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SELF GENERATED DC LINK – VOLTAGE SOURCE INVERTER AS VOLTAGE DROP COMPENSATOR FOR POWER TRANSMISSION LINES

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Increasing the power transfer across the existing power transmission lines and compensating for the voltage drops across these lines are two major challenges which will have great effects on the existing power networks and on the construction of new transmission lines.The Instantaneous Voltage Controller (IVC), the theory of which was presented in [1, 2, 3, 4], was initially operated on Current Source Inverter (CSI) principle to modulate the transmission line reactance. Modulation of the transmission line reactance has great effects on controlling the power flow across the power transmission lines and subsequently on the stability of power transfer and on voltage drop across the power lines. This paper investigates the operation of IVC as Voltage Drop Compensator (VDC) for power transmission lines based on Voltage Source Inverter (VSI) instead of CSI. The voltage drop compensation presented in this paper is based on switching the VSI to act on the voltage error between the load voltage and a sinusoidal reference voltage. The voltage on the load is maintained equal to the reference sinusoidal voltage by inclusion a feedback from the voltage error into the power module capacitor. The voltage instability associated with increased load demand caused by inability of power systems to meet demand for reactive power [5] can also be solved using Voltage Drop compensation. The computer simulation of this design shows that the VDC is effective in preventing the voltage instability by reducing the inductive reactance of the line and by that allowing the transfer of more active reactive power across the line.

KEYWORDS: *Flexible Ac Transmission (Fact's), Power System Stability, Voltage Drop Compensation.*

1. INTRODUCTION

This paper presents the Voltage Drop Compensator (VDC) with self generated dc link Voltage Source Inverter. The purpose of VDC is to compensate for voltage drops on the power transmission line reactance and to control the voltage on the load or at the bulk supply point of the load centres. The voltage drop compensator, the circuit of which is shown in Figure 1, is operated in the mode to control the load voltage by comparing it to a sinusoidal reference voltage. Controlling the load voltage by this way causes the capacitor voltage to be out of phase with the voltage drop across the transmission line reactance. The mathematical model of VDC is presented in Equations [1-7]:

$$\frac{di}{dt} = \frac{v_s + (R_S + R_{TL} + R_L)i - v_c}{(L_S + L_{TL} + L_L)} \tag{1}$$

$$\frac{di_{dc}}{dt} = \frac{v_{dc} + (1-2D)v_c - R_{IGBT}\, i_{dc}}{2L_F} \tag{2}$$

$$\frac{dv_c}{dt} = \frac{i + (2D-1)i_{dc} + k_{VEFB}v_{ia}}{C} \tag{3}$$

$$\frac{dv_{dc}}{dt} = -\frac{i_{dc}}{C_{dc}} \tag{4}$$

$$v_{ia} = K(v_i + \int v_i dt) \tag{5}$$

$$v_i = v_o - v_o^* \tag{6}$$

$$k_{VEFB} = n_1 \omega C_{ac} \tag{7}$$

Where, R_s and L_s are the resistance and inductance of the source. The parameter D in Eqns. (2,3) is equal to 1 for operation in the mode to increase the capacitor voltage and equal to 0 for operation in the mode to decrease the capacitor voltage.

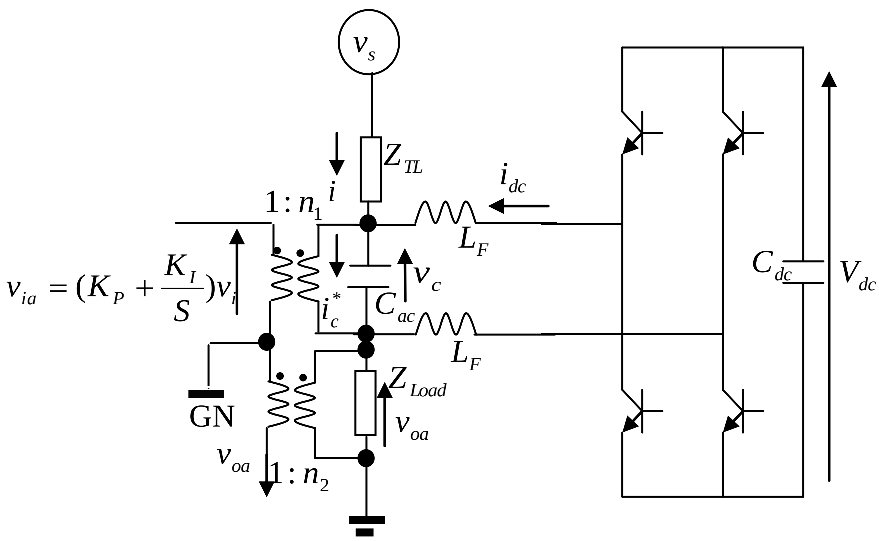

Figure 1: Circuit Diagram of the Voltage Drop Compensator without Rectifiers

2. ADVANTAGES OF USING VDC IN POWER TRANSMISSION LINES

There are several advantages of using VDC as part of the transmission line. These are:

1. Increasing the power transfer over the existing transmission systems and eliminating the need to construct new transmission lines.
2. Solving the problem of the right of way limitation.
3. Improving the stability of power transmission by decreasing the transmission line reactance and reducing the phase angle between the receiving and the sending ends voltages.
4. Preventing the voltage instability resulted from sever load demand and increased transmission line impedance.
5. Maintaining the shape of the output voltage by forcing it to follow a sinusoidal reference voltage, for example. This solves the problems of distorted voltage supplied to sensitive equipment and eliminates the distortions. The parameters for the above circuit are shown in Table1.

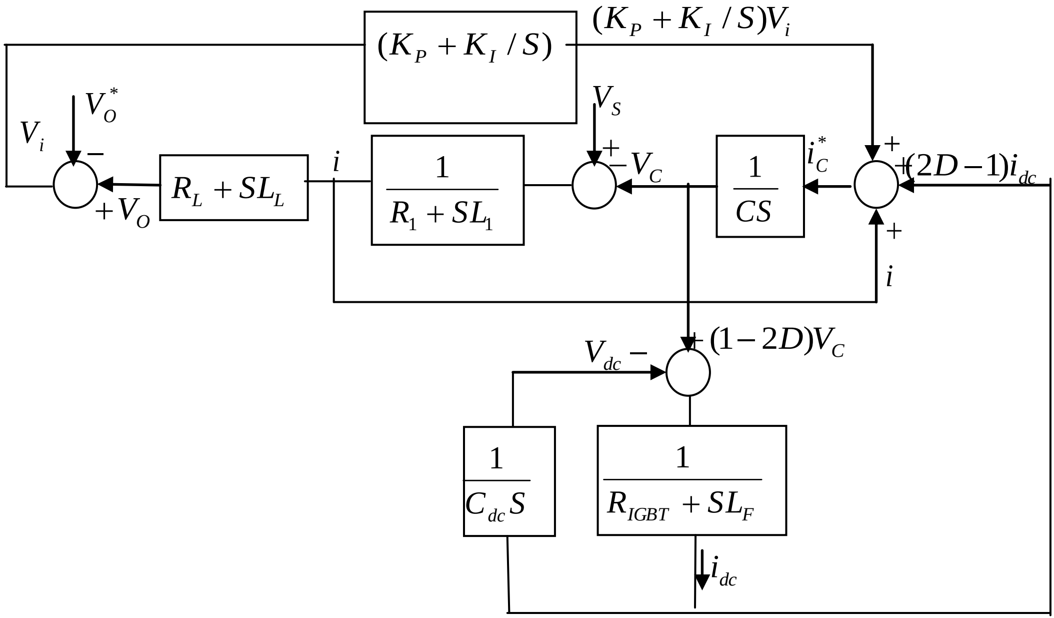

Figure 2: Block Diagram of the Voltage Drop Compensator without Rectifiers and with Voltage Error Feedback

Table 1: Parameters of the Source and Transmission Line				
$R_{TL} + R_S$ Ω	$L_{TL} + L_S$ mH	C_{ac} μF	C_{dc} μF	Load Power (VA)
6	160	65	80	360

3. PERFORMANCE OF VOLTAGE DROP COMPENSATOR ON 132KV LINE

The dc link voltage v_{dc} in Equation (2) is generated internally without using rectifiers. Generating the dc link voltage with rectifiers has the disadvantages of injecting harmonics into the network and causing higher dc currents in the dc link which result in higher switching losses. The performance of the voltage drop compensator without rectifiers was studied on 100 km double circuits 2x400mm2, ACSR with thermal current rating $S_{th} = 404MVA$, 1668 Amperes. The computer simulation of this line is done by setting the source voltage of 132V, which represents 132KV line-to-line. The load power is set to 120 and 360 VA representing 120 and 360 MVA at the receiving end. The load of 120 VA is 30% of the thermal power rating of the two circuits and is considered as the base power for simulation. The simulation is done with 120 and 360 VA load with and without VDC. The waveforms of load and reference voltages without VDC are shown in Figures (3,4). The load voltages are equal to 0.84 pu and 0.58 pu, respectively.

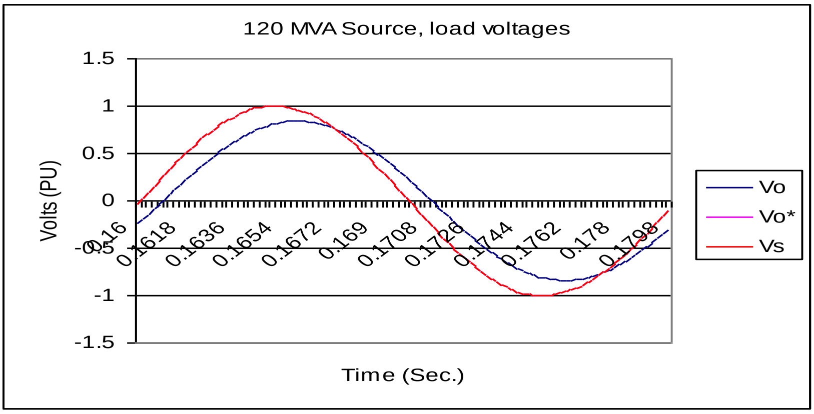

Figure 3: 120 VA (1 p.u.) load and source voltages without VDC voltage (Vo=0.84 p.u).

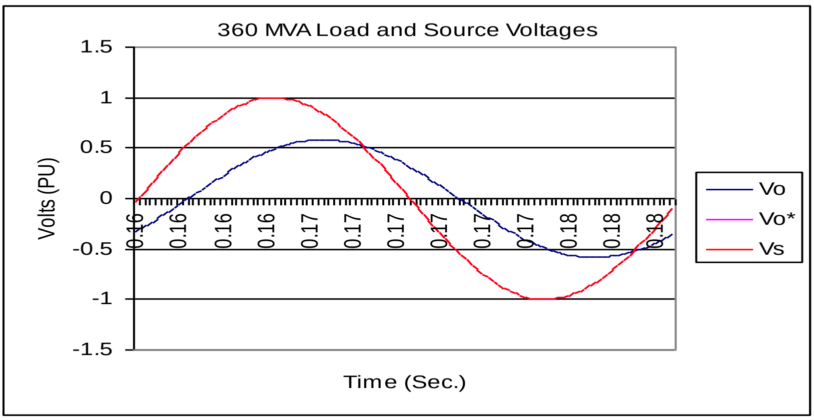

Figure 4: 360 VA Load and source voltages without VDC voltage (Vo=0.58 p.u).

4. VOLTAGE DROP COMPENSATOR PERFORMANCE:

The performance of the voltage drop compensator to compensate for the voltage drop across the transmission line and to control the load voltage was studied by solving the mathematical model of the design of Eqns. (1-7). Computer simulation of the effects of VDC with self generating dc link voltage on voltage magnitudes and power angles are shown in Figures (5,6). The effects of VDC are to make the voltage drop across the transmission line v_{TL} and the voltage across the capacitor v_C out of phase, as seen in Fig. 7. The effects of VDC on increasing the load voltage and on decreasing the power angles are summarized in Table 2.

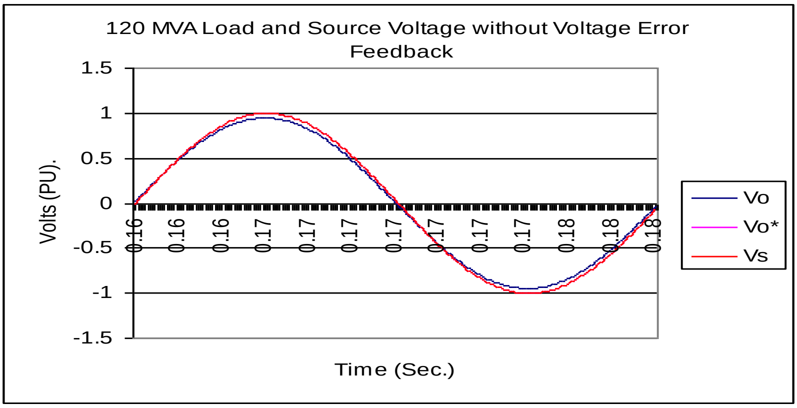

Figure 5: VDC with 120 VA Load ($V_o = 0.94 p.u.$)

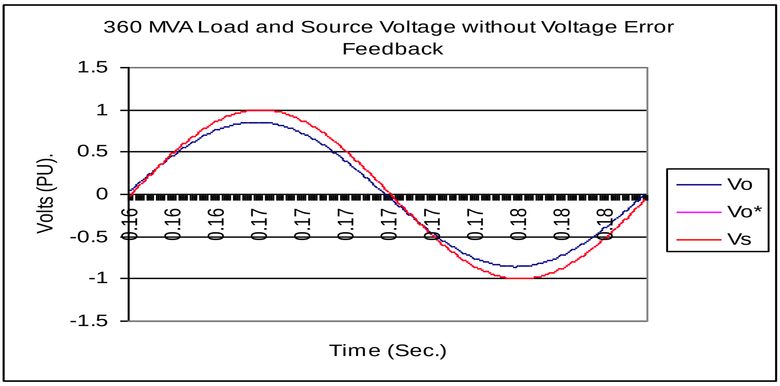

Figure 6: 360 VA load and source voltages $V_o = 0.854 p.u.$ with VDC

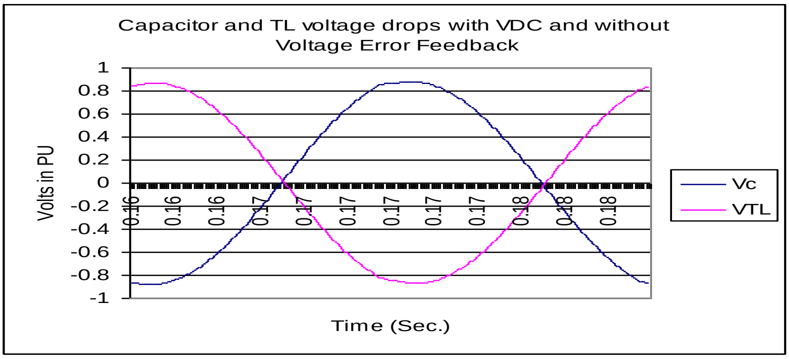

Figure 7: Voltage drops on TL and AC capacitor for 360 VA Load with VDC and without VEFB

Table 2: Effects of VDC on load voltage and power angle $\delta_{SR} = \delta_S - \delta_R$ without Voltage Error Feedback (VEFB)

S_{Load} (VA)	Without Voltage Drop Compensator		With Voltage Drop Compensator	
	Vo in p.u.	δ_{SR} in deg	Vo in p.u.	δ_{SR} in deg.
120	0.84	14.4	0.94	1.65
360	0.58	32.4	0.854	3.15

5. VOLTAGE DROP COMPENSATOR WITH VOLTAGE ERROR FEEDBACK (VEFB)

The load voltages as seen in Figures (5, 6) are less than 1.0 p.u. Due to this the energy output to the load is less than 1.0 p.u. as seen in Fig. 8. The un modulated capacitor current and the dc link voltage are shown in Figures (9,10), respectively. To make the load voltage follow the reference voltage, the voltage error $v_{ia} = (k_P + k_I / S)v_i$ from Figure 2 is feedback into the ac capacitor through a transformer to modulate the capacitor current by Eqn. (3).

Modulation of the capacitor current by the voltage error feedback (VEFB) improves the voltage on the load as seen in Fig. 11 compared to Fig. 6. Modulation of the capacitor current introduces a phase shift between the load and the capacitor current. The load and the modulated capacitor currents are shown in Fig. 12 as compared to Fig. 9. The voltage V_{LTL} , and V_C together with energy output and the dc link voltage are shown in Figures (13, 14, 15). The effects of voltage error feedback on the load voltage levels are summarized in Table 3.

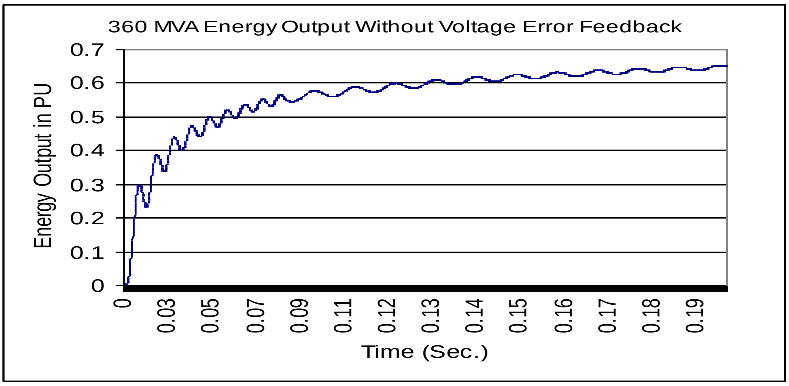

Figure 8: Energy Output to 360 VA load without Voltage Error Feedback.

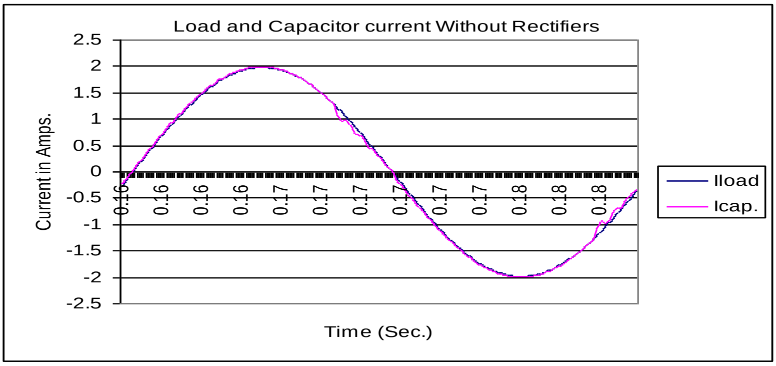

Figure 9: Load and Capacitor current without Voltage Error Feedback for modulation.

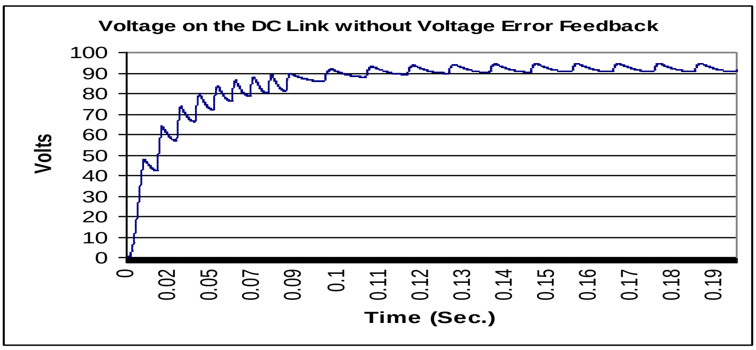

Figure 10: Self generated dc link voltage without Voltage Error Feedback signal.

Table 3: Effects of VDC with VEFB on load voltage and power angle $\delta_{SR} = \delta_S - \delta_R$

S_{Load} (VA)	VDC Without VEFB		VDC With VEFB	
	Vo in p.u.	δ_{SR} in deg.	Vo in p.u.	δ_{SR} in deg.
120	0.94	1.65	1.0	0
360	0.85	3.15	0.992	0

6. ACTIVE AND REACTIVE INCREASED POWER TRANSFER

The increase in the active and reactive power transfer is due to controlling the capacitor voltage v_c to remain out of phase with transmission line voltage drop. This reduces the reactance of the transmission lines. The effects of voltage error feedback on voltage drops on transmission line reactance and on power module capacitor are seen in Fig. 13, as compared to Figure 7. These voltage drops are proportional to the load current and are always opposing each other. Due to this compensation, more power can be transmitted over the line regardless of the load as long as it is less than the thermal limits of the line.

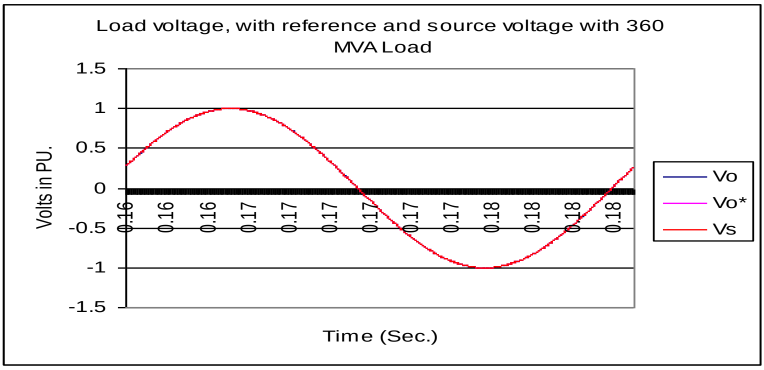

Figure 11 : Load and Reference Voltages with Voltage Error Feedback under 360 VA load.

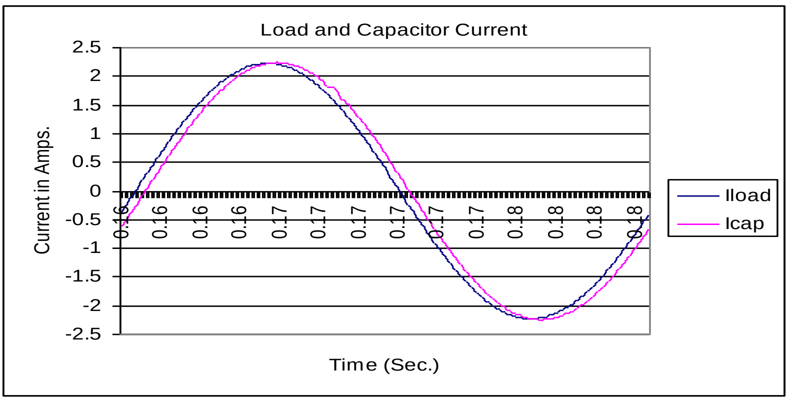

Figure 12: Load and Capacitor current without rectifiers and with Voltage Error Feedback.

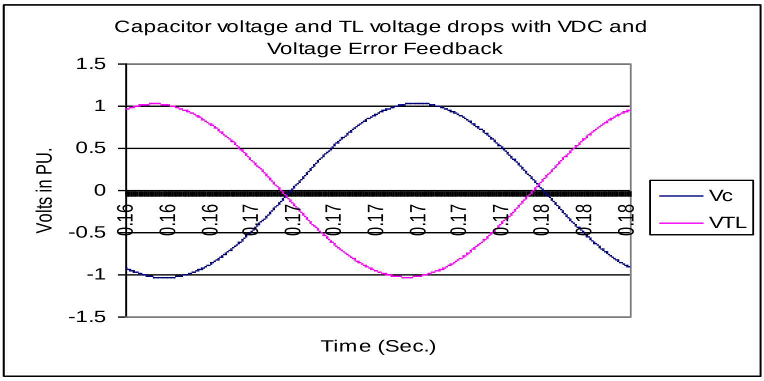

Figure 13: Voltages on TL and AC Capacitor with Voltage Error Feedback

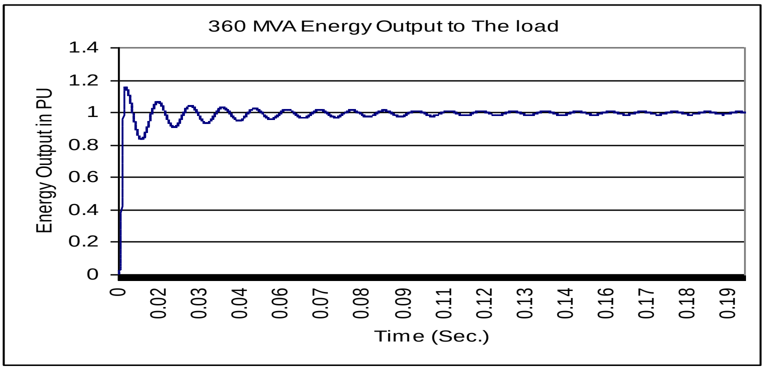

Figure 14: Energy Output to the load (360 VA) with VDC and with Voltage Error Feedback

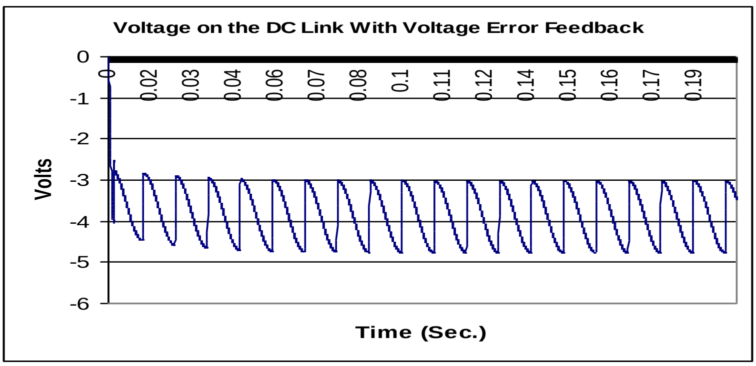

Figure 15: DC Link Voltage without rectifiers and with Voltage Error Feedback

7. CONCLUSIONS

This paper introduces new design for voltage drop compensation in power transmission lines using self generated dc link Voltage Source Inverter. Using this design it is possible to control the voltage across the capacitor to cancel the voltage drop across the transmission line inductance. A Voltage Error between the reference and the actual load voltage is introduced and feedback to modulate the capacitor current which improves the load voltage wave shape and reduces the error between the actual and reference load voltages. Using self generated dc link voltage source inverter reduces the harmonics which would be otherwise generated and injected into the transmission systems if a rectifier is used to maintain the dc link voltage.

8. REFERENCES

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وصلة تيار مستمر ذو توليد ذاتي – عاكس مصدر جهد كمعادل هبوط الجهد لخطوط نقل القوي الكهربائية

زيادة القدرة المرسلة عبر خطوط النقل الكهربائي العاملة والتعويض عن فاقد الجهد المصاحب لهذه القدرات في هذه الخطوط تعتبر من التحديات الكبيرة التي تواجه هندسة الطاقة الكهربائية. حل هاتين المشكلتين سيكون له أثرا كبيراً على خطوط النقل الكهربائي الحالية والمستقبلية. منظم الجهد اللحظي Instantaneous Voltage Controller (IVC) الذي سبق نشر نظرية عمله في الأبحاث [1,2,3] كان مبنياً في عمله على Current Source Inverter (CSI) للتحكم بمقاومة خطوط النقل. وقد اثبت الأبحاث السابقة أن التحكم بمقاومة خطوط النقل له أثرا كبيراً على اتزان نقل الطاقة الكهربائية وعلى التعويض في فاقد الجهد الكهربائي. هذا البحث ينظر في إمكانية استخدام منظم الجهد اللحظي كمعوض للجهد في خطوط نقل الطاقة باستخدام Voltage Source Inverter (VSI). وتتلخص فكرة البحث في الوقت الحاضر في تصنيع معوض للجهد الكهربائي للثلاثة أطوار للتحكم في الجهد الكهربائي عند مركز الأحمال أو عند المستهلك . يتم التحكم في جهد الحمل بواسطة فرق الإشارة بين الجهد المرجعي والجهد الفعلي عند المستهلك أو على مراكز الأحمال للتعويض عن الفاقد في الجهد الكهربائي ولزيادة القدرة المرسلة عبر خطوط النقل الكهربائي. التمثيل الرياضي لأداء هذا التصميم يثبت مقدرة هذا التصميم على مضاعفة القدرة المرسلة عبر خطوط النقل إلى عدة أضعاف في إطار القدرة الحرارية للأسلاك الموصلة للتيار.