ACTA TECHNICA CORVINIENSIS
BULLETIN OF ENGINEERING

[1.] NABIL M. HAMMAD

HIGH POWER QUALITY, REGULATED DC POWER SUPPLY FOR AUTOMOTIVE APPLICATIONS

Abstract:

Power electronics based power systems are being increasingly considered for transportation systems such as land, sea/undersea, air, and space vehicles due to their advantages in efficiency, performance, flexibility, and power density. In order to have superior performance, the rectifier-converter systems need to be rigorously regulated. The DC power supply is ingredient part in the automotive industries because it has been used as a DC power supplies for a wide range of loads. Meanwhile, it is mandatory for battery charging. These types however, cause many problems such as poor power factor, high input current harmonics distortion and uncontrolled DC voltage.

In this paper, an improved input power factor correction with low input current total harmonics distortion that uses a combined control system consists of two nested loops with a feedback of the DC voltage and input current as long as a feed forward from the output power. The system has been analyzed, modeled, simulated and experimentally verified.

The novel feature of the proposed control scheme resides in fact that it is not only achieve nearly unity power factor with minimum input current total harmonics distortion only but it also introduce superior performance in DC voltage transient conditions.

Keywords:

Rectifier; Power quality; DC voltage regulation; transient response

INTRODUCTION

With the growing of electrical power demand and introducing of 42 volt systems in modern vehicles, new factors should be considered in ordered to cope with the new standards. [1,2]

At present the diode rectifiers along with their traditional voltage regulators are dominant in most vehicles. Those systems although they have the advantages of being economical and reliable but they have some problems including:

1. *High alternator current total harmonics distortion.*
2. *Low input power factor.*
3. *Poor DC voltage transient performance.*

These problems could be more significant with the upcoming higher voltage such as 42 V systems. [3,12]

Trying to overcome those problems the active current wave shaping using a single switch boost converter will be used in this paper based on the proposed control combined control system.

The focus of this paper is on the analysis and modeling of the proposed circuit concentrating on DC voltage transient response and alternator power quality. Also the effect of the control circuit design on the system transient performance will be studied. Then the circuit had been simulated using the produced model and an experimental prototype had been built and tested. The experimental results confirm the *validity of both mathematical study and simulation results.*

PRINCIPLE OF OPERATION

This circuit type was explained severally in literature. So, we will focus on the basics of this type. Fig (1) shows the proposed system block diagram including the vehicle alternator, full wave rectifier and boost converter.

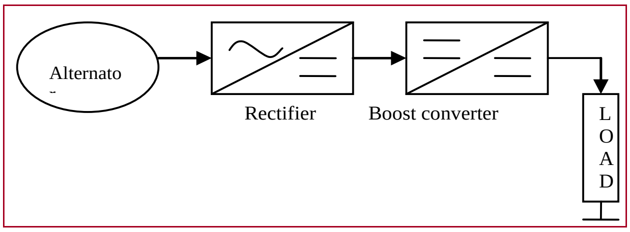


Fig 1.Overall system block diagram

The boost converter power circuit that consists of boost inductor L, boost switch S, boost diode D and boost capacitor C as shown in Fig. (2).

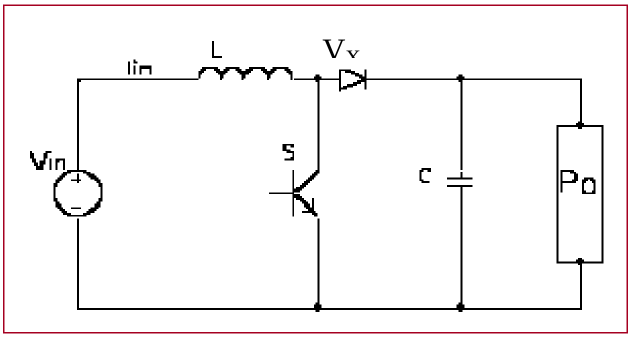


Fig 2.Boost converter power circuit

With continuous conduction, the voltage of the node connected between the transistor and reactor V_x *is equal to the input voltage* V_{in} *when transistor is on and the output voltage* V_o *is equal to* V_x *when the transistor is off.*

The boost converter has two modes of operation.

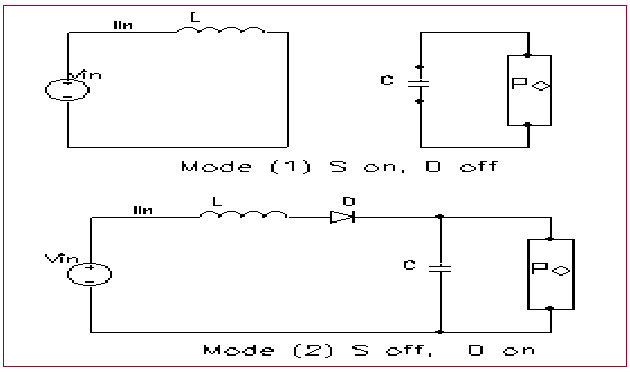


Fig 3.Boost converter modes of operationt

Mode (1) when the boost switch (S) is turned on as explained in Fig. (2), the inductor current builds up and the energy is stored in the magnetic field of the inductor. At this time the boost diode (D) is off and the capacitor (C) supplies power to the load.

Mode (2) when the boost switch is turned off and the stored energy in the inductor together with the energy coming from the AC supply is pumped to the output circuitry consists of the capacitor and the load.

In mode (2)

$$V_{in} - L\frac{dI_{in}}{dt} - V_o = 0 \qquad (2)$$

The control system consists of two nested loops, the outer is to control the DC output voltage and the error produced from this loop is multiplied by a sample of the input voltage to get the input current reference required by the inner current control loop as shown in Fig (4).

In order to obtain a sinusoidal input current in phase with the input voltage the control system should act in such a way that V_{in} *sees a resistive load equal to the ratio of* V_{in} *and* I_{in}*. This has been achieved by the already produced current reference to the actual current passing through the inductor. The error is then compared to a triangular waveform to generate the necessary boost switch gating signal.*

In this way the error is forced to remain between the maximum and minimum of the triangular waveform these results in that the inductor current follows the reference current very closely. Therefore, the inductor current is always restricted within the amplitude margin defined by the reference with the superimposed triangular waveform.

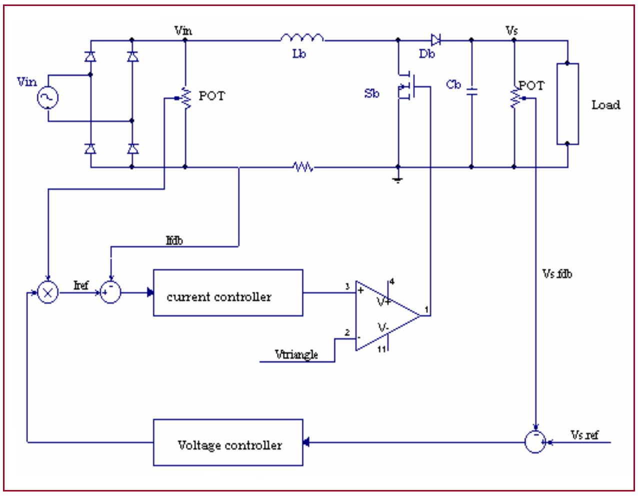


Fig 4. Boost converter complete circuit diagram

BOOST CONVERTER DESIGN CONSIDERATION

The power components of boost converter include the boost inductor L_b, the boost capacitor C_b, boost diode D_b and the boost switch S_b as shown in Fig (2) which explains the boost converter circuit diagram. The following design procedure will include two main elements which are the boost inductor and capacitor. The inductor of the boost converter should be chosen to minimize the current ripple. While the capacitor design is based on the permissible output voltage ripple [5].

There are two voltages controlling the inductor current. One is the rectified sinusoidal input voltage which is applied to one side of the inductor, and the other one is the voltage across the boost switch S_b, which varies between zero and V_o due to switching process and is applied to the other side of the inductor. The voltage that contributes to the ripple is the voltage across the switch.

To consider the worst case for ripple, the duty cycle of the switch is taken to be 50% for this analysis. Based on the above assumption and considering that;

V_s is the output voltage

F_{sw} is the boost switching frequency

I_{Ir} is the rms value of the fundamental component of current ripple at 50% duty cycle

The following equation can be written:

$$(V_s/2)(4/\pi\sqrt{2}) = (2\pi F_{sw} L_b) I_{ir} \qquad (3)$$

Where;

$(V_s/2)(4/\pi\sqrt{2})$ is the rms value of fundamental component of switched voltage for 50% duty cycle.

$(2\pi F_{sw} L_b)$ is the reactance impedance of L_b

Considering that the maximum permitted amount of ripple is 5%, therefore, I_{Ir} = .05I, (where I is the rms value at 100Hz the inductor current). Then;

$$L_b = (1.433)\,(V_s)\,/\,(F_{sw})\,(I) \qquad 4)$$

To find the value of C_b for the desired output voltage, it can be noted that the capacitor-resistor combination at the output of the converter acts as a low-pass filter for the current through the boost diode. This current can be considered as being supplied by a current source I_s, whose value is controlled by the output voltage controller. Furthermore, Fourier analysis of the diode current shows that this current is of a sinusoidal nature, considering only its dc and fundamental components. Therefore;

$$I_s \cong K(1-\cos 2\omega t) \qquad (5)$$

The gain of the filter for the dc component of the current I_s is K_v, where its gain for the ac component is;

$$|G_{AC}| = \frac{K_v}{((2K_vC_b\omega)^2+1)^{1/2}} \qquad (6)$$

Therefore;

$$r = 2\frac{|G_{AC}|}{G_{DC}} = \frac{2}{((2K_vC_b\omega)^2+1)^{1/2}} \qquad (7)$$

Where r is the output voltage ripple, which is defined as the ratio of the peak to peak value of the ripple component to the dc component of the output voltage. As a result, C_b can be found in terms of r to be;

$$C_b = \frac{(4-r^2)^{1/2}}{2rK_v\omega} \qquad (8)$$

Using equations (4) and (8) the main power elements of boost converter can be determined [5].

SIMULATION RESULTS

In order to verify that the proposed control system performs as expected numerous simulations were conducted to investigate the system performance.

Fig. (5) shows the system transient response at 50% step load increase, the upper one is the output power and the lower is the DC voltage using the proposed combined control system. It is clear that the system performance is highly improved compared to the same system using the DC voltage feedback only shown in Fig.(6) which arranged in the same manner as Fig. (5).

From Fig. (7) it is evident that as the capacitor value increased the transient response is improved on the account of the initial cost. So, this capacitor value can be chosen to maintain the transient response and minimize the initial cost.

To study the system frequency response, a Bode plot is constructed for different control systems including open loop, DC voltage feedback and combined system as shown in Fig. (9). It is noticed that the system using either the DC voltage feedback or the proposed combined control system is stable and the later suppresses *very effectively the variation of the DC output voltage.*

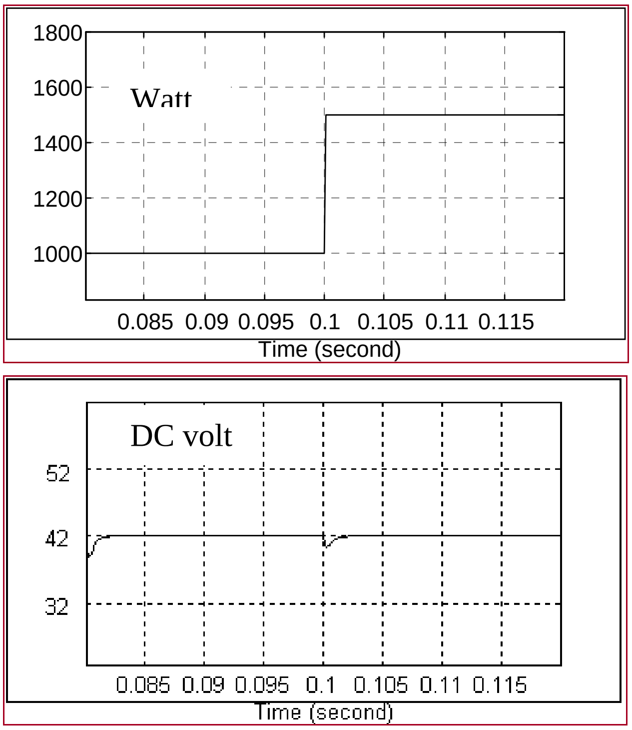


Fig (5) System transient response using the combined control system. Load power Upper trace & DC voltage lower trace

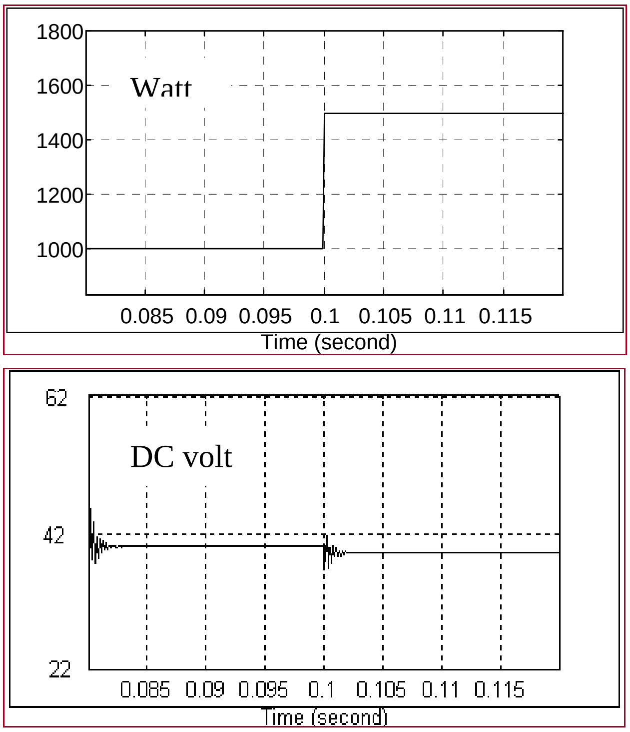
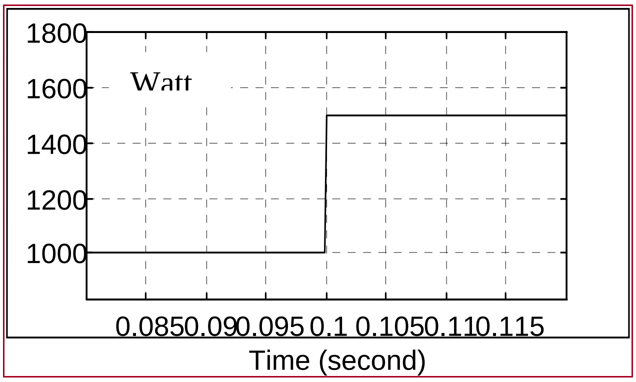
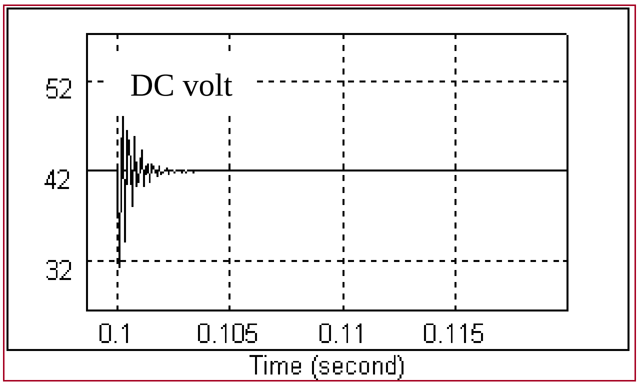


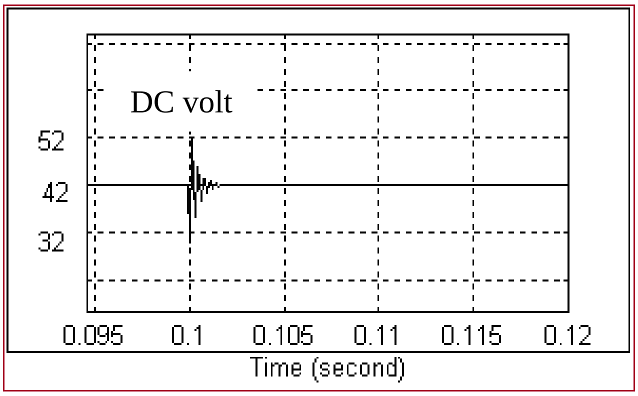
Fig (6) System transient response using the DC feedback only. Load power Upper trace & Dc voltage lower trace.



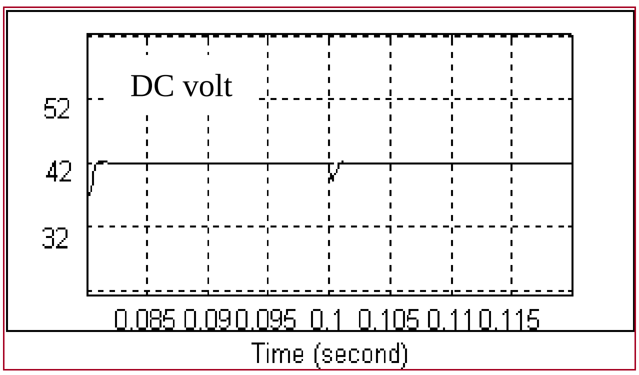
Output power



DC voltage at C= 10 uF

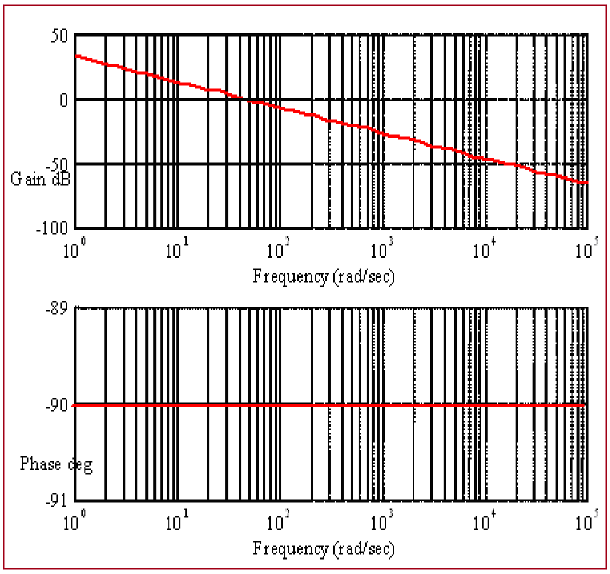


DC voltage at C= 20 uF

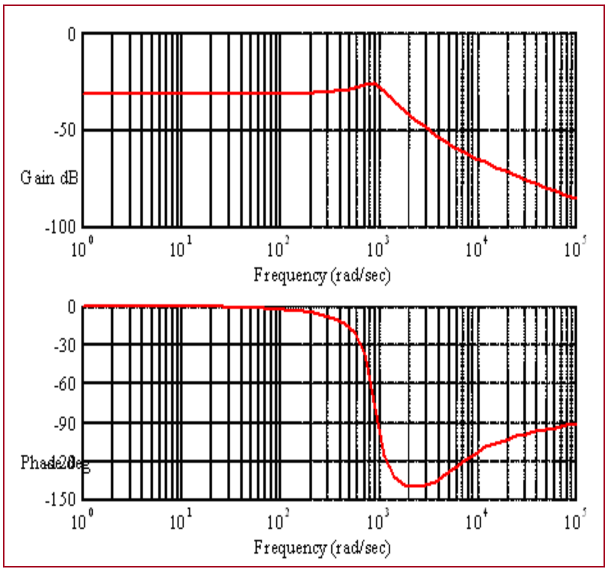


DC voltage at C= 100 uF

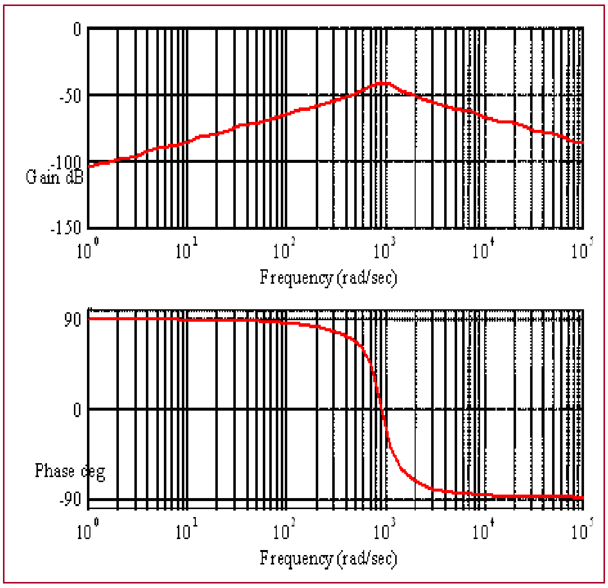
Fig (7) Effect of capacitor value on the system response



Open loop system



Feedback system



Combined system

Fig (8) System frequency response

EXPERIMENTAL RESULTS

The boost converter had been built and tested. It shows a promising results, considering the input current wave shaping the attention has been paid to the input power factor improvement and the input current total harmonic distortion minimization. Those two points can be covered if the control system acts in a way that makes the input source sees the load as a resistive load. This resistive load will draw a current with a unity power factor and minimum input current total harmonic distortion.

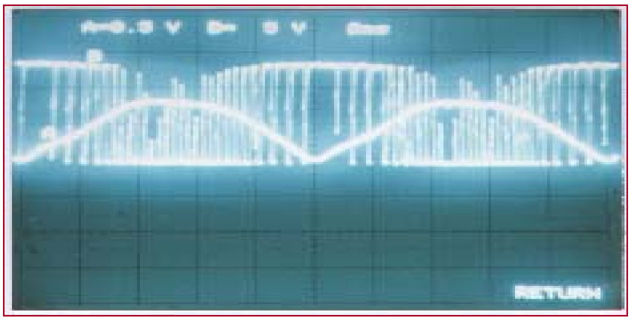


Fig (9) Boost switching device drive signal with input reference current.

The output of the two nested loops control system is shown in Fig (9) which explains the boost converter switching device gating signal in addition to its input current reference. It can be noted that; at the input voltage zero crossing area the on duty ratio of the boost switching device is approaching unity. While it is minimum at peaks of the input voltage waveform.

To demonstrate the effect of the boost converter on the input current wave shaping the input current of the regular diode bridge rectifier is shown in Fig (10). It can be noticed that input current is pulsed current out of synchronism with input voltage.

The boost converter AC input current waveform with the input voltage is shown in Fig.(11). The transient response improvement using the proposed control system is shown in Fig (12). The input current harmonic spectrum has been practically measured at three rectifier configurations. The first is the regular diode bridge rectifier THD is approaching 34%., the second is the boost converter using the conventional control system gave a total harmonic distortion around 3.5% and the last *one is the boost converter using the proposed control system The total harmonics distortion is highly reduced and becomes lower than 0.7%.*

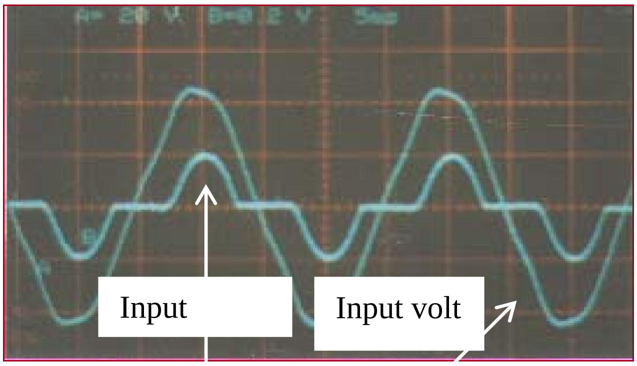


Fig (10) Diode bridge rectifier input current and voltage.

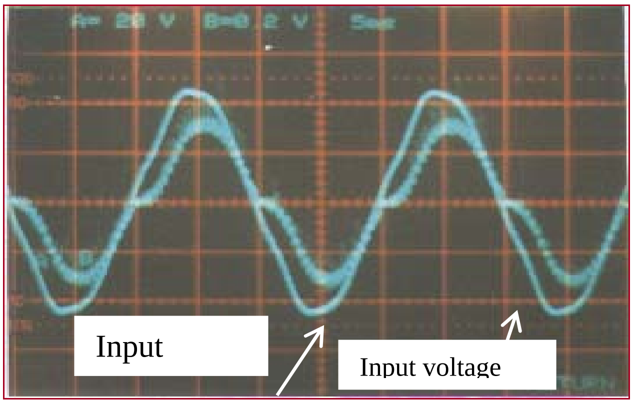
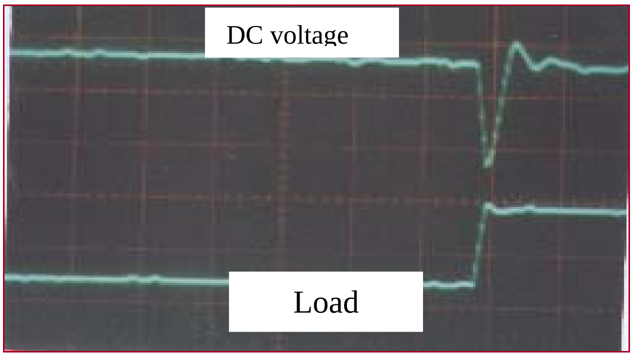
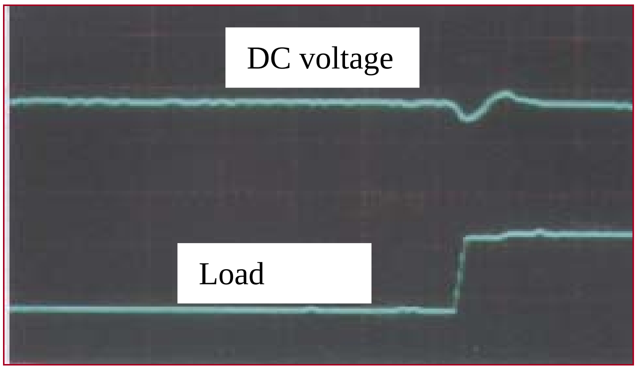


Fig (11) Boost converter input current and voltage.



Feed back control only



Proposed control system

Fig (12) Boost converter transient response

CONCLUSION

A new high power quality DC voltage regulator for vehicles applications has been proposed, simulated, and prototyped and tested successfully.

It is shown throughout this paper a simple boost converter based combined control system that achieved the following

Nearly unity power factor operation with minimum input current total harmonic distortion is obtained using a single switch boost converter based on the proposed combined control system.

The system transient response is highly improved thanks to the combined control system including Dc out voltage feedback along with output power feed forward control scheme.

REFERENCES

[1] M. Vimont, "42 Volts in a Car: Why?", First International Congress "42V PowerNet - the first solutions", Sept. 28-29, 1999, Villach /Austria.

[2] Hans-Dieter Hartman, "Standardization of the 42V PowerNet - History, Current Status, Future Action", First International Congress on 42V PowerNet, (Villach, Austria: September. 1999).

[3] J.M. Miller, D. Kaminski, H-P Sch6ner, T.M. Jahns, "Making the Case for a Next Generation Automotive Electrical System", Proceeding of the International Congress on Transportation Electronics, Convergence 1998, Hyatt Regency Hotel, Dearborn, MI USA. October 19-21, 1998, pp 41-51.

[4] Graf, "Semiconductor Technologies and Switches for New Automotive Electrical Systems", EAEC European Automotive Congress, Barcelona, June 30 -July 2 1999.

[5] M. Kazerani, P. D. Ziogas and G. Joes, "A novel active current wave shaping technique for solid state input power factor conditioners" in IEEE trans. On industrial electronics, vol. 38, No. 1, Feb. 1991, PP 72-78.

[6] S. Wall and R. Jakson, "Fast controller design for practical power factor correction system" IEEE power electron. PESC 1993, PP 1027-1031.

[7] S. Manias "Novel full bridge semi controlled switched mode rectifier" IEE proceeding B, 138 (5), 1991, PP 252-256.
[8] R. Duke, S. Round and N. Mohan, "Achieving sinusoidal rectifier input current while minimizing the KVA rating of controllable switches" IEEE power electron. PESC 1993, PP 796-7
[9] Alireza Khaligh, S. S. Williamson, A. Emadi, " Control and stabilization of DC/DC Buck-Boost converters loaded by constant power loads in vehicular systems using a novel digital scheme" power electronics and motion control conference, 2006. EPE-PEMC2006
[10] M. Al Sakka, J. Van Mierlo, H. Gualous, P. Lataire, "Comparison of 30KW DC/DC converter topologies interfaces for fuel cell in hybrid electric vehicle" 13th European Conference on Power Electronics and Applications, 2009. EPE '09.
[11] A. Khaligh, A. M. Rahimi, A. Emadi, "Modified Pulse-Adjustment Technique to Control DC/DC Converters Driving Variable Constant-Power Loads" IEEE Transactions on Industrial Electronics, Volume: 55, Issue: 3 2008 , Page(s): 1133 – 1146
[12] R. Stence, " Shifting to 42-volt hybrid system" SAE paper No. 2004-01-3067
[13] A. S. Samosir, A. H. M. Yatim "Implementation of New Control Method based on Dynamic Evolution Control for DC-DC Power Converter" International Review of Electrical Engineering Vol. 4. n. 1, pp. 1-6
[14] B. Kenny, P. Kascak "DC bus regulation with a flywheel energy storage system" SAE paper No 2002-01-3229
[15] C. M. Wang, C. H. Yang "A novel high input power factor soft-switching single-stage single-phase AC/DC/AC converter" Vehicle Power and Propulsion, 2005 IEEE Conference
[16] R. Y. Kim, J. S. Lai " Aggregated modeling and control of a boost-buck cascade converter for maximum power point tracking of a thermoelectric generator" Twenty-Third Annual IEEE Applied Power Electronics Conference and Exposition, 2008, PP 1754-1760
[17] T. Bhattacharya, V.S. Giri, K. Mathew, L. Umanand "Multiphase Bidirectional Flyback Converter Topology for Hybrid Electric Vehicle" IEEE Transactions on Industrial Electronics Volume: 56 , 2009, PP 78-84
[18] J. Berryhill, K. Li, J Ward " Summary of 42 V PWM testing results" SAE paper No. 2002-01-0518
[19] A.A.Ferreira, J.A. Pomilio, G. Spiazzi, L. de Araujo Silva, "Energy Management Fuzzy Logic Supervisory for Electric Vehicle Power Supplies System" IEEE Transactions on Power Electronics, Volume: 23 , , 2008 PP 107-115
[20] M. Tao; B. Hongqi; W. Daqing " Novel three-phase power factor corrector suitable for charging systems" IEEE Vehicle Power and Propulsion Conference, 2008
[21] A. Khaligh, A. M. Rahimi, M. Khaligh, A. Emadi, "Sensitivity Analyses of Pulse Adjustment Control Technique of a Buck-Boost Converter Operating in Discontinuous Conduction Mode and Driving Constant Power Loads" IEEE Vehicle Power and Propulsion Conference, 2006. VPPC '06
[22] L. del Re, G. Steinmaurer, N. Hannoschock "Cost-effective pollution abatement for SI engines with a 42V board net" SAE paper No. 2000-05-0055
[23] K. Furmanczyk, M. Stefanich "Power Conversion Technologies for Reducing Current Harmonics on the More Electric Aircraft" SAE paper No. 2006-01-3086

AUTHORS & AFFILIATION

[1.] NABIL M. HAMMAD

[1.] FACULTY OF ENGINEERING, HELWAN UNIVERSITY, CAIRO, EGYPT

ACTA TECHNICA CORVINIENSIS
– BULLETIN of ENGINEERING
ISSN: 2067-3809 [CD-Rom, online]

University Politehnica Timisoara,
Faculty of Engineering Hunedoara,
5, Revolutiei,
331128, Hunedoara,
ROMANIA
http://acta.fih.upt.ro

ANNALS
of
FACULTY ENGINEERING HUNEDOARA
– INTERNATIONAL
JOURNAL of ENGINEERING
ISSN: 1584-2665 [print, online]
ISSN: 1584-2673 [CD-Rom, online]

University Politehnica Timisoara,
Faculty of Engineering Hunedoara,
5, Revolutiei,
331128, Hunedoara,
ROMANIA
http://annals.fih.upt.ro