Enhancement of Power Quality Using Dynamic Voltage Restorer in Cigarette Industries

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Abstract-*Power Electronics and Advanced Control Technologies have made it possible to mitigate power quality problems and maintain the operation of sensitive loads. Among power system disturbances, voltage sags and voltage swells are widely accepted to be the most prominent power quality problems to end users. In this study evaluation of TCC network voltage sags and swells disturbances and impacts to utilities without custom power devices is carried out. At present a wide range of flexible controllers which capitalize on new available power electronics components are emerging for custom power applications. A literature review was carried out in order to explore the status of the custom power devices that have been proposed and/or installed in the industrial distribution systems. Dynamic Voltage Restorer (DVR) based on Voltage Source Converter (VSC) was found to provide the best economic solution. The modeling and simulation of DVR using Matlab/Simulink is presented. A control system based on direct quadrature zero (d-q-0) techniques is presented. The simulation results have shown that the DVR performance is satisfactory in mitigating voltage sags and swells.*

Keywords: *custom power devices, power quality*

I. INTRODUCTION

Electricity in modern society is the most convenient and useful form of energy. Without electricity, the present social infrastructure would not at all be feasible. The increasing per capital consumptions of electricity throughout the world reflects a growing standard of living of the people. The optimum utilization of this form of energy can be ensured by an effective distribution system [1]. TANESCO vision is to be an efficient and commercially focused utility supporting the development of Tanzania. Its mission is to generate, transmit and supply electricity in the most effective, competitive and sustainable manner possible. Power electronic based equipment, such as Flexible AC Transmission Systems (FACTS), High-Voltage DC (HVDC), and Custom Power technologies constitute some of the most-promising technical advancements to address the new operating challenges being presented today [2]. The economical utilization of generation, transmission and distribution system assets are of vital importance to enable utilities in industries to produce high quality products so as to remain competitive and sustainable. Modern technology such as computers and controls are largely responsible for the rise in the impacts of power quality but can also provide a tailor made solutions to these problems [3]. A power quality problem is defined as an occurrence manifested in voltage, current, or frequency deviation which results in failure of operation of end use equipment. It is well known that distribution systems are affected by stochastic events such as faults on lines, sudden failures of power plants and random fluctuations in demand [1]. Since power quality problems have existed for a long time, the conventional methods of mitigation of these problems also are quite well developed. For example, passive filters based on inductors and capacitors were used and are still used in many power transmission and distribution applications. However, the use of passive elements at high power level makes these devices bulky. Moreover, the passive filters have a fixed range of operation [3]. Heavily loaded transmission and distribution system and system faults produce voltage sags, swells and magnify imbalance in the system. The distribution system nonlinear loads of own and/ or other consumers also create disturbances traveling to nearby consumers. Such voltage variations are not desirable. The situation is catastrophic for consumers with sensitive loads such as Tanzania Cigarettes Company (TCC) Limited Dar es Salaam, where significant losses have been reported. This situation is therefore calling for a study that will investigate the capability of Custom Power device that can be used to improve the power quality; analyze the contingencies at TCC Dar es Salaam distribution line, so as to forecast the future situation and hence improve TANESCO and TCC’s revenue.

The objective of this paper is to improve power quality problems at TCC. In order to achieve the objective the following are the specific objectives:

i. To determine the loss in revenue that TANESCO incurred as a result of supplying poor power quality to TCC Ltd for that duration of which TCC relied on captive power.

ii. To apply Dynamic Voltage Restorer (DVR) for power quality improvement

II.LITERATURE REVIEW

Modern industrial processes are based on a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very sensitive to disturbance and thus industrial loads become less tolerant to power quality problems such as voltage dips/sags, voltage swells and harmonics [4]. A growing number of loads are sensitive to customer's critical processes which have costly consequences if disturbed by either poor quality flow or power interruption. Voltage sags/swells can occur more frequently than other power quality phenomenon. These sags/swells are the most important power quality problems in the power distribution system [5].

A. Main Sources of Sag, Swell and Interruptions

Heavily loaded transmission and distribution system and system faults produce voltage sags, swells and magnify imbalance in the system. Faults at either the transmission or distribution level may also cause transient voltage sags or swells in the entire system or large part of it. Non-linear loads of other consumers such as welding sets, rectifiers, variable speed drives, arc/induction furnaces requiring variable high reactive power, large motor starting, inadequately designed wiring, heavy unbalanced loading, voltage swings and imbalance; these effects are transmitted to nearby consumers through the distribution system. In addition Consumer's own equipment of non-linear loads creates harmonics and voltage problems. Use of extensive nonlinear loads is one of the major reasons of deteriorating the quality of power supply [7]; [1]. Voltage deviations commonly in the form of voltage sags/swells can cause severe process disruption and result in substantial production loss. These PQ problems can cost significant financial loss per incident based on process downtime, loss of productivity, idle work forces and other factors.

B. Effects of Voltage Sags

Voltage sags are the most common power disturbance which certainly gives affecting especially in industrial and large commercial customers such as damage of the sensitivity equipment and loss of daily production and finances. Voltage sags causes process downtime, effect on production quality, failure/malfunction of customer equipment and associated scrap cost, cleanup cost, maintenance and repair cost. Also, it causes system halt, loss of data and shutdown, hardware damage, motor stalling and reduced life of motors [8], [9]. Examples of the sensitive equipment to the voltage sag are Programmable Logic Controllers (PLC), Computers, controller power supplies, motor starter contactors, control relays and adjustable speed drive.

C. Effects of Voltage Swells

Voltage swells can affect the performance of sensitive electronic equipment, causes data error, produce equipment shutdowns, may cause equipment damage and reduce equipment life. It causes nuisance tripping and degradation of electrical contacts. Also it can cause overheating, destruction of industrial equipment such as motor drives and damage to lighting. With electronically controlled equipment, 6% to 10% voltage above normal value may result in damage [11].Voltage swells causes most of the problems as voltage sags.

D. Use of Custom Power Devices to Improve Power Quality

The developments of power electronics devices such as FACTS and Custom Power have introduced an emerging branch of technology providing the power system with the versatile new control capability. There are many different methods used to mitigate voltage sags and swells, but the use of custom power devices is considered to be the most efficient method [4]. Custom Power Devices can be classified into two major categories namely network reconfiguring type and compensating type. The network reconfiguration devices are usually called switchgear and they include current limiting, current breaking and current transferring devices. The compensating types are: Distribution Static Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR), Unified Power Quality Conditioner (UPQC), Power Factor Corrector (PFC) and Active Filters (AFs). Compared to the other Custom Power devices, the DVR clearly provides the best economic solution for its size and capability [10]. A DVR injects a voltage in series with the system voltage to correct the voltage fluctuations.

E. Dynamic Voltage Restorer (DVR)

Dynamic Voltage Restorer (DVR) is a Custom Power device used to eliminate supply side voltage disturbances. DVR also known as Static Series Compensator [14] maintains the load voltage at a desired magnitude and phase by compensating the voltage sags/swells and voltage unbalances presented at the point of common coupling [12]. The general configuration of a DVR consists of an injection/Booster transformer, a Harmonic filter, a Voltage Source Converter (VSC), DC charging circuit, a control circuit and protection system as shown in **figure 1.**

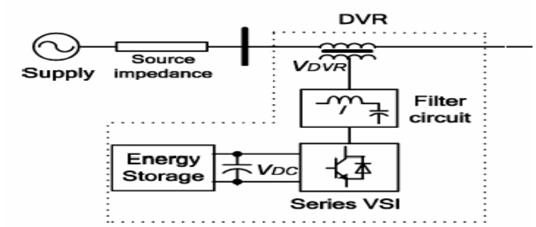

Figure 1: Typical DVR Circuit Topology (Single Line Representation).

In most sag correction techniques, the DVR is required to inject active power into the distribution line during the period of compensation. Hence the capability of energy storage unit can be a limiting factor in the disturbance compensation process especially for sag of long duration [6]

III METHODOLOGY

Power quality recording instruments used by TANESCO to detect disturbances, at substations are outlined. The part provides basic information on how the prominent sags/swells power quality problems can be mitigated using Dynamic Voltage Restorer (DVR).

A. Area of the Study

The area of the study was Temeke District, particularly Tanzania Cigarettes Company (TCC) Ltd Dar es Salaam. The area is selected purposely because Tanzania Cigarettes Company (TCC) Ltd has tried to invest and relied in captive power facilities even though the cost is higher than that of the grid. The researcher investigated the distributionnetwork to TCC in order to identify the prominent concern voltage sag/swell and intermittent outages power quality problems, taking into account the economic viability and technical repercussion.

B. Research Methods and Techniques Adopted

The study was based on a survey conducted in TANESCO departments, substations and TCC where relevant data and information was obtained by a combination of measurements, observations and calculations of Energy consumption, sags/swells records and through documentary review. Usually there exist different methods and techniques that can be employed in a research. However, these techniques mainly depend on the nature and type of research under investigation. The nature and data to be collected describe the types of techniques to be used in collecting the data. According to [13], there are essentially two types of data namely primary and secondary data.

C. TANESCO Revenue Losses Incurred as a Result of Supplying Poor Power Quality to TCC

In order to estimate the revenue losses incurred by utility company (TANESCO) due to power quality disturbances the following computation is done as follows:

(i) Obtain the industrial power factor, industrial working hours per day and number of working days per month.

(ii) Compute customer installed load or maximum load at full operation without any power quality interference. This is done by taking load factor of 0.4 which is the TANESCO standard norms for industrial load factor applied to TCC.

(iii) Compute the difference between averages consumed energy in kWh units of customer from TANESCO bill with the calculated consumed energy (maximum demand) in kWh units obtained from customer installed load capacity.

D. Data Analysis

The data collected was subjected to editing, classification in terms of the needs of each specific objective, tabulation and computation to enhance analysis and interpretation. Content analysis was employed in the context of the research objectives and research questions put-forth in the study. Some data obtained from questionnaires was summarized in tables and analyzed in forms of frequencies and percentages in relation to the research objectives and questions of the study. Thereafter simulation results using MATLAB/Simulink are presented to verify the capability of DVR Custom Power device in voltage sag/swell mitigation.

IV. DATA PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

A. TANESCO Revenue Losses at TCC

Evaluation of network sags/swells disturbances and consequence financial impact without custom power devices is necessary for the purpose of deciding on the level of investment in mitigating devices and losses incurred by the utilities. TANESCO financial losses due to voltage sags or swells power quality problems at TCC can be estimated based on the definition of power quality to sensitive loads as the relative absence of utility related voltagevariations, particularly the absence of outages, sags, swells, surges and harmonics as measured at the point of service. Table 1 shows the summary of monthly energy charges (in kWh units) for Tanzania Cigarette Company Limited from 2013 up to 2016 and the power factor (PF) for the year 2016

Table 1: Energy Charges (kWh unit) for Tanzania Cigarette Company Limited

MONTH	2013 kWh	2014 kWh	2015 kWh	2016 kWh	2016 PF
Jan.	461,060	516,016	472,935	484,971	0.90
Feb.	490,907	480,951	432,255	95,686	0.85

Mar.	457,719	470,836	424,874	78,385	0.94
Apr.	486,516	424,034	494,446	111,245	0.89
May	439,135	383,754	533,959	96,710	0.75
June	537,291	340,928	296,978	109,595	0.96
July	527,113	155,494	575,396	32,900	0.89
Aug.	497,700	439,374	542,144	74,305	0.90
Sept.	402,555	296,978	515,631	63,845	0.91
Oct.	477,407	651,025	540,840	97,163	0.94
Nov.	506,412	452,875	569,232	184,758	0.94
Dec.	544,938	382,909	571,528	38,785	0.90
Total	**5,828,753**	**4,995,174**	**5,970,218**	**1,468,348**	10.77
Av.	**485,729.4**	**416,265.5**	**497,518.2**	**122,362.3**	**0.90**

In this case the researcher assume energy charges data table 1 were due to poor power quality as each month of these four consecutive years, power supplied to TCC was disturbed as shown in figure 1 of statistical graph of power quality disturbances at TCC as from 2013 up to 2016.

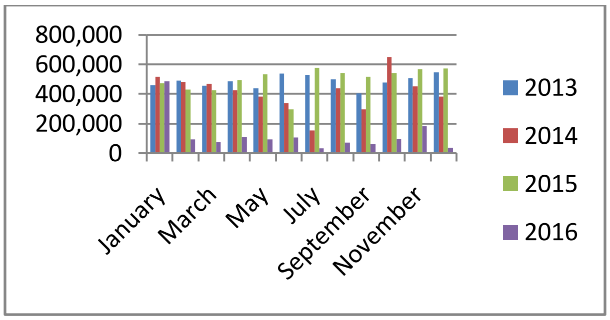

Figure 1: Frequency Voltage Disturbances due to sags and swells at TCC

According to the data from TCC the industrial installed load capacity is 2,500kVA, industrial operating time is 24 hours and the average power factor from calculations for the year 2016 is 0.90. Researcher assumes if there were no power quality disturbance to these sensitive loads, TCC would have operated at its maximum production, utilizing TANESCO power supply hence resulting in maximum energy consumption based on load power factor and Industrial installed load capacity. TCC maximum energy in kWh units at full operations without any interference for load factors of 0.4 is therefore calculated as in (1)

$$E_{\max} = 0.4 L_{ins} x C_{pf} \quad (1)$$

Then, equation (2) compute consumed energy in kWh units at full operation without power quality disturbances and power outages for a month of 30 days.

$$A_{E\max} = E_{\max} x 24 x 30 \quad (2)$$

Where: $E_{\max}$ = Maximum energy consumed in kWh units at full operations

L_{ins} = Industrial installed load capacity

C_{pf} = Industrial power factor

$A_{E\max}$ = Calculated consumed energy in kWh units at full operation without power quality disturbance and power outage for a month of 30 days.

Based on the data from TCC:

$E_{\max} = 0.4 L_{ins} x C_{pf}$ = 0.4 × 2500,000 × 0.9 = 900 kWh

$A_{E\max} = E_{\max} x 24 x 30$ = 900,000 × 24 × 30 = 648,000 kWh/ Month.

Computation is done based on equation (2) to find maximum consumed energy in kWh units at full operation without power quality disturbance and power outage for each month of the four years under investigation. It is found that the maximum demand for all months of 30 days is 648,000 kWh/ Month, those of 31 days is 669,600 kWh/ Month while in February of 28 considerable operation days is 626,400 kWh units. The difference between calculated maximum consumed energy/demand in kWh units and the Energy Charges shown in table 1 gives the Energy Loss or energy not purchased from TANESCO in kWh units as shown in table 2.

Table 2: TANESCO Energy Loss/ notpurchased (in kWh unit) at TCC

Month	Max. Demand kWh	2013 kWh	2014 kWh	2015 kWh	2016 kWh
Jan.	669,600	208,540	153,584	196,665	184,629
Feb.	626,400	135,493	145,449	194,145	530,714
March	669,600	211,881	198,764	244,726	591,215
April	648,000	161,484	223,966	153,554	536,755
May	669,600	230,465	285,846	135,641	572,890
June	648,000	110,709	307,072	351,022	538,405
July	669,600	142,487	514,106	94,204	636,700
Aug.	669,600	171,900	230,226	127,456	595,295
Sept.	648,000	245,445	351,022	132,369	584,155
Oct.	669,600	192,193	18,575	128,760	572,437
Nov.	648,000	141,588	195,125	78,768	463,242
Dec.	669,600	124,662	286,691	98,072	630,815
Total	**7,905,600**	**2,076,847**	**2,910,426**	**1,935,382**	**6,437,252**
Av.	**658,800**	**173,071**	**242,536**	**161,282**	**536,438**

However the energy loss or energy not purchased in kWh units when expressed as a percentage of the maximum demand in kWh units statistical graph in figure 2 shows clearly that TCC has decided to rely in captive power. The average revenue loss that TANESCO incurred for the year 2016 is 81.5% of the total revenue due to maximum demand if quality power had been supplied to TCC

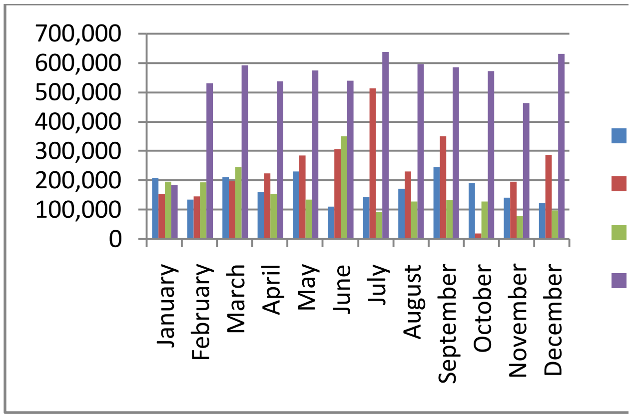

Figure 2: TCC Captive Power Production Expressed as a Percentage of the Maximum Demand equals TANESCO Energy not purchased.

Figure 2 shows that Tanzania Cigarette Company (TCC) Limited as from February 2016 relies on captive power facilities even though the cost is higher than that of the grid. According to the data from TCC, running cost of captive power is 130Tsh per kWh while that of TANESCO is 96.50Tsh per kWh. TotalTANESCO revenue losses at TCC Ltd in kWh units for the four years under investigation are:

2,076,847kWh + 2,910,426kWh + 1,935,382kWh + 6,437,252kWh = 13,359,907 kWh units. TANESCO revenue losses in these four years can therefore be estimated as: 13,359,907 × 96.50 = 1,289,231,026.00 TZS, which is equivalent to 586014 USD at an exchange rate of 2200/=TZS per USD. However 48.2% of this loss equals to 282459USD is due to the year 2016 where TCC relied almost totally on captive power.

A. Impacts of Voltage Sags and Swells at TCC

Voltage sags/swells are accepted to be the most prominent power quality problem when considering the financial consequences to TCC. Complete loss of TANESCO voltage result in higher financial losses when compared to voltage sags/swells problems.

However the much higher frequency of occurrence of voltage sags/swells and increased sensitivity of TCC equipment to voltage disturbances resulted into unacceptably high number of very costly interruptions of production processes. For TCC factory even a momentary outage may shut down a production line, nevertheless the utility restore services in 5 minutes or in three hours, the factory need no interruptions of any kind to avoid loss of production, equipment damage, reject cost, process restart cost and downtime losses. Voltage dips that last less than 100 milliseconds can have the same effect on an industrial process as an outage that lasts several minutes [15]. Table 3 shows industrial and commercial operation losses referred as direct impact of power quality disturbances at TCC for the year 2013. Besides these costs, the researcher was informed other indirect impacts associated with voltage disturbances at TCC as:

(i) the cost of restoring brand equity;
(ii) the financial cost of loss of market share;
(iii) the cost of revenue/income being postponed and
(iv) Wages paid despite of idleness during restoration.

TCC financial losses for the year 2013 for rejects of cigarette, equipment damage and buying diesel for running the generator give 610,729.68USD. The total financial losses for four years under investigation can be calculated as 610,729.68 USD × 4 = 2,442,918 USDthis was merely direct economic impacts.

B. The Control of DVR System

The basic functions of a controller in a DVR are the detection of voltage sag/swell events in the system; computation of the correcting voltage, generation of the trigger pulses to the sinusoidal PWM based DC - AC inverter, correction of any anomalies in the series voltage injection and termination of the trigger pulses when the event has passed. The controller may also be used to shift the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of energy sags/swells. The proposed d-q-0 transformation or Park’s transformation is used to control the proposed DVR. The d-q-0 method gives the sag depth and phase shift information with starts and end times. The quantities are expressed as the instantaneous space vectors. In order to show the performance of the DVR in voltage sags and swells mitigation a simple distribution network was simulated using MATLAB/SIMULINK program. A detailed system shown in Figure 3 has been modeled by MATLAB/SIMULINK. Voltage sags and swells were simulated by temporary connection of different impedances at the supply side bus. A DVR was connected to the system through a series injection transformer with a capability to insert a maximum voltage of 50% of the phase to ground system nominal voltage. The transformer can be connected in delta – open or star – open [16] windings. Apart from this, a series filter is also used to remove any high frequency components of the power. In this configuration the filters are installed in both the high voltage side and low voltage side. There are two general types of DVRs: Minimal energy control DVRs and In Phase Compensation DVRs. One includes energy storage and the other does not include energy storage. In this simulation (figure 3) the In Phase Compensation (IPC) method is used. The injected voltage is in phase with supply voltage. The load considered in this study is 2.5MVA capacity with lagging power factor. The system parameter and constant value are listed in table 3. It is assumed that the voltage magnitude of the load bus is maintained at 1p.u during the voltage sags/swells condition.

Table 3: System parameters and constant values

Main Supply Voltage per Phase	240V
Line Impedance	Ls =0.5mH, Rs =0.1Ω
Series Transformer turns ratio	1:1
DC Bus Voltage	120V
Filter Inductance	2mH
Filter Capacitance	1μF
Load Resistance	40Ω
Load Inductance	60mH
Line Frequency	50Hz
Switching/sampling frequency	10kHz

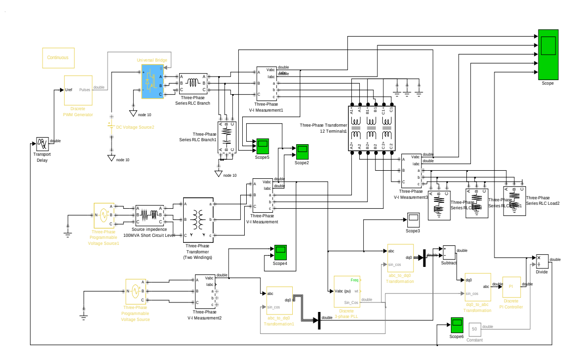

Fig. 3: Simulation Model of DVR

C. Simulation Results and Discussions

A detailed system shown in Figure 3 has been modeled by MATLAB/SIMULINK. The simulation results for the proposed three-phase three wire system using DVR are shown in Fig. 4 to 9 by considering voltage sags and voltage swells separately.

D. Voltage Sags

The first simulation of three phase voltage sag is simulated at 55% voltage sag initiated at 0.15s and it is kept until 0.35s with total duration of 0.2s as shown in figure 4. In figures 5 and 6 the voltage injected by DVR and the corresponding load voltage with compensation is shown. As a result of DVR, the load compensation is kept at 1p.u irrespective of voltage sag.

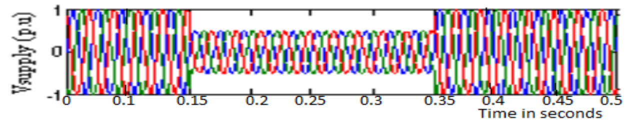

Fig. 4: Simulation Results During Voltage Sag

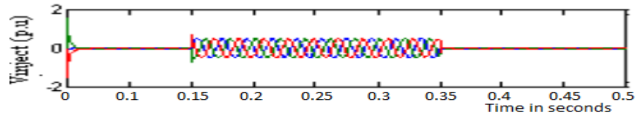

Fig.5: Voltage Injected by Series Compensator

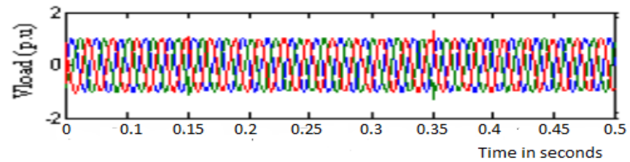

Fig. 6: Compensated Load Voltages

E. Voltage Swells

The second simulation shows the DVR performance during the voltage swell condition. The simulation started with the supply voltage, thereafter at 0.15s swell is generated as shown in figure 6. In this figure the amplitude of supply voltage is increased to about 30% from its nominal voltage. Figures 7 and 8 show the injected and the load voltage respectively. As can be seen from the results, the load voltage is kept at the nominal value with the help of the DVR. Similar to the case of voltage sag, the DVR react quickly to inject the appropriate voltage component (negative voltage magnitude) to correct the supply voltage.

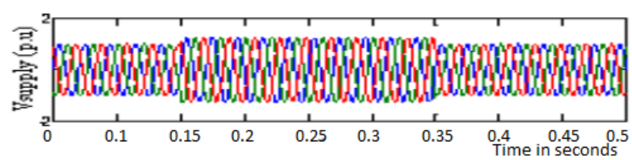

Fig.7: Simulation Results During Voltage Swell

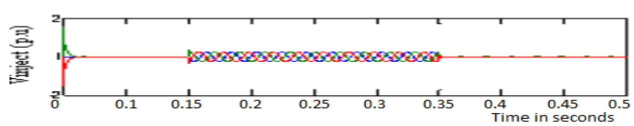

Fig. 8: Negative Voltage Injected by Series Compensator

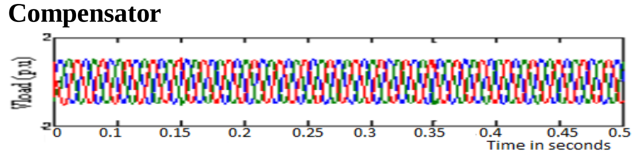

Fig. 9: Compensated Load Voltages

IV. CONCLUSIONS

A literature review was carried out in order to explore the status of the custom power devices that have been proposed and/or installed in the industrial distribution systems. The review included distribution static compensator (DSTATCOM), Static Transfer switch (STS), Active Filters (AFs) and Dynamic Voltage Restorer (DVR). The conclusion of the review is that the dynamic voltage restorer is generally accepted as the most suited power electronics apparatus for mitigation of voltage sags and swells. Its appeal includes low cost, small size and fast dynamic response to the disturbances. Evaluation of network sag/swell disturbances and consequence financial impact without custom power devices is necessary for the purpose of deciding on the level of investment in mitigating devices and losses incurred by the utilities. The modeling and simulation of a DVR using Matlab/Simulink has been presented. A control system based on d-q-0 technique, which is a scaled error between source side of the DVR and its reference for sag/swell correction has been presented. Simulation results show that the DVR performance is satisfactory in mitigating voltage sags and swells. The main advantage of DVR is low cost and its control is simple. It can mitigate short duration voltage sags/swells efficiently.

ACKNOWLEDGEMENT

This work would not have been the same without endurance encouragement and continuous consultations and valuable contributions from TANESCO and TCC staff members.

LIST OF ABBRIVIATIONS AND ACRONYMS

AFs	Active Filters Company
DSTATCOM	Distribution Static compensator
DVR	Dynamic Voltage Restorer
FACTS	Flexible AC Transmission Systems
HVDC	High-Voltage DC
IPC	In Phase Compensation
PFC	Power Factor Corrector
PLC	Programmable Logic Controllers
STS	Static Transfer switch
TANESCO	Tanzania Electricity Supply
TCC	Tanzania Cigarette Company
UPQC	Unified Power Quality Conditioner
UPS	Uninterrupted Power Supply
USD	United State Dollar
VSC	Voltage Source Converter

REFERENCES

[1] A. Pabla, Electric Power Distribution, Fifth Edition Tata McGraw-Hill Publishing Company Limited, New Delhi, 2003

[2] Paserba, J. John, F. Gregory, t. Masatoshi and A .Tomohiko , "FACTS and Custom Power" Symposium of Specialists in Electric Operational And Expansion Planning (Vii SEPOPE) Curitiba, Brazil, May 21-26 2000.

[3] A. Ghosh, and G .Ledwish, Power Quality Enhancement using Custom Power Devices, Kluwer Academic Publishers, 2002

[4] Hingorani, "Introducing custom power" IEEE Spectrum, Vol.32, No.6, pp 41-48, 1995

[5] H.M. Rosli Omar, N. A Rahim, "Power Quality Improvement in Low Voltage Distribution System Using Dynamic Voltage Restorer", 2010, 5th IEEE Conference on Industrial Electronics and Applications

[6] H.M. Rosli Omar, N. A. Rahim "Mitigation of Voltage Swells Disturbances in Low Voltage Distribution Systems", Asian Power Electronics Journal, Vol. 4, No 3 December 2010

[7] D.M. Vilathgamuwa, H.M.Vijekoon and S.S. Choi "Interline Dynamic Voltage Restorer: a Novel and Economical Approach for Multiline Power Quality Compensation," IEEE Transaction on Industry Applications, Vol. 40, pp 1678 -1685 Nov – Dec. 2004.

[8] S.W. Wahab, A .MohdYusof "Voltage sags Mitigation Using Dynamic Voltage Restorer (DVR)
System", Elektrika Journal of Electrical Engineering 8(2): 32-37, 2006

[9]Ceati, (2007), "Power Quality Energy Efficiency Reference Guide", CeatiEutig group 102 pages

[10] Ali O Al-Mathnani, Hussain, S., Azah, Mohamed., M.A. Hannan , "Power Quality Improvement Using DVR with Two Fast Vector Control", The 4th International Power Engineering and Optimization Conf. (PEOCO290), Shah Alam, Selangor Malaysia: June 2010

[11] M. F. McGranaghan, D. R. Mueller and M. J. Samoty, "Voltage sags in industrial systems", IEEE Trans. Ind. Applications, 397-403., 1993

[12] S.S. Mahesh, M.K. Mishra, B.K Kumar, and V. Jayashnhar, "Rating and Design Issues of DVR Injection Transformer", IEEE Applied Power Electronics Conference and Exposition, 449-455, 2008

[13] C.R. Kothari, Research methodology: Methods and techniques, New Delhi: New Age International Publishers, 1994

[14] D.M. Lee, "A Voltage Sag Supporter Utilizing a PWM Switched Autotransformer" Georgia, Institute of Technology Electrical and Computer Engineering, 2004

[15] Mark McGranaghan, Bill Roettger, (2002), "Economic Evaluation of Power Quality", IEEE Power Engineering Review February 2002.

[16] P. Usha Rani, S. Rama Reddy, "Dynamic Voltage Restorer using Space Vector PWM Control Algorithm", European Journal of Scientific Research Vol. 56 No 4 (2011), pp. 462 – 470.
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