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A Novel Methodology for Controlling Transient Current in Electrical Power System and Its Applications in DC Chopper

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Abstract – **Certain advancement in the automotive embedded electronics in car and applications the capacity of the current 14 volt voltage system no longer meets the demand of the on-board devices. In order to be backward compatible with the existing 14v system and to introduce extensive modifications, a dual 14v/42v is being developed as a compromising solution to the problem. Based on the new system this article is proposes** a **synchronous buck/boost converter an attractive topology for 42V/14V dual voltage systems since it offers the possibility of bi-directional operation without additional components. In this paper, transient currents generated during converter startup or changes in operation modes between buck and boost are analyzed and a cost effective solution to remove the transient currents is proposed. The validity of the proposed control strategy is investigated through simulation and experiment with bi-directional converters.**

Index Term- **Bi-Directional DC-DC Converter, Dual Voltage System, Buck-Boost Converter**

I. INTRODUCTION

Bi-Directional DC/DC converter has gained interest in both the industry and in the academic world of the power electronics field, which can perform as a platform for the transaction between different voltage values and make management of power at the two level of power system. It has a promising prospect in application of automation electronics, photo voltaic cell, solar energy generation and wind power generation, etc. A typical luxury class vehicle today draws between 1200W to 1500W of steady state power from the electrical system and has about 2.5 km of wiring in the harness[l]. 42V electrical power systems are on their way to replacing the present l4V systems in automobiles and 42V/14V dual voltage systems have been proposed to provide backward compatibility with the existing components in 14V system[2][3]. Fig. 1 shows one of the popular architectures for implementing the 42V/14V dual voltage system. A bi-directional DC/DC converter is equipped with 42V and 14V buses and batteries are connected to each bus, respectively[4]. In implementing a DC/DC converter, a non-isolation buck or boost is a good topology because the isolation between 42 and 14V buses is not required in automobiles and the voltage conversion ratio of input and output is only about 1/3 or 3. The voltage conversion ratio is not exactly 1/3 or 3 because of power losses, efficiency and control methodology. A German forum has come up with a proposal to boost present in car voltage level from 14 volt to 42 volt, which in turn Increases the power capacity of the 8 KW.

In this article, we introduce the bi-directional DC/DC converter. It contains control circuit which is able to determine the operating mode depending on the inductance current direction; it then stabilizes the closed loop system stable without changing the parameters. The DC/DC converter is used in automotive environment which has strict requirement for cost, volume and efficiency. A Buck/Boost converter is build for this purpose.

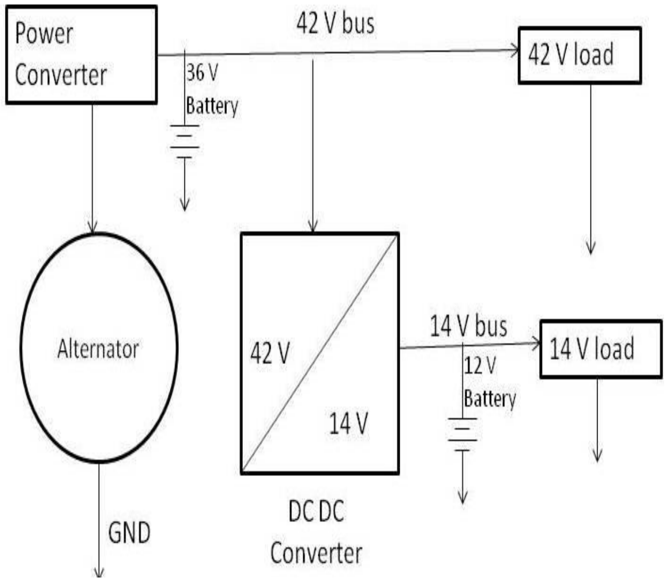


Fig.1 Basic block diagram of 14V/42V System.

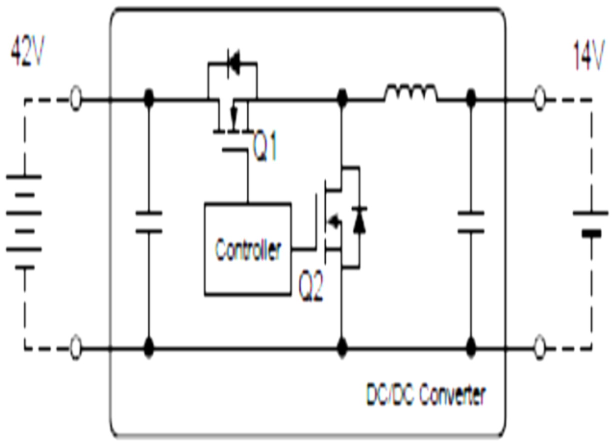


Fig.2. Synchronous buck/boost converter with voltage source in input and output side.

In Fig. 2 switches Q1 and Q2 are operated as the main switch or as the freewheeling diode according to the operating direction. Unlike typical converters for power supplies, this synchronous buck/boost converter has voltage sources on both sides of its input and output. Therefore, whenever the controller is started up and the operation mode is changed between buck and boost, abnormal transient currents can flow because the transient switching duty is not the same as the regular duty related with the converter input voltage and the output load voltage.

Most of the research paper deals with control method, improvement of efficiency, and noise problems in the converter. They did not deal with converter start up[7-12].

Compared with previously discussed approaches, the converter in this paper has the following characteristics and advantages:

1) The bi-directional converter has voltage sources on both input and output.

2) When the controller is implemented by a conventional PWM IC, the transient currents during the start up and mode changing between buck and boost are analyzed.

3) A cost effective solution to remove the transient current is proposed.

II. Flow of Transient Current during Startup

The voltage conversion ratio of the synchronous buck/boost converter is given by:

$$\frac{V_{14v}}{V_{42v}} = \frac{T_{q1\,on}}{T_{q1\,on} + T_{q1\,off}} \quad (1)$$

Where, $T_{q1\,off} = T_{q2\,on}$ and $T_{q2\,off} = T_{q1\,on}$

If the bus voltages, V42V and V14V are 36V and 12V, which are the nominal voltages of the batteries, the switching duty for Q1 and Q2 should be about 1/3 and 2/3, respectively. If the bus voltages are changed according to the battery charge and discharge conditions during the converter operation, the switching duty has to be changed as much as the changed in the bus voltage ratio. Since the DC/DC converter has a voltage source load on both sides of the input and output, there are some points to consider for smooth operation when the controller is started up or when the operation mode is changed between buck and boost.

When most converters are turned on, the switching duty and output voltage are designed to increase slowly because of a soft-start function. However, the soft-start in this DC-DC converter will show an abnormal transient current. If the input and output voltages are 42V and 14V, and the bi-directional converter is operating as a buck converter, the duty ratio will start from 0, and it will be operated in boost mode until the duty ratio reaches 0.33. If there is no voltage source at the output, output voltage will increase from 0V to 14V. If there is a voltage source at the output and the duty ratio is less than 0.33, the output voltage cannot increase according to the duty ratio, because the output voltage is already 14V. When this happens, Q2 becomes the main switch, and it is operated in boost mode. Therefore, the direction of the inductor's current flows in reverse.

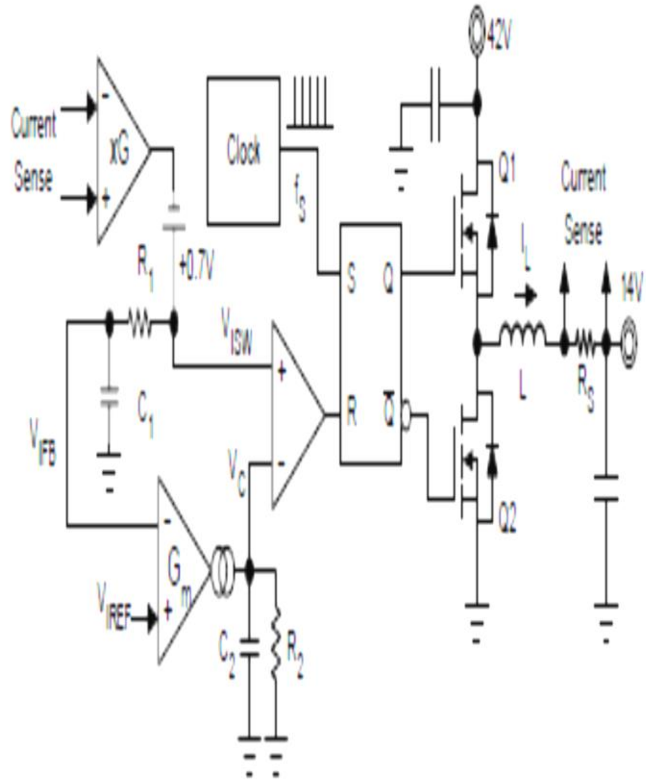


Fig.3. Current Mode Synchronous buck converter circuit.

Due to the capacitor (C2) of the error amp compensator, the error amp output, VC, is slowly increased. Since the current feedback loop has an offset voltage (0.7V), Q2 is turned on and the output source voltage becomes short until VC reaches the offset value. Most of the PWM ICs have the voltage offset in the feedback loop or on the error amp output to get the noise margin. Even though there is no offset, an abnormal negative transient current flow during startup and an abnormal negative current cannot be detected protected against because the PWM IC including op amp, comparator and differential amp for current sensing operates with only a single voltage supply.

III. PROPOSED CONTROL METHOD

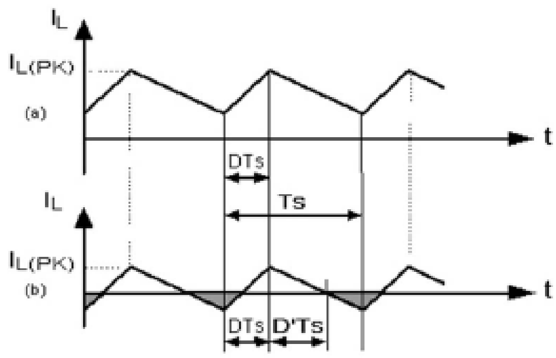


Fig.4. Inductor Current Waveform. (a) When load is large (b) When load is Small.

Fig. 4 shows the inductor current waveform according to the amplitude of the load current. The synchronous buck/boost converter with voltage sources at the input and output terminals is always operated in a Continuous Conduction Mode (CCM) and the current can flow in the reverse direction as the output current decreases. This is due to a path which allows reverse current flow [13]. Therefore, when the load is large, as shown in Fig. 4(a), the inductor current always flows from input to output. However, when the load is small, the inductor current can flow in reverse from output to input as shown in the shaded region of Fig. 4(b). This happens because the current from the output can flow through the Q2 switch with the role of a diode. However, the control IC which is fed by a positive single power supply cannot detect the negative feedback current as shown in the shaded region of Fig. 4(b). As a result, the controller operates the converter in a Discontinuous Conduction Mode (DCM) according to the output current level [14][15]. Therefore, this converter should be analyzed separately for each mode.

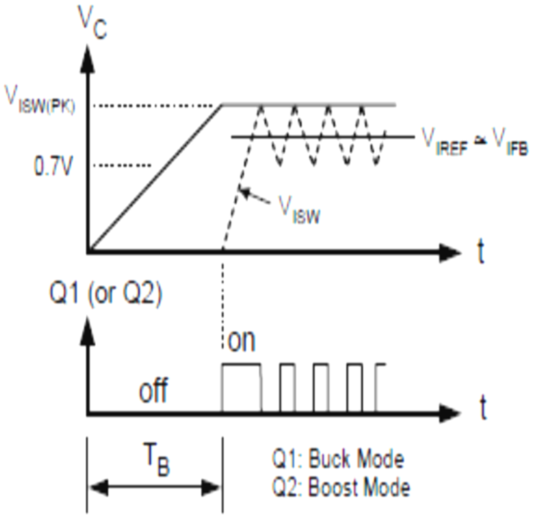


Fig.5 Method to remove Transient Current during Startup.

Therefore, as shown in Fig.5 if the current reference, VIREF, during startup is fixed and the switching is stopped until VC reaches the value, VISW (PK), so the transient current can be removed. The error amp configuration in the switching blocked condition is shown in Fig. 6

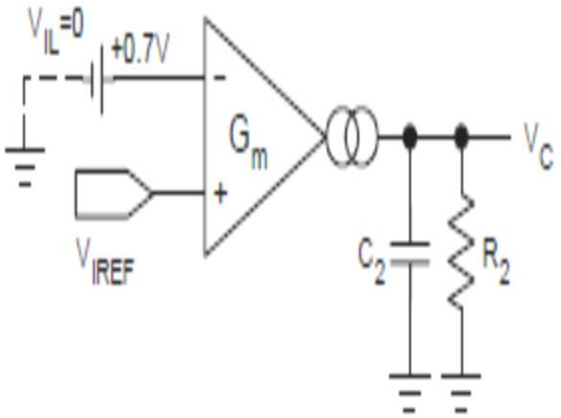


Fig.6. Error Amp During Gate block.

Two PWM controllers are used to implement the bi directional operation. Only one PWM controller should be in operation at a time. When changes in operation modes are required, the controller in operation has to be turned off before the other controller can be turned on. The switching signal outputs from the controllers are combined with OR gates and are sent to the gate drive circuit. The gate enable circuit is designed to block the gate signal with a microprocessor until the error amp output reaches the correct level to reduce the transient current.

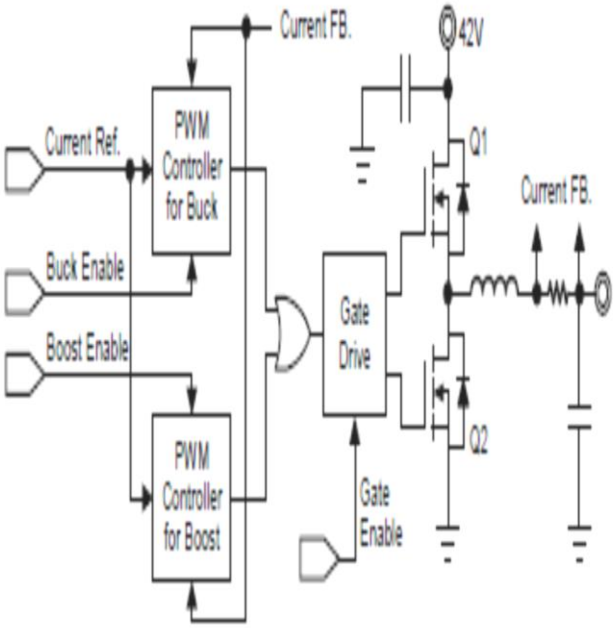


Fig. 7. Block diagram of the proposed controller

Two PWM controllers are used to implement the bi directional operation. Only one PWM controller should be in operation at a time. When changes in operation modes are required, the controller in operation has to be turned off before the other controller can be turned on. The switching signal outputs from the controllers are combined with OR gates and are sent to the gate drive circuit. The gate enable circuit is designed to block the gate signal with a microprocessor until the error amp output reaches the correct level to reduce the transient current. Whenever changing the operation mode, the same situation with the startup happens and the microprocessor should enable and disable the switching signal with this circuit. The microprocessor can get 42V and 14V through the AD converter. It also searches for the adequate TB according to the input, output voltage and initial inductor current. Therefore, when the output voltage is lower than the reference voltage, the converter outputs the maximum current. If the output voltage reaches the reference voltage, it controls the current to maintain the desired voltage, which is the same process used by battery chargers, so there is no possibility for the control signals of the two controllers to collide.

IV. EXPERIMENTAL RESULT

When the buck controller is enabled with the buck enable signal, the controller outputs the PWM switching signals for Q1 and Q2. However, the actual switching is delayed until the microprocessor enables the switching. The switching enable time is determined by the microprocessor using a blocking time table. Fig. 8 and 9 show the proposed method in simulations as well as the experimental results.

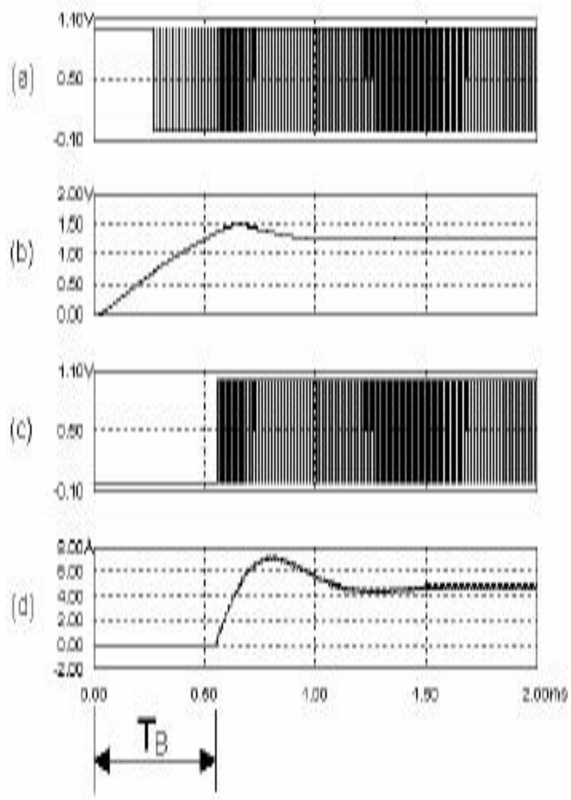


Fig.8. Simulation Result during Buck Mode.

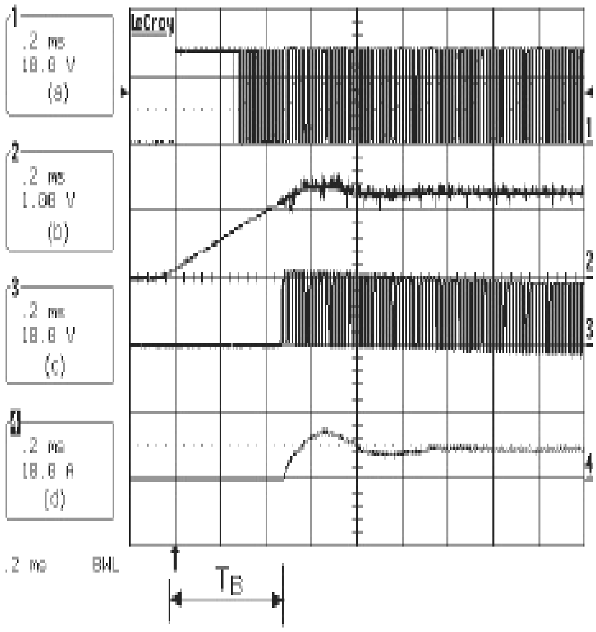


Fig.9. Experimental Result during Buck Mode.

Fig. 8(1) shows the Q2 switching waveform before gate block. Although the Q2 turn on signal appears during start up, it is blocked by the gate block signal. Fig. 8 (2) shows the error amp output VC. Fig. 8 (3) shows the actual switching waveform applied to the switching component. The switching starts only after the error amp output Vc reaches a certain level calculated according to the input and output voltage. Fig. 8 (4) shows the output current. Fig. 9 shows the experimental results which are identical to the results of Fig. 8. Fig. 10 shows the switching signals and inductor currents under interleaved operation in which the two main switches work alternatively with an 180° phase shift[18][19].

Fig. 11 shows the experimental results when the blocking time is not suitable. Fig.11(a) shows the transient current without the blocking time during startup, which is almost the same result as the result shown in Fig. 5. Fig.11(b) shows the transient current when the blocking time is shorter than the nominal value, and the output current flows in reverse until the error amp output reaches the nominal value. Fig. 11(c) shows the transient current when the blocking time is longer than the nominal value and the output current flows much more than the nominal load current.

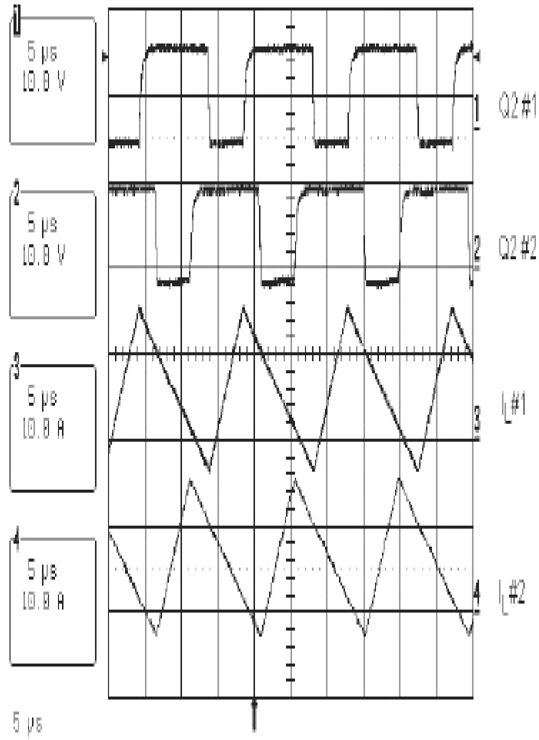
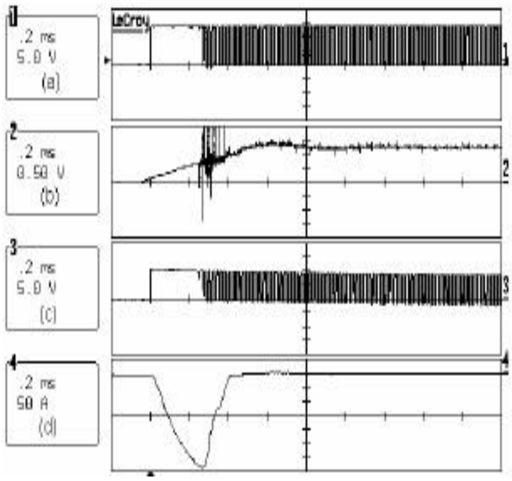
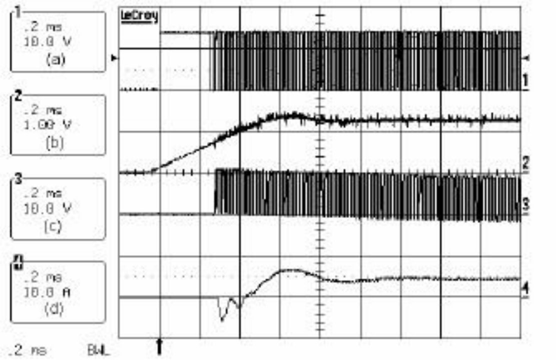


Fig.10. Gate Signal in interleaving Mode

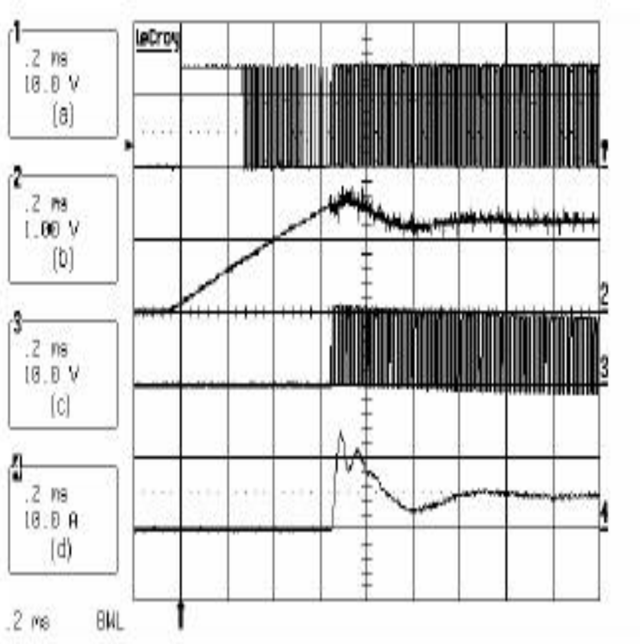
Fig. 12 is the current waveform during operation mode change with 0.5 sec stop duration. There is no significant current transient during operation mode changes and the current is varied according to the battery condition due to partially loaded conditions.



(a) Transient Current without blocking.



(b) Start up with an abnormal Short blocking time



(c) Start up with an abnormal long blocking time

Fig. 11 Experimental results when the blocking time is not suitable.

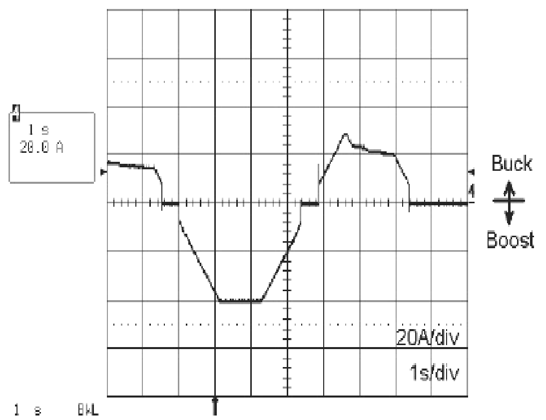


Fig. 12 Current Waveform of a 14 V Terminal.

V. CONCLUSIONS

This paper presents the transient current during startup of the synchronous buck/boost converter with voltage sources on both input and output terminals and proposes a cost effective solution to remove the transient state. This scheme can be easily implemented with simple additional circuits and a low cost microprocessor. As the microprocessor is only used to read the table and set the timer, large computational resources are not required for this method. Therefore, the program can be ported in the microprocessor to be used for other function such as CAN communication. This proposed circuit design can further be reinforced by extensive experimentations and further research in this field.

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