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Direct Converter Based DVR to Mitigate Single Phase Outage

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Abstract: ***The aim of this paper is to present a new simplified topology for a Dynamic Voltage Restorer (DVR) which has ability to mitigate single phase outage also. The proposed DVR has a multi-winding transformer, a direct converter and a series transformer for each phase. The multi winding transformer is connected between the direct converter and the grid. Only three bi-directional controlled switches are employed per phase. The direct converter is used to synthesis the required compensating voltage and the series transformer is used to add the compensating voltage in grid. The DVR can compensate balanced voltage sag, balanced swell, unbalanced swell and single phase outage by taking power from the grid. For compensating the voltage sag or outage in any one phase, the other two phase voltages are added using the multi winding transformer. The added voltage is pules-width modulated (PWM) using controlled switches to compensate the sag. Swell is compensated by taking power from the same phase. The simulation results confirm that the proposed topology can mitigate balanced sag of 50%, balanced swell of 100%, unbalanced swell of 100% and single phase outage.***

Index Words: ***Direct converter, dynamic voltage restorer (DVR), voltage sag, voltage swell, single phase outage***

I. INTRODUCTION

Power quality is getting polluted both in transmission side and distribution side, due to the usage of non-linear power electronic devices and the occurrence of faults. The degradation of power quality necessitates compensation on both the sides. For power quality improvement generally the FACTS devices are used at the transmission side and the Custom Power System (CUPS) devices are used at the distribution side. In the present situation, all most all industries are automated with field programmable gate arrays, micro controllers, microprocessors, or computers which are highly sensitive to the supply voltage variations. Even a small fluctuation in the supply voltage will affect these sensitive loads which in turn affect the entire automated processes resulting in huge data and economic losses [1-3]. A recent literature survey reveals that, voltage sag should be considered as the most important issue in power quality [4, 5], due to the frequent operation of tripping devices.

Out of many CUPS devices, the DVR and the Uninterruptible Power Supply (UPS) are the recent developments for power quality improvement. The UPS suffers with disadvantages like higher cost and higher losses compared to DVR since the UPS need more number of switches and huge batteries.

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But the DVR need minimum number of switches and will be active only when the power quality is degraded. The basic operation of DVR is to inject a voltage in series with the load voltage to mitigate power quality issues [6]. DVRs could be grouped based upon their topology. The first group includes DVRs based on inverter in which a battery is used as a DC source and the inverter will generate the required AC voltage for compensation.

The second group includes DVRs based on rectifier and inverter, in which a rectifier will convert the available AC power from the grid to DC power. This DC is stored in a battery then the inverter is used for compensation. In both the topologies, in order to maintain the DC link voltage, a DC link capacitor or a battery should be connected between the inverter and rectifier. Moreover the above mentioned topologies have disadvantages like less compensating time, expensive and bulky batteries [6, 7]. The third group of DVRs are realized using direct AC/AC converters without a DC link. Zero energy sag corrector without capacitors [8], a DVR using indirect matrix converter and flywheel [9], a direct converter based DVR [10-15] are some of the DVR topology under group three.

Though many DVR topologies based on direct converters are found in the literature, could not compensate single phase outages. However the proposed topology can mitigate voltage sag, swell and also single phase outage.

II. DVR TOPOLOGY

Each phase has been provided with a direct converter, LC filter, 1:1 multi winding transformer and a series transformer as shown in the Fig.1. The direct converter has three bidirectional power switches. Under normal condition in phase ‘a’, the switches Saa and Saa’ is in open condition and the switch Sga will be in closed condition. So the power will flow from grid to the load as the secondary of the series transformer is shorted by the switch Sga.

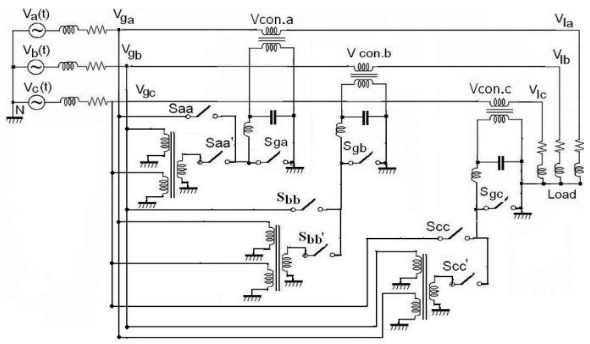

Figure 1.Proposed DVR topology

III. CONTROL PROCEDURE

A. Sag Compensation

The multi winding transformer has two primary windings and one secondary winding. The primary windings are wound with additive polarity such that the added voltage appears at the secondary winding. If there is voltage sag in phase 'a', then the voltage from the phases 'b' and 'c' are added by the multi-winding transformer. The resultant voltage will be out of phase with phase 'a' voltage.

Under balanced conditions,

$$v_a + v_b + v_c = 0; \qquad (1)$$

The multi-winding transformer adds the 'b' phase and 'c' phase voltages to enable the 'a' phase sag compensation as:

$$-v_a = (v_b + v_c) \qquad (2)$$

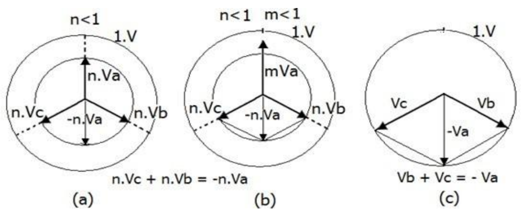

Figure 2. Phasor diagram for compensating (a) Balance sag (b) Unbalanced sag (c) Single phase outage

The generation of compensation voltage is illustrated in the phasor diagram shown in Fig.2.The balanced sag condition is shown in Fig.2 (a). All the phase voltages are equal to nV with n<1. In Fig. 2(a), the addition of phase 'b' and phase 'c' voltages and the generation of the resultant (with a 180° phase shift) meant for the compensation of sag in phase 'a' are seen. The compensation process for an unbalanced sag condition in which |Va| <m.V with m<1 is shown in Fig.2 (b). However, the phase 'b' and phase 'c' voltages are equal, but show a sag. i.e., |Vb|=|Vc|=n.V and m < n < 1.The magnitude of the available compensation voltage is somewhat smaller. Fig.2(c) illustrates the compensation when an outage occurs in 'a' phase alone. The normal voltages available from the phases 'b' and 'c' (viz., |Vb|=|Vc| =V) are added using the multi winding transformer to derive a compensation voltage for the phase 'a'. This voltage has a magnitude equal to the rated voltage |V| and phase shift =180°.In all the above three cases, the resultant voltage is pulse-width-modulated to the desired extent using bi-directional switches S_{aa}', S_{ga} and added to the phase 'a' voltage using the series transformer of appropriate polarity. In the same way, the compensation for the other phases is implemented.

B. Swell Compensation

In order to compensate the voltage swell, power from the same phase is utilized by the converter. The excess voltage which is available here can be advantageously used for compensation purposes. If there is a voltage swell in phase 'a' then the bidirectional switches S_{aa} and S_{ga} will be alternately modulated to mitigate the voltage swell.

C. Switching Pulse Generation

The amplitude of the grid voltage U_{gmax}, has been obtained from single-phase d-q transform [14]. U_{ref} is the desired terminal voltage, set a-priori in the micro controller program. The block diagram shown in Fig.3 and Table. I are self-explanatory to understand the switching pulse generation.

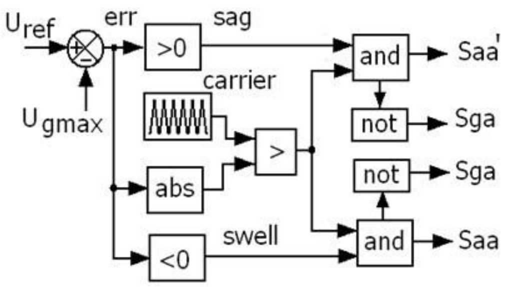

Figure 3. Switching pulse generation

Table.I Dvr Switches To Be Modulated Under Various Conditions

Line Condition	*Phase a*	*Phase b*	*Phase C*
Sag / outage	Saa'& Sga	Sbb' & Sgb	Scc' & Sgc
Swell	Saa & Sga	Sbb & Sgb	Scc & Sgc

IV. SIMULATION RESULTS

The proposed topology has been simulated in MATLAB. Supply frequency is set at 50Hz. Inductive load of 0.8 power factor lagging is connected to the lines.

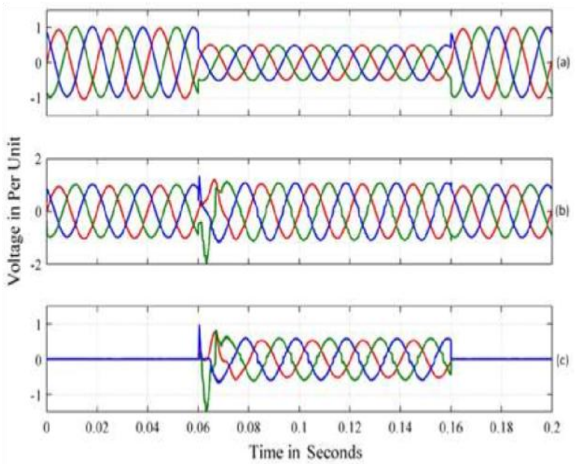

Figure 4. Mitigation of balanced voltage sag (a) Grid voltage (b) Load voltage (c) Compensation voltage produced by the DVR

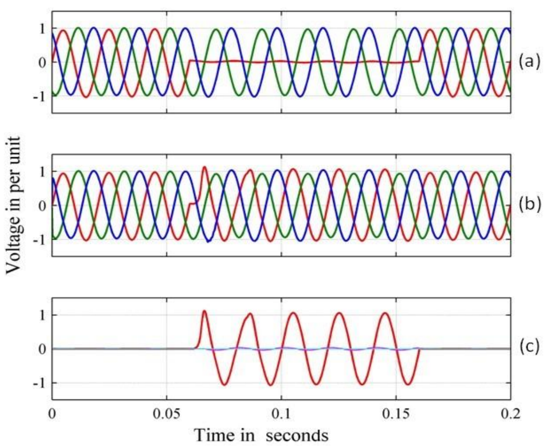

Figure 5. Mitigation of Single phase outage (a) Grid voltage (b) Load voltage (c) Compensation voltage produced by the

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DVR

Converter's carrier frequency is set at 8 kHz. Passive LC filters were used at the output of the converters (1.732mH and 15μF). Series transformer's turns-ratio is 1:1. The ability of the DVR to mitigate balanced voltage sag of 50%, single phase outage, balanced and unbalanced voltage swell are shown in the Fig.4, Fig.5, Fig.6 and Fig.7 respectively.

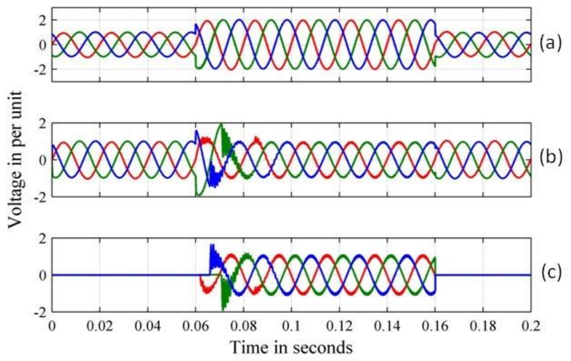

Figure 6. Mitigation of balanced voltage swell
(a) Grid voltage (b) Load voltage (c) Compensation voltage produced by the DVR

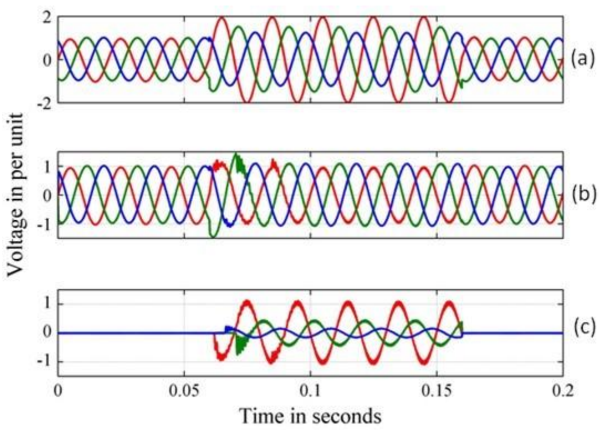

Figure 7. Mitigation of unbalanced voltage swell
(a) Grid voltage (b) Load voltage (c) Compensation voltage produced by the DVR

V. PERFORMANCE ANALYSIS

The comparison of the performance of the present procedure as against those available in technical literature is now considered and summarized in Table 2. To begin with, the topology presented in [13] based on a matrix converter cannot mitigate single phase outage and 3 switches are to be modulated during compensation, making the generation of switching pulses somewhat complicated. The zero energy sag corrector without capacitors proposed in [8] can compensate all types of sags but not the voltage swells. Yet another DVR based on an indirect matrix converter developed in [9] can compensate balanced voltage sags of 60%, whereas the capability of the scheme for swell compensation has not been considered. Additionally, this procedure needs a flywheel for energy storage. A computation intensive procedure, which runs throughout the cycle, has been described in [10].

TABLE.II COMPARISON DVR TOPOLOGIES BASED ON DIRECT CONVERTERS

S.No	*Topology Proposed by*	*No. of*	*Compensating Range*			*THD %*	*Description n*
			Sag	*Swell*	*1 phase*		
1	Perez et al	4	25%	50%	NIL	-	DVR based on Matrix Converter
2	Prasai & Divan	10	96%	NIL	NIL	-	Zero Energy Sag Corrector
3	Wang & Venkataram anan	4	60%	NIL	NIL	-	Indirect Matrix Converter &Flywheel
4	Babei et al	5	33%	100 %	NIL	12.2 %	DVR Based On Direct Converter
5	Abdul Rahman & Somasundaram	4	50%	100 %	NIL	0.56 %	DVR Without Energy Storage Devices
6	Abdul Rahman & Somasundar am	4	50%	100 %	NIL	7%	DVR Based On Direct Converter
7	Abdul rahman et al	4	50%	100 %	NIL	1.5%	DVR Based On Direct Converter
8	Abdul rahman et al	3	50%	100 %	NIL	3%	DVR With Center Tapped Transformer
9	Proposed topology	3	50%	100 %	100%	3%	DVR With Multi-winding Transformer

The direct converter operates with 5 switches per phase. In spite of these, the compensation range for voltage sag is only 0-33% and of the range for the voltage swell is 0-100%. Even though the topologies described in [11-14], can mitigate 50% sag and 100% swell using direct converters, the generation of the switching pulses for the DVR is a bit complicated since 3 switches are to be modulated during compensation while the compensation of single phase outage is not possible. The DVR with only 3 switches proposed in [15] also can mitigate only sag and swell. In proposed topology, a multi winding transformer is used only with 3 bi-directional switches of which only 2 switches are used at a time. So less switching loss and easier generate switching pulses.

VI. CONCLUSION

A three-phase DVR characterized by the absence of the conventional DC link, is presented. The absence of DC link in the system has advantages like less cost, less weight, less maintenance. The DVR has only three bidirectional switches of which only 2 are modulated at any time. The control of DVR is done by using a very simple PWM procedure.

During the voltage swell, the available large voltage for compensation enables 100% compensation. For the voltage sag compensation in any one phase, power from the other two phases has been taken by adding these two voltages with the help of a multi-winding transformer. During unbalanced sag, if the other phase voltages are normal then the sag compensation range could surpass even the usual limit of 50%. The DVR is able to mitigate 50% of balanced and unbalanced voltage sag, 100% of voltage swell and single phase outages effectively. The DVR is simple to fabricate and cost effective in applications.

REFERENCES

1. Y Usman, M K Abdullah, A N Mohammed, Estimating Electricity Consumption in the Commercial Sector of Nigeria's Economy, International Journal of Recent Technology and Engineering (IJRTE), Vol.8, No.2S, 2019.
2. N.Pandiarajan, G.Emayavaramban, A.Amudha, M.Siva Ramkumar, IR.V.Mohamed Mansoor, K.Balachander, S.Divyapriya, M..Sivaram Krishnan, Design and Electric Spring for Power Quality Improvement in Pv-Based Dc Grid, International Journal of Recent Technology and Engineering (IJRTE), Vol.8, No.1S5, 2019.
3. I Swetha Monica, N Vani Annapurna Bhavani, Praveen Kumar Bandila, Advanced Voltage Support Scheme for Grid Balancing Under Active Power Oscillations, International Journal of Recent Technology and Engineering (IJRTE), Vol.8, No.1S3, 2019.
4. M.V.S.Sivakrishna, K.S.S.Prasad Raju, Comparison of Control Strategies for Shunt Active Power Filter in Distribution Systems, International Journal of Recent Technology and Engineering (IJRTE), Vol.8, No.1S3, 2019.
5. N.Vani Annapurna Bhavani, K. Swetha, Praveen Kumar Bandila, Power Quality Improvement for Low Active Power Demand using Advance Voltage Support Scheme, International Journal of Recent Technology and Engineering (IJRTE), Vol.8, No.1S3, 2019.
6. R. Omar, N.A. Rahim and A. Ahmad, Voltage Swells Improvement in Low Voltage Network Using Dynamic Voltage Restorer, American Journal of Applied Sciences, Vol. 8, No. 1, pp. 55- 62, 2011.
7. M. Muhamad and A. Nasrudin, Phase angle analysis for three-phase PWM switched autotransformer voltage-sag compensator, Arabian Journal of Science and Engineering, Vol. 37, No. 7, pp.1987–2001, 2012.
8. A. Prasai, and D.M. Divan, Zero-energy sag correctors - Optimizing dynamic voltage restorers for industrial application, IEEE Trans. Ind. Appl., Vol. 44, No. 6, pp. 1777–1784, 2008.
9. B. Wang, and G. Venkataramanan, Dynamic voltage restorer utilizing a matrix converter and flywheel energy storage, IEEE Trans. Ind. Appl.,Vol. 45, No. 1, pp. 222–231, 2009.
10. E. Babaei, M.F. Kangarlu, and M. Sabahi, Mitigation of Voltage Disturbances Using Dynamic Voltage Restorer Based on Direct Converters, IEEE Transactions On Power Delivery, Vol. 25, No. 4, pp.2676-2683, 2010.
11. S. Abdul Rahman and P. Somasundaram, Mitigation of voltage sag& swell using AC/AC converter, Australian Journal of Electrical & Electronics Engineering, Vol. 11, No. 2, pp.186 – 194, 2014.
12. S. Abdul Rahman, P.A. Janakiraman and P. Somasundaram, Mitigation of voltage sag and swell using Carrier Modulated PWM technique, Journal of Electrical Power and Energy Systems, Elsevier, Vol. 66, pp. 78-85, 2015.
13. J. Perez, V. Cardenas, L. Moran and C. Nunez, Single-phase ac-ac converter operating as a dynamic voltage restorer (DVR), Proceedings of IECON, Paris, pp. 1938–1943, 2006.
14. S. Abdul rahman, and P. Somasundaram, Mitigation of voltage sag and swell using Dynamic Voltage Restorer without energy storage, International Review on Electrical Engineering, vol. 7, pp. 4948–4953, 2013.
15. S. Abdul Rahman, P. Somasundaram and P.A. Janakiraman, Mitigation of voltage sag& swell using DVR with minimum switch count, Journal of Power Electronics, Vol. 14, No. 6, pp. 1769–1773, 2014.

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Dr. S. Abdul Rahman, was born in Ilayangudi, Tamilnadu, India on 12.07.1978. He completed his under graduation in Electrical & Electronics Engineering in University of Madras and post-graduation in power electronics and doctorate in Anna University, Chennai, India. Now he is working as an Assistant Professor in University of Gondar, Ethiopia. His area of interest are power quality improvement and direct converters.