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AC-DC-AC Single Phase Converter with Reduced Number of Controlled Switches

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ABSTRACT: This paper proposes a unidirectional single phase ac-dc-ac converter with reduced number of controlled switches. The proposed system consist of a single phase ac-dc-ac converter which generates stabilized single phase ac voltage using a control algorithm. The intermediate dc stage of the ac-dc-ac converter is utilized by the fly-back converter to generate stabilized dc voltage using a control algorithm. Moreover, the ac-dc-ac converter reduces the Weighted Total Harmonic Distortion (WTHD) of the output ac voltage. The dual output system reduces the cost of installation and also reduces the floor spacing. The proposed system can be used in various biomedical applications including tissue engineering etc. A simulation of the proposed system is modelled and evaluated with desirable results in MATLAB/Simulink.

KEYWORDS: single phase ac-dc-ac converter, fly-back converter, Weighted Harmonic Distortion (WTHD), Total Harmonic Distortion (THD).

I. INTRODUCTION

The use of electric field for measuring cell and tissue properties has a long history. However, the advancement in the use of electric fields in tissue engineering is only very recent. As our population lives longer, there is an increase in the demand for biomedical devices and procedures is expected to grow. With technology advancing and the demand for cutting-edge medical equipment and devices expanding, biomedical engineering is a rapidly growing field.

The unbalance in voltage can be conceptualized as unequal magnitude or phase angle of voltages. The power quality issues of supply voltage like sag, swell, unbalance, flicker, harmonics, etc. are compensated using series compensation and current power quality issues like harmonics, unbalance, reactive current, etc. are compensated using shunt compensation [1]. The distortions in the supply voltage can eventually affect the normal working of the devices. The implementation of ac-dc-ac systems in devices is important as it enables the load to be fed from an ac electric system with desired output voltage and with reduced harmonic distortions.

Harmonics can cause ageing of components, mostly due to overheating of motors, cables etc. Also, due to resonance phenomena, harmonics can cause the destruction of capacitors which are used to compensate reactive power [2]. Ac-dc-ac systems enables the load to be fed from an ac electric system with desired output voltage at all loading conditions and transients [3]. Jacobina *et al.* [4] proposed a single phase ac-dc-ac converter having three-leg configuration with reduced number of controlled switches. In the field of biomedical engineering there are various instruments which operate on ac and dc. Namely, X-Ray Mobiles, Electrocardiograph channels, Anesthesia machines with ventilator and monitor, Electro surgical units etc. works on ac and examination lamp, Fetal monitor, suction machines etc. works on dc. The harmonics, under voltage, over voltage etc. issues can adversely affect the normal working of the instruments. The implementation of a ac-dcac systems in instruments enables the load to be fed from an ac electric system with desired output voltage and with reduced harmonic distortions.

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Tissue engineering is another rapidly growing field [5]. There is an excellent review of DC electric fields and their role in biological systems. It is therefore no surprise that externally applied DC currents have been found to have many biological effects, and that many cells respond to steady DC electric fields. Such responses include galvanotaxis, which involves cells actively moving to either the cathode or the anode, and electrotropism, which involves the orientation of cells in electric fields [6]. Galvanotaxis and electrotropism could be used in tissue engineering, to guide cells to predefined positions, or orient cells in particular directions (e.g., neurons). Steady DC electric fields are also involved in the maintenance of cell polarity in natural tissues, in particular epithelial cells. There clearly is an opportunity to control cell polarity in artificial tissues using externally applied DC electric fields. AC electric fields across the membrane also decrease with increasing frequency, and thus AC electric fields are preferable for cell manipulation. The interaction between the dipole induced by the electric field and the electric field itself can lead to a variety of effects. These effects include electro-orientation, electro-rotation, dielectrophoresis and electrostretching.

The various fields such as the biomedical applications, tissue engineering, unified charging infrastructure of electric vehicles uses both ac and dc. The proposed ac-dc-ac system is a dual output system which gives stabilized ac output and dc output with reduced harmonics. Thereby the cost of installation of two different sources for ac and dc can be minimized to the cost of installation of a single system. It also reduces the floor spacing. By adopting the proposed system installation of voltage stabilizers in different equipment can also be reduced.

Paper is organized as follows. Section II describes the block diagram and the working of an ac-dc-ac configuration. The proposed system is given in Section III. PWM control strategy and control of the proposed system is given in Section IV and Section V respectively. Section VI describes the simulation results. Finally, Section V presents conclusion.

II. SYSTEM DESCRIPTION

The block diagram of the proposed ac-dc-ac system is shown in Fig. 1(a). The proposed configuration consist of two sections, an ac-dc-ac converter and a fly-back converter. Ac-dc-ac converters gives a stabilized ac output voltage with reduced harmonics, and the fly-back converter gives stabilized dc output voltage by employing the control strategy. The ac-dc-ac converter consist of three legs with four controlled switches and two diodes is shown in Fig. 2. The converter controlled legs consist of top switches q_s and q_l and complementary bottom switches $\bar{q}$ and $\bar{q}$. The following equations can be derived for the output (v_l) and input (v_g) converter voltages from the system in Fig. 1(b).

$$e_g = r_g i_g + L_g \frac{di_g}{dt} + v_g \quad (1)$$

$$e_l = -r_l i_l - L_l \frac{di_l}{dt} + v_l \quad (2)$$

$$i_s = i_g - i_l \quad (3)$$

$$v_g = v_{g0} - v_{s0} \quad (4)$$

$$v_l = v_{l0} - v_{s0} \quad (5)$$

where r_l and r_g represent the resistance of inductors L_l and L_g , respectively, l_l and l_g represent the inductance of inductors L_l and L_g respectively, and v_{g0} , v_{s0} and v_{l0} are the converter pole voltages. Two operation conditions can be highlighted:

Case 1: $i_g < 0$

$$\text{The diode } \bar{d}_g \text{ conducts, then, } v_{g0} = -\frac{v_c}{2} \quad (6)$$

From (4) and (5)

$$v_{s0} = -\frac{v_c}{2} - v_g \quad (7)$$

$$v_{l0} = v_l - v_g - \frac{v_c}{2} \quad (8)$$

From (7) and (8) the pole voltages are within the limits if, $-v_c < v_g < 0$ and $v_g \leq v_l$

Case 2: $i_g \geq 0$

$$\text{The diode } d_g \text{ conducts, then, } v_{g0} = \frac{v_c}{2} \quad (9)$$

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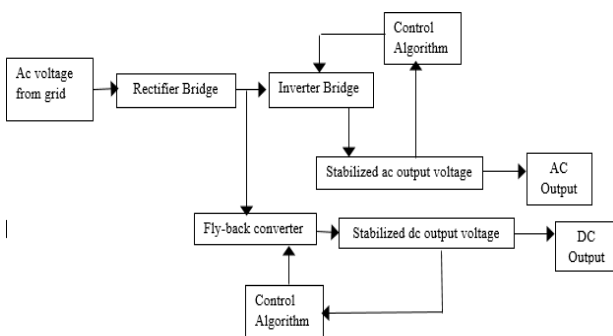
Vol. 8, Issue 6, June 2019

From (4) and (5)

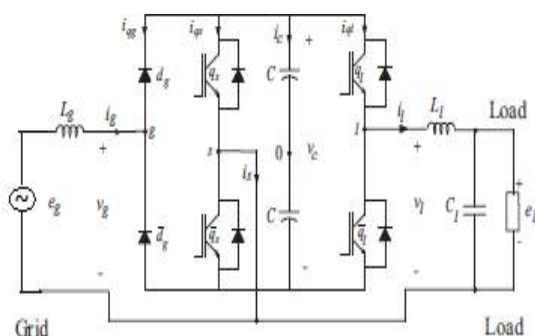
$$V_{s0} = \frac{v_c}{2} - V_g \quad (10)$$

$$V_{l0} = V_l - V_g + \frac{v_c}{2} \quad (11)$$

From (10) and (11) the pole voltages are within the limits if, $0 < v_g < v_c$ and $v_g \geq v_l$



(a)



(b)

b)

Fig. 1. System description (a) Block diagram of proposed system (b) Ac-Dc-Ac single phase converter

III. PROPOSED SYSTEM

The circuit diagram of the proposed system shown in Fig. 2 consist of an ac-dc-ac converter which consist of a rectifier, and an inverter stage. The proposed configuration consist of four controlled switches in two legs and two diodes in the other leg. By such a configuration the power and the voltage across the switches can be reduced. The ac-dc-ac converter gives stabilized ac output voltage with constant amplitude and frequency even when the input supply ac voltage fluctuates. The harmonic content in the output voltage is also reduced. A feedback control strategy is adopted for voltage stabilization. The intermediate dc stage is given as an input to a fly-back converter. By adopting another control strategy for the fly-back converter it gives stabilized dc output voltage. The proposed system is a dual output system with stabilized ac output voltage with reduced harmonics and a stabilized dc output voltage. Thereby, the fluctuations in the grid voltage and the harmonics will not affect the normal working of the device.

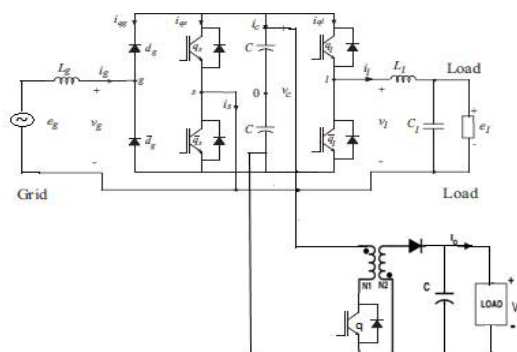


Fig. 2 Circuit diagram of proposed system

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Vol. 8, Issue 6, June 2019

IV. PWM CONTROL STRATEGY

The reference voltages provided by the controllers are denoted by v_g^* and v_l^* ,

$$v_g^* = v_{g0}^* - v_{s0}^* \quad (12)$$

$$v_l^* = v_{l0}^* - v_{s0}^* \quad (13)$$

Assuming the previous operating conditions, the reference pole voltages are given by,

Case 1: $i_g^* < 0$

$$v_{s0}^* = -\frac{v_c^*}{2} - v_g^* \quad (14)$$

$$v_{l0}^* = v_l^* - v_g^* - \frac{v_c^*}{2} \quad (15)$$

Case 2: $i_g^* \geq 0$

$$v_{s0}^* = \frac{v_c^*}{2} - v_g^* \quad (16)$$

$$v_{l0}^* = v_l^* - v_g^* + \frac{v_c^*}{2} \quad (17)$$

The reference pole voltages v_{s0}^* and v_{l0}^* are compared with high frequency triangular carrier signal to obtain gating signals.

V. CONTROL OF THE PROPOSED SYSTEM

Sinusoidal Pulse Width Modulation (SPWM) technique is used for switching the ac-dc-ac converter. In the control algorithm the output voltage is compared with a reference value. If the measured ac output voltage is less than the reference voltage then duty ratio of the switching pulse is increased by the control scheme to obtain a stabilized ac output voltage. The Weighted Total Harmonic Distortion (WTHD) of the output voltage is also reduced. The dc output voltage of the fly-back converter is also compared with another reference value so as to vary the duty ratio of the switching pulse.

VI. SIMULATION RESULTS

The system is modeled and evaluated in MATLAB/Simulink. The proposed system has been simulated for three different cases:

1. Case 1(Fig. 3.a.) : $e_g = 194$ V(rms), $e_l = 250$ V(rms), $v_o = 30$ Vdc
2. Case 2(Fig. 3.b.) : $e_g = 230$ V(rms), $e_l = 250$ V(rms), $v_o = 30$ Vdc
3. Case 3(Fig. 3.c.) : $e_g = 282$ V(rms), $e_l = 250$ V(rms), $v_o = 30$ Vdc

An RL load (load resistance and inductance $R_l = 100 \Omega$ and $L_l = 30 \mu\text{H}$, respectively) is used in all the three cases. A non-linear ac voltage source is used to vary the input ac voltage. The ac output voltage of the ac-dc-ac converter is stabilized at 250 V(rms) and dc output voltage of the fly-back converter is stabilized at 30 V. A voltage reference value is set for the voltage stabilization by providing a feed back control strategy. Sinusoidal Pulse Width Modulation (SPWM) technique is

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Vol. 8, Issue 6, June 2019

Fig. 3 shows the simulation results of all the three cases. The higher order harmonics are not as severe as lower order. Total Harmonic Distortion (THD) does not consider the severity of lower order but treats all harmonics equally. But Weighted Total Harmonic Distortion (WTHD) gives a better measure of harmonic pollution by using the order of each harmonic component as its weight factor. This index gives the severity of lower order harmonics. WTHD of the output voltage generated by the converter is given by

$$\text{WTHD}(\%) = \frac{100}{\gamma_1} \sqrt{\sum_{h=2}^{N_h} \left(\frac{\gamma_h}{\gamma_1}\right)^2}$$

where γ_1 and γ_h are the fundamental voltage amplitude and the corresponding harmonic component amplitude of h^{th} order, and N_h is the number of considered harmonics. THD of the output ac voltage is found to be 0.98% relative to the fundamental. The WTHD of the grid voltage is found to be 0.81% and the WTHD of output ac voltage is found to be 0.0461%.

Parameter	Symbol	Value
Grid voltage	e_g	230 V(rms)
Reference load voltage	e_l^*	250 V(rms)
Reference fly-back converter voltage	v_o	30 Vdc
Dc-link voltage	v_c	90 V
Dc-link capacitance and fly-back converter capacitance	c	2200 μF
Grid and load frequencies	f_g / f_l	50 / 50 Hz
Sampling frequency	f_s	20 kHz

Table I. Parameters used in simulation

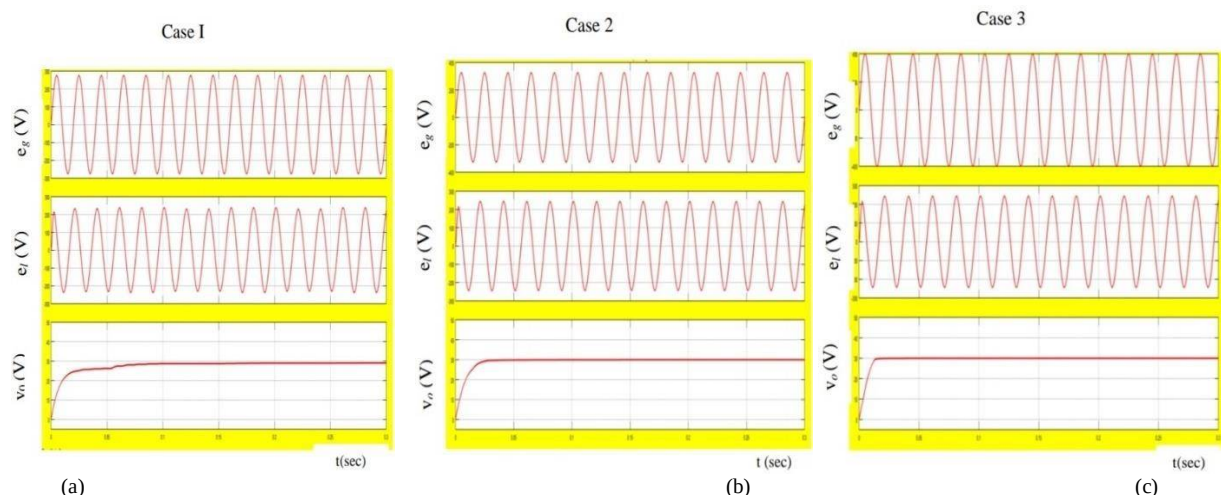


Fig. 3. Simulation results of proposed system

VII. CONCLUSION

The proposed ac-dc-ac converter topology generates a stabilized ac output voltage with reduced voltage harmonics. The fly-back converter utilizes the intermediate dc stage to generate stabilized dc output voltage. The ac and dc voltage

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Vol. 8, Issue 6, June 2019

stabilization is performed by using a control strategy which compares the output voltage with a reference value. The proposed topology can be employed in various applications where both ac and dc voltage are used such as in biomedical applications including tissue engineering, unified charging infrastructure for plug-in electric vehicles etc.. The proposed topology also reduces the WTHD of the ac output voltage. Regenerative operation is not feasible due to presence of diode in the proposed topology. The proposed system is simulated for three different cases.

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