DSP-Based Direct Source Current Control for Three-Phase Four -Wire Power Conditioner

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Abstract – **A DSP-based source current control for power conditioner is presented to compensate current harmonics and asymmetries of three-phase four-wire emergency generators caused by nonlinear and/or unbalanced loads. Three-phase voltage type converter with split-dc-capacitor is adopted as the power circuit and a new direct source current control method is suggested, which simplifies the controller. The proposed control method shapes the generator current sinusoidally inphase with the voltage and allows the generator to supply maximum power even to single phase loads. An IGBT based 100kVA prototype with the controller realized with a DSP (TMS320C32) is built and tested to verify the performance of the power conditioner.**

I. Introduction

The wide use of nonlinear loads in three-phase ac lines is leading to transmit high levels of power under unbalanced and non-sinusoidal conditions. This results in a variety of undesirable phenomena on the power system such as current harmonics and asymmetries, which are responsible for the increase of losses in the ac power lines and transformers. They also cause malfunctions in sensitive equipment and can create significant interference with communication circuits. In the case of the small generator (emergency purpose) instead of ac mains, these nonlinear and unbalanced loads cause much serious problems such as the generation of reverse pulsating torque, overheating, and mechanical stress, which result in low efficiency and low utilization factor of generator.

To compensate the unbalanced and non-sinusoidal currents in the ac line, active filtering techniques by using three phase voltage or current type converters have been presented and their control theories have well established [1-6]. An active filter provides constant power or sinusoidal current to the source, even under unbalanced voltage conditions and describes a three-phase four-wire shunt scheme using a conventional three-leg converter [2]. Particular attention has been paid to the harmonic current injection shunt active filter with PWM voltage source inverter [3]. Active filter control circuit based on the instantaneous i_d-i_q method was achieved even under unbalanced and non-sinusoidal conditions [4]. A three-phase Active filter operates with fixed switching frequency and can be compensate the reactive power and current harmonic component of the load current. Current harmonic compensation is done in time domain [5]. Recent research on harmonic and reactive power compensation, the high performance control based on microprocessors such as digital signal processor (DSP) has become more popular and allows more possibilities to active filter applications [6]. The active filtering techniques for the small-scale emergency generators (several hundreds kVA), have not been presented yet.

This paper deals with a power conditioner for the three-phase four-wire emergency generator to compensate unbalanced and non-sinusoidal current. Three-phase voltage type converter with split-dc-link-

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under a serious power unbalance of generator such as a single phase loads.

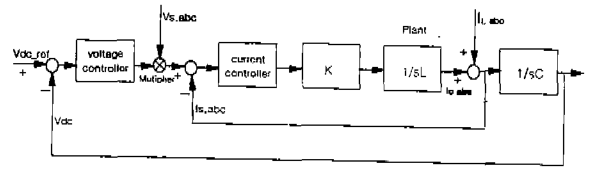


Fig. 3 Block diagram of the control loop.

III.Hardware Design and Realizations

A. Power Circuit Design

The circuit schematic of the proposed power conditioner is shown in Fig. 2. The power rating of the power conditioner for a 100 kVA emergency generator is selected as 100kVA to allow the generator to supply its maximum power (100kVA) even to the worst case of unbalanced loads (single-phase loads). For the 100kVA single-phase load, the phase current (or load current) will be about 450Arms and this current should flow not through the neutral line but through the center of the split dc-capacitors as shown in Fig. 4 and each phase current of the generator should be 150Arms to generate 100kVA. Since there are no loads in the b-phase and c-phase, the currents of b-phase and c-phase should flow through the conditioner and the difference between the load current and a-phase current should also flow through the conditioner as shown in Fig, 4. So, three 1200V/600A IGBT modules from Semikron are used for main devices. The dc link voltage should be higher than the peak-to-peak voltage of the phase to control the conditioner input current and should be as high as possible for better current controllability. The dc-link voltage is chosen as 750V by considering the voltage rating of dc-link capacitor and IGBT modules. The size of dc-link capacitors should be big enough to hold the each capacitor voltage during a line cycle. The voltage deviation from its nominal voltage is calculated by following condition;

$$Cd = \frac{3\ 375}{2\Delta V} \qquad (4)$$

For 40V voltage deviation, the dc-capacitors are chosen with 41mF for each and constructed with ten 8200uF/450V electrolytic capacitors for two capacitors. The input inductor is designed with 800uH from 15% of current ripple.

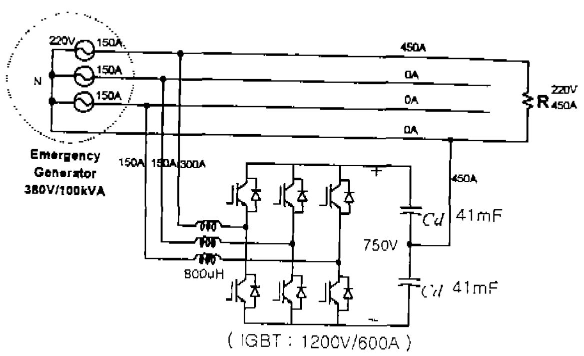


Fig. 4 Design of power circuit (currents at the worst case of unbalanced load).

B. Controller Design and Implementations

To implement the proposed direct source current control method, a TMS320C32 based DSP board is designed and the sampling rate is chosen as 12kHz by considering losses of IGBTs and input inductors and the speed of DSP. The second-order butterworth filter was used with 6kHz cut-off frequency to eliminate the high frequency noise and harmonics in the sensed signals of the generator voltages and currents and dc-link voltage. The unit gain frequency of the outer voltage loop controller is about 100Hz, which is high enough for dc-link voltage regulation because dc-link capacitor bank is very large. The bandwidth of the designed inner current control loop is about 6kHz, which is much higher than the outer loop. The current control loop should be as fast as possible because the reference of this loop is AC and is implemented by only a scalar gain.

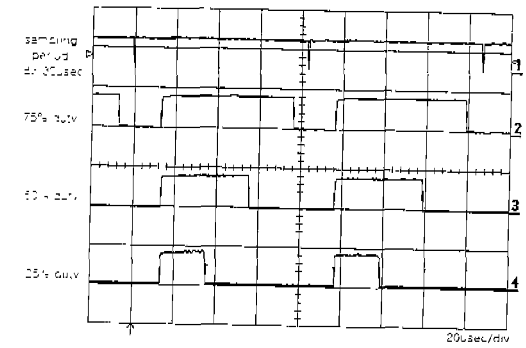


Fig. 5 Waveforms of SPWM (a-phase).

The direct current control can be easily implemented using DSP in the time domain and SPWM method is used for current control..
Fig. 5 shows the a-phase gate signal of SPWM, where the sampling period represents the speed of inner current control loop. The SPWM has 2460-resolutions, which is very precise. The SPWM pattern is delivered to an erasable programmable logic device (EPLD) which is devoted to generating switching signals. The direct source current controller is achieved without sensing and manipulating the load current and power conditioner current, which reduces the count of current sensors and calculations. So, the control system can be

capacitor is adopted for the power circuit and a new direct source current control method is suggested, which simplifies the controller and reduces the count of current sensors. The proposed power conditioner shapes the generator current sinusoidally inphase with the voltage and allows the generator to supply maximum power even to the single-phase load.

An IGBT based 100kVA prototype is built with the controller realized with DSP (TMS320C32) and tested under several load conditions to verify the performance of the proposed power conditioner.

II. Overall System Configuration and Control

A. Overall System Configuration

The three-phase four-wire distribution system is used in Korea as shown in Fig. 1. The 22,900V-distribution line is reduced to 380V by using the step-down transformer and the neutral line is connected directly. The customers can use three-phase 380V power by selecting three lines or single-phase 220V by selecting one of three lines and the neutral. Even though there are a lot of single-phase loads, the power line is usually balanced (over than 80%). The emergency generator loaded on a truck is usually used to back up the power when the emergency situation (parts replacement, fixing up, building construction, etc) comes from the distribution line. Since the emergency generator is small and able to back up the only a small part of the distribution network, a seriously unbalanced and nonlinear loads can be connected and then, serious problems such as overheating and mechanical stress by vibration may happen in the generator. In this case, the generator can supply only a part of the maximum power. For an example, the generator can supply only 30% of total power if a single-phase load is connected. To solve these problems, a shunt power conditioner is added for the emergency generator as shown in Fig. 2. Three-phase voltage type converter with split-dc-capacitor is adopted for the power circuit and a DSP based digital controller is used.

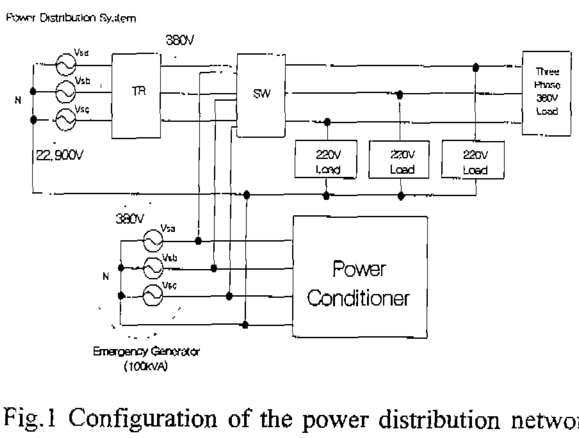


Fig.1 Configuration of the power distribution network and emergency generator backs up.

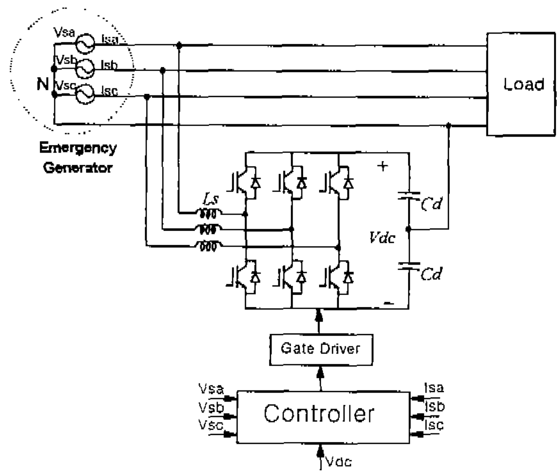


Fig. 2 Construction of the power conditioner.

B. Control Strategy

The power conditioner shapes the generator current sinusoidally inphase with the voltage even when the nonlinear and/or unbalanced loads are connected. To do this, a new direct source current control method is suggested as shown in Fig. 3. This considerably simplifies the controller (less calculations) and reduces the count of current sensors comparing to the previous works [1-2] which include load current and the converter input current feedback, and complex DQ transforms. The direct source current controller consists of the inner source current control loop and the outer dc-link voltage control loop. The outer loop is regulated with simple PI-controller while the current loop is controlled by P-gain only because this loop has AC reference. To make sinusoidal current references in phase with source currents, each source voltages is sensed and multiplied to the voltage loop current commands. The instantaneous three phase current references and error signals of inner control loop are defined as follows;

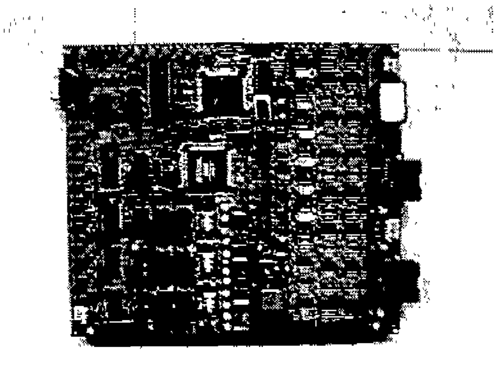
$$I_{s,abc\_ref} = (controller)\bullet(V_{dc\_ref} - V_{dc})\bullet V_{s,abc} \quad (1)$$

$$I_{s,abc\_err} = I_{s,abc\_ref} - I_{s,abc} \quad (2)$$

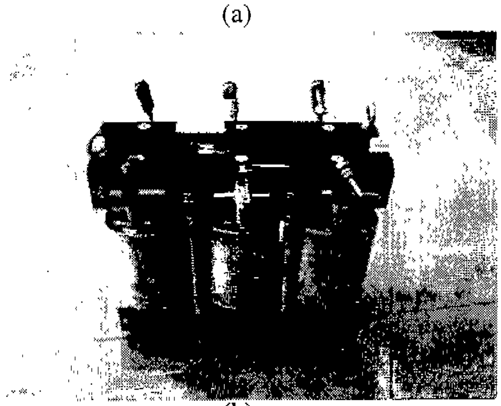
where, V_{dc} is dc-link voltage, $V_{s,abc}$ are source voltages and $I_{s,abc}$ are source currents. The source currents are presented in (3)

$$I_{s,abc} = I_{L,abc} + I_{C,abc} \quad (3)$$

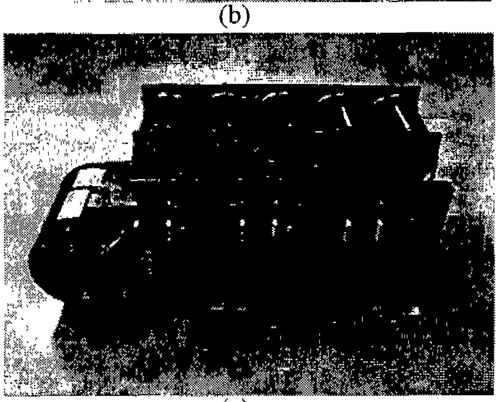
where, $I_{L,abc}$ are load currents and $I_{C,abc}$ are three phase inverter currents. Current feedback loop shapes $I_{s,abc}$ sinusoidally inphase with $V_{s,abc}$. The proposed direct-current-control method independently controls each source currents. So, it is possible to control independently the current harmonics and asymmetries of the each phase. This controller is well operated implemented with low cost Fig. 6 shows the external appearance of overall system



(a)



(b)

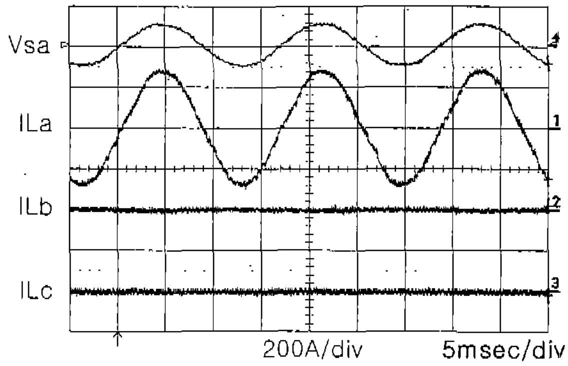


(c)

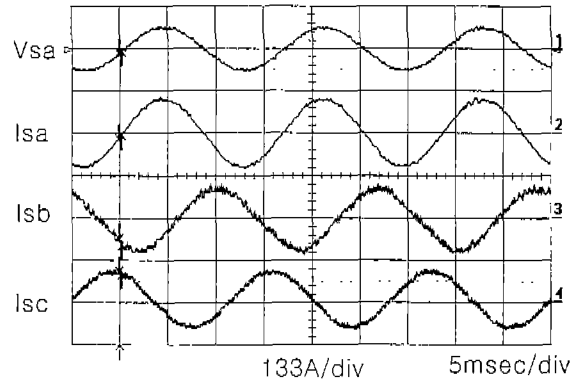
Fig. 6 External appearance (a) controller, (b) reactor, (c) power module

IV. Experimental Results

The 100 kVA emergency generator system with the proposed power conditioner is tested under various load conditions. Fig. 7 shows source current and load current waveforms when a 1 Ω resistor is connected between the a-phase and the neutral, which is the worst condition of phase unbalance. As shown in Fig. 6(a), the load current flows only through the a-phase and the neutral and the currents in the other two phases are zero. Due to the operation of power conditioner, the source currents, however, are balanced and shaped sinusoidally inphase with source voltages as shown in Fig. 6(b). Without the power conditioner, the generator terminal voltages will be different when the unbalanced load is connected since AVR (automatic voltage regulator) can not be properly operated. With the power conditioner, the terminal voltages of generator are almost the same.



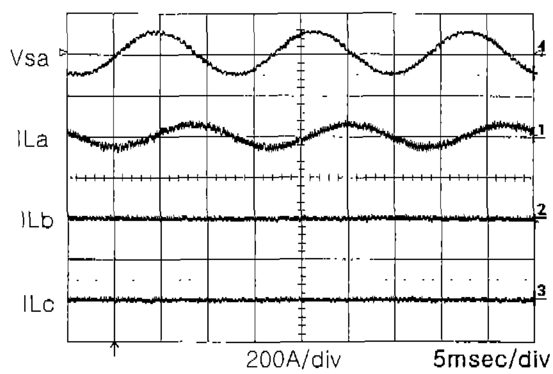
(a)



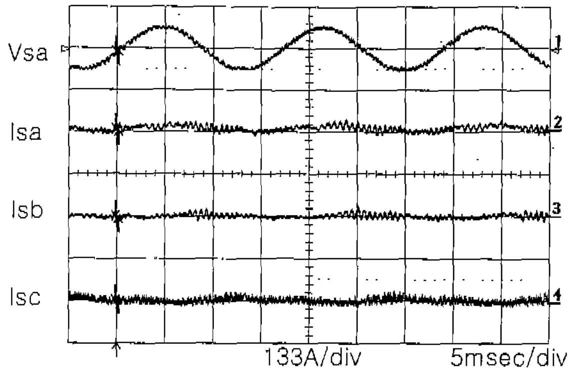
(b)

Fig. 7 Experimental waveforms under the single-phase resistive load: (a) load side currents, (b) source side currents.

Fig. 8 shows source and load current waveforms when an 8.33mH inductor is connected to the a-phase and the neutral. The load current flows only through the a-phase and the neutral and the phase shift between the source voltage and load current is 90 degree as expected. Due to the operation of power conditioner, the source currents are all zero since there is no active power consumption. The power conditioner supplies reactive power to the load. The source currents are balanced anyway. There should be no current in the neutral linc but there are some source currents, which are caused by the power dissipation in the power conditioner.



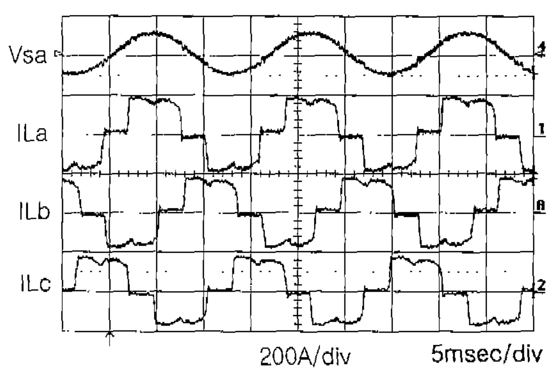
(a)



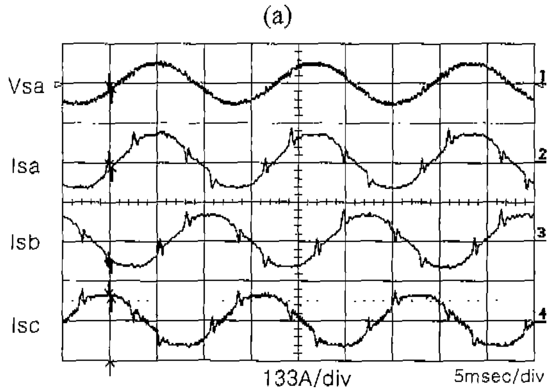
(b)

Fig. 8 Experimental waveforms under single-phase inductive load: (a) load side currents, (b) source side currents.

Fig. 9 shows source and load current waveforms when a three-phase diode rectifier with 6 Ω resistor is connected. The load side current waveforms are almost six-step waveforms, which means a lot of harmonics are included. The current harmonics are almost eliminated by operating the power conditioner and thus, the source currents are balanced and shaped almost sinusoidally inphase with source voltages. A little current spikes in the source currents, however, still remained, which can be completely eliminated by increasing switching frequency and the nominal dc-link voltage. But this leads to the increased cost. The performance of the power conditioner and the cost should compromised.



(a)



(b)

Fig. 9 Experimental waveforms under the three-phase rectifier load: (a) load side currents, (b) source side currents.

V. Conclusions

The 100kVA IGBT-based power conditioner for 100kVA three-phase four-wire emergency generator system is realized by conventional three-leg four-wire inverter and a new simple direct source current control method. The power conditioner is tested under various load conditions. The power conditioner shapes the source currents sinusoidally inphase with the source voltage with any nonlinear and/or unbalanced load and allows the generator to supply the maximum power even to the single-phase loads. The proposed power conditioner can effectively used for the three-phase four-wire small scale generators.

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