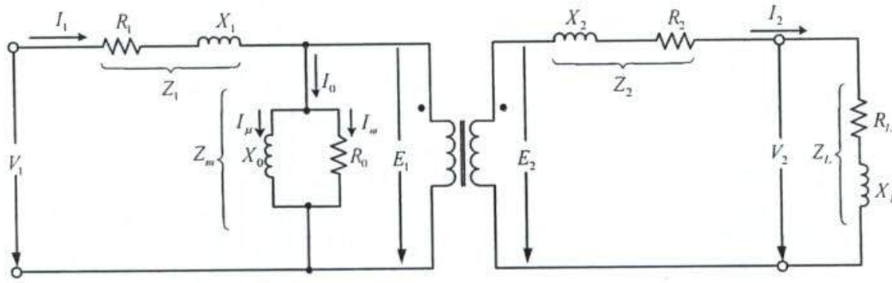


Fig. 4. The equivalent circuit of series connected transformer.

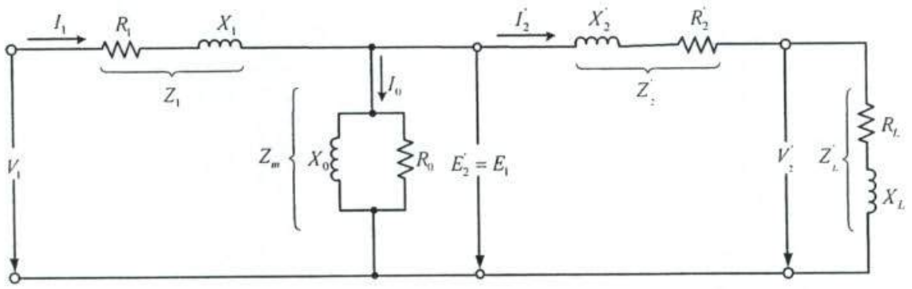


Fig. 5. The complete equivalent circuit of series connected transformer.

The complete equivalent circuit of transformer can be evaluated V_2' from the ratio of the voltage;

$$V_2^{'} = \left(\frac{I_2^{'} Z_2^{'}}{I_1 Z_1 + I_0 Z_m} \right) V_1 \tag{9}$$

The transformer is connected between converter and power system will caused a phase shift and voltage drop due to the drawback of the transformer. Moreover, the transformer rate is 2 time of DVR rate because the saturation of transformer and inrush current. Thus, the transformer is large and expensive.

2.3. Inrush Current

When transformer connected to AC power supply the initial state will be surge current flow into through the primary winding, called inrush current. This is similar to the start-up of the motor suddenly.

When starting injects voltage to transformer, the magnetic flux and current in the coil will start at zero and gradually increases as shown in Fig. 6. So in the beginning of transformer flux is approximately twice the maximum size of the normal because the total area under waveforms of the voltage in first half cycle. In the ideal transformer, the magnetic current increases of approximately twice the normal maximum as well because generation magnetomotive force (mmf) which is flux higher than the normal. Winding currents generated mmf to cause flux in winding increases more than twice the maximum value of normal flux. This is causing inrush current in transformers. That requires a transformer rated is the 2 times of the rated DVR. If the transformer has a magnetic field residues in the core during the time of the connection to supply makes inrush current may have increased the intensity. From Fig. 7 and 8 the peak value ($I_{inr\,p}$) of the inrush current can be estimated as follows: [10].

$$I_{inr\,p} < \frac{U_i}{R_{s\,ext} + R_i} \tag{10}$$

The rise time $t_{inr\,r}$ is given by:

$$t_{inr\,r} \approx \frac{L_{s\,ext} + L_i}{R_{s\,ext} + R_i} \tag{11}$$

The time to half value $t_{inr\,h}$ is given by:

$$t_{inr\,h} \approx 0.7 \times (R_{s\,ext} + R_i) \times C_i + t_{inr\,r} \tag{12}$$

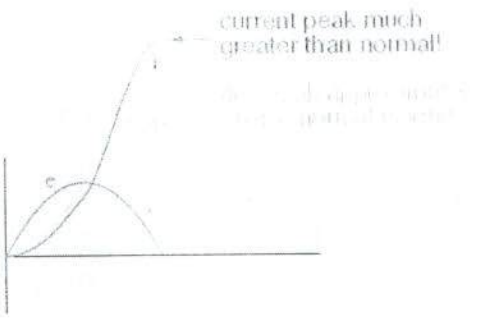


Fig. 6. Current, flux and voltage waveform of series connected transformer.

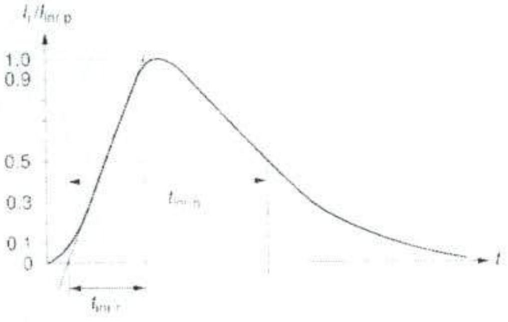


Fig. 7. Inrush current waveform.

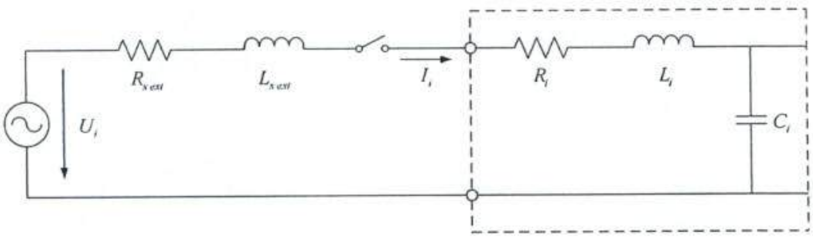


Fig. 8. Circuit of occurred inrush current.

3. Simulation results

The simulation program is Matlab/Simulink. DVR will be connected to the secondary side of transformers in the distribution system as shown in Fig. 9. The defined as fault in the power system at a time 0.1 seconds until 0.04 seconds, three-phase voltage 380 V 50 Hz, Switching frequency 20 kHz, $C_f = 8\mu F$, $L_f = 2mH$, $R_f = 32\Omega$, $C_{bus} = 6{,}600\ \mu F$, Criteria of the voltage sag $|V| \le 198$ V , $\Delta\theta > 1.85°$ or $\Delta\theta < 1.75°$ and load is series RL , it has value 13 Ω and 19 mH respectively.

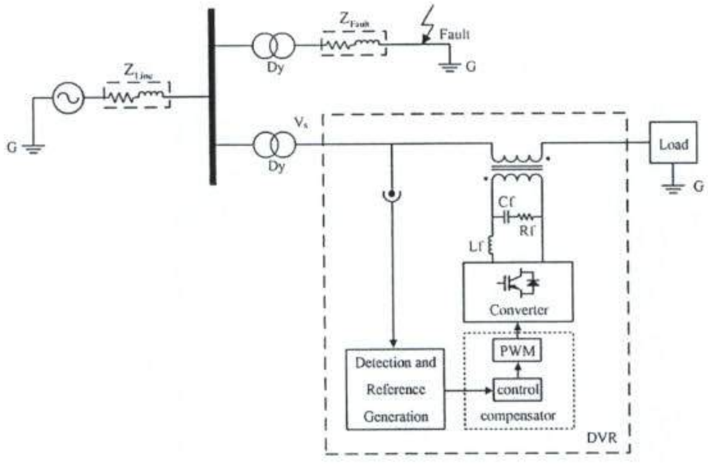
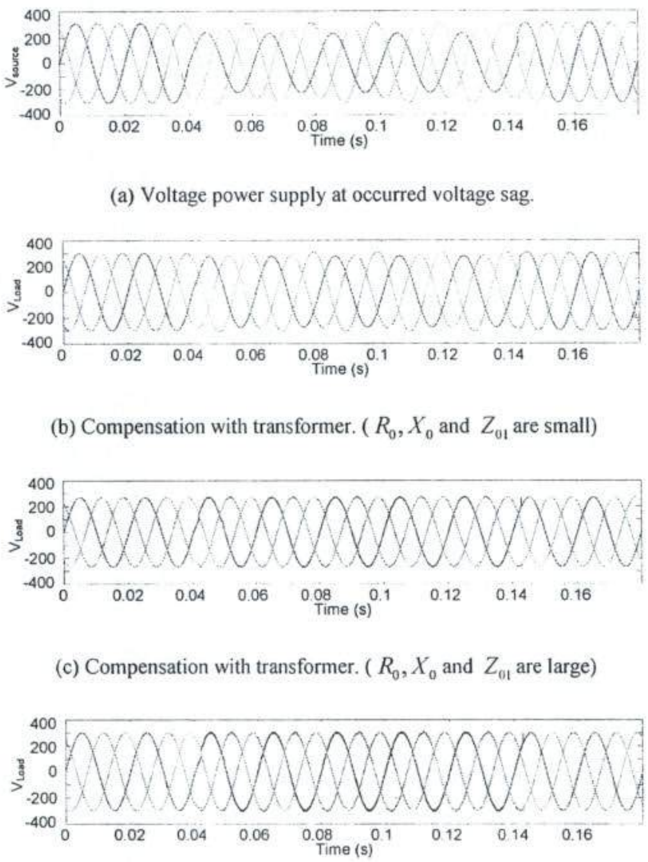


Fig. 9. Circuit Simulation of the DVR.



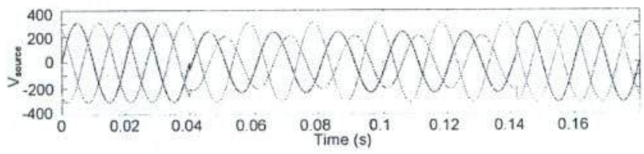
(a) Voltage power supply at occurred voltage sag.

(b) Compensation with transformer. (R_0, X_0 and Z_{01} are small)

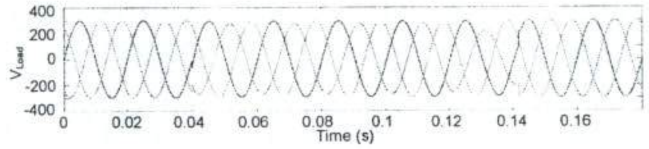
(c) Compensation with transformer. (R_0, X_0 and Z_{01} are large)

(d) Compensation without transformer.

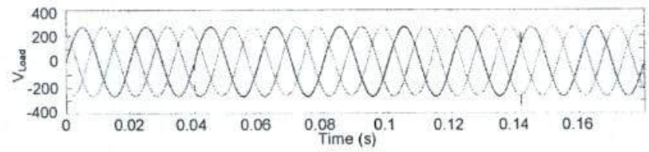
Fig. 10. Compensation with DVR In case of a single-phase fault at phase A to ground.



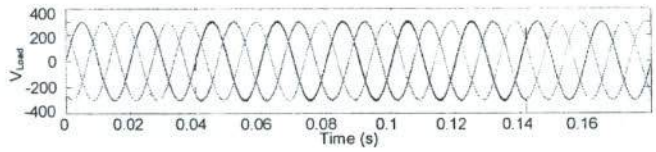
(a) Voltage power supply at occurred voltage sag.



(b) Compensation with transformer. (R_0, X_0 and Z_{01} are small)



(c) Compensation with transformer. (R_0, X_0 and Z_{01} are large)



(d) Compensation without transformer.

Fig. 11. Compensation with DVR In case of a double-phase fault between phase A and B.

4. Conclusions

The comparison between with and without transformers is considered in this paper. In Fig. 10 is compensation with DVR in case of a single-phase fault at phase A to ground. Compensation with transformer if R_0, X_0 and Z_{01} are small will be compensated bad and if R_0, X_0 and Z_{01} are large will be compensated bad and voltage drop as shown in Fig. 10(b), Fig. 10(c). In Fig. 10(d) showed that compensation without transformer will be compensated very well. In Fig. 11 is compensation with DVR in case of a double-phase fault between phase A and B. Compensation, both with and without transformers in this case same as in the previous case. Therefore Simulation results showed that the without transformers are performance better than with transformer, because the voltage after the installation of the DVR is about 1.0 p.u. compared with voltage of the power system is 1.0 p.u.. For the compensated with transformer, the key factors affecting the performance of the DVR is impedance of the transformer. If the large impedance, the residual current in the transformers will the voltage drop of the transformers were large. Therefore, the size of the transformer should be selected to the impedance suitable can reduce voltage drop in the transformer and better compensation. Moreover, if build a prototype. The DVR without transformers can reduce the cost of the transformer.

Acknowledgements

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