DSP Control of Power Conditioner for Improving Power Quality

Changjiang Zhan * Manchung Wong ** Zhiyong Wang * Yingduo Han**

* Department of Electrical Engineering
Tsinghua University, Beijing 100084,
P. R. China

** Department of Electrical and Electronics Engineering
FST, University of Macau,
Macau

Abstract: Based on the concept of customer power, the paper proposed a new device that is universal custom power conditioner (UCPC). The UCPC has series and shunt power converters with a battery energy storage system (BESS) for multi-function operation to compensate the voltage variation, flicker, reactive power, harmonics, imbalance, uninterruptible power supply, peak load power supply, active and reactive power control in transmission system. The circuit and control topologies are addressed. A control structure based on dual DSP TMS320C32 and synchronous A/D sampling technology are discussed.

Keywords: Power Quality, Active Filters, UPS, Unified Power Flow Controller, Unified Power Quality Conditioner, FACTS

I. INTRODUCTION

Further increasing the power reliability and improving the power quality are the main trend of the development of the advanced power system control. Notwithstanding the concepts relating to FACTS are gaining popularity internationally for enhancing stead-state power transfer limits as well as improving power system dynamic response. The problems in distribution system and transmission system are voltage sad or dip, voltage fluctuation and flicker, active and reactive power control, power interruption, harmonics and imbalance etc.

Based on the view point of the customer, the paper proposed a new device that called the Universal Custom Power Conditioner (UCPC) that has series and shunt power converters with a battery system (BESS) for multi-operations in transmission system. The goal of UCPC utilizing the energy storage battery is to achieve synthetic compensation functions, such as: short time uninterruptible power supply (UPS), reactive power compensation, active power and reactive power control, harmonic damping or isolating, unbalance control, user terminal voltage fluctuation control, flicker elimination and active power storage control in one device. Because it has a unified standard digitized controller based on multiple-DSP control topology, it can fulfill different compensation functions depended on the supply and load conditions.

The concept difference between the Universal Custom Power Conditioner (UCPC) and the Distribution System Conditioner (DS-UniCon) that proposed is the active power and reactive power control to damp the oscillation. As we know that the voltage quality, current quality, reactive power, imbalance and power interruption are the main problems in the distribution system, however, in transmission system the active and reactive power control is also needed to take into account. However, the same prototype of circuit structure is shown in Fig. 1. The UCPC and DS-UniCon are the unified approach for power conditioning: one is in transmission system and the other is in distribution system. It is because in the past years all the above mentioned problems are investigated individually and independently such as active filters, Static VAR compensator etc. so that individual approach cannot provide the effective and economic means than the unified approach.

Because the tri-level or neural point clamped (NPC) PWM converter is the main circuit of the proposed UCPC: the paper focuses on the dual-DSPs control of the shunt unit based on tri-level PWM converter as a shunt-connected power quality conditioner. The paper presents a new control structure based on dual-DSP TMS320C31 and synchronous A/D sampling technology. The paper discusses the design of the hardware and software of dual-DSP control system of tri-level PWM converter in detail. Some experiment and simulation results are shown to verify that UCPC can synthetically fulfill reactive power compensation, harmonic current compensation even for unbalanced load with the multiple-DSP control based on modified dead-beat control algorithm.

II. UNIVERSAL CUSTOM POWER CONDITIONER (UCPC)

A. System Function and Topology of UCPC

Figure 1 shows the main circuit topology of UCPC. The main structure of tri-level shunt PWM converter is also shown in Figure 2. Since the main structure of tri-level series PWM converter has the similar characteristic of shunt one, it isn't described here. The basic functions for improvement of power reliability and power quality of UCPC are summarized as following:

<u>Series PWM Converter:</u>

- To compensate voltage harmonics, including negative and zero sequence components at the fundamental

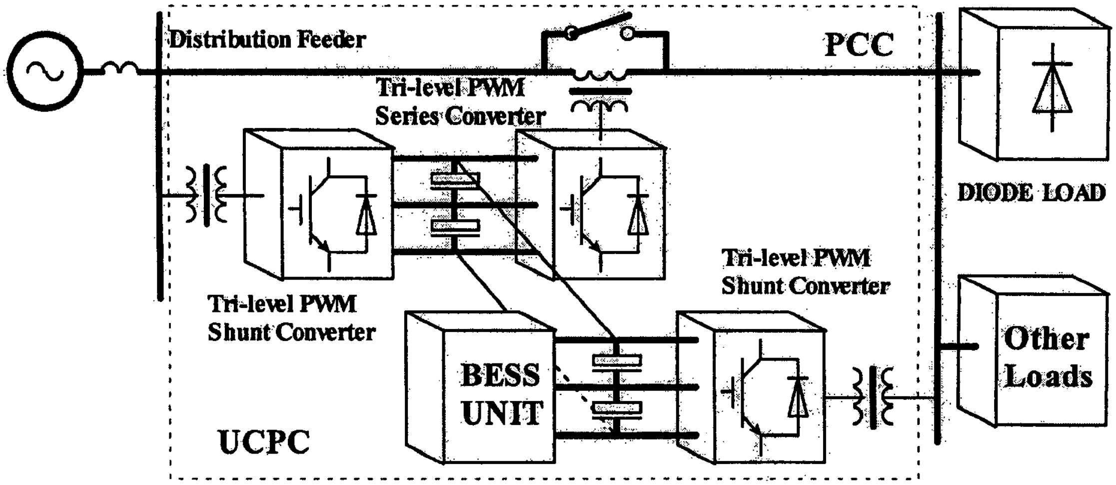

Figure 1: The main circuit topology of UCPC

frequency.

- ✧ To improve the transmission system stability or damping oscillation.
- ✧ To control the active and reactive power flow.
- ✧ Sag and swell control, voltage variation, voltage flicker control and power factor control.

Shunt PWM Converters:

- ✧ To eliminate or absorb in current harmonics, including negative and zero sequence components at the fundamental frequency.
- ✧ To compensate the reactive power of load.
- ✧ To regulate and control the DC link voltage.
- ✧ To have active and reactive power control to damp the oscillation.
- ✧ To storage and control the energy of battery, UPS and outage control.

Battery energy storage system (BESS):

- ✧ To shift system loads from daily peaks to lows.
- ✧ To be a potential standby generator.
- ✧ To store or release the battery energy in order to prolong the battery life cycle.

B. Modified Deadbeat Control Algorithm of UCPC

The diagram of control system of shunt convert is shown in Figure 3. The control algorithms consist of two parts: upstream and downstream algorithm. The upstream one provides the high accuracy detecting of the power supply synchronous frequency, the rapid detecting of positive and negative sequence voltage and α–β axis voltage or current references calculation depended on the present supply and load conditions. The downstream one deals with regulating the dc link or battery voltage and shaping current waveform to track the references. It is realized by means of dead-beat control technology based on voltage space vector PWM method. Generally, deadbeat control is a digital feedback strategy that is designed to control the pulse width so that

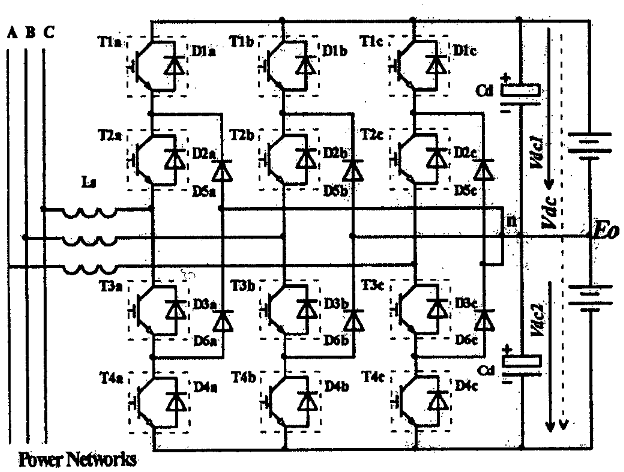

Fig. 2 The main circuit of tri-level shunt PWM converter

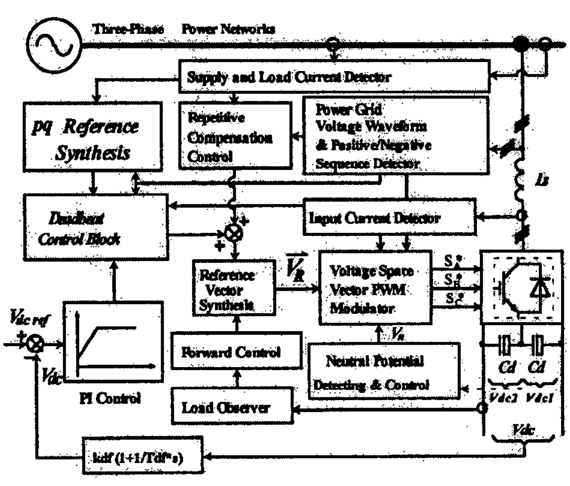

Fig. 3 The principle diagram of control system based deadbeat control with repetitive compensation strategy

the output of converter can track the reference at every sampling instant. Any deviation from the reference due to a load disturbance or nonlinear load is corrected with in one sampling interval Ts. The state equation of converter is:

$$\dot{X} = AX + BU \qquad (1)$$

where

$$X=\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix}, U=\begin{bmatrix} -v_d+v_{sd} \\ -v_q+v_{sq} \end{bmatrix}, A=\begin{bmatrix} -\frac{R_c}{L_c} & w \\ -w & -\frac{R_c}{L_c} \end{bmatrix}, B=\frac{1}{L_c} \qquad (2)$$

$$\begin{bmatrix} i_{cd}(k+1) \\ i_{cq}(k+1) \end{bmatrix} = G\begin{bmatrix} i_{cd}(k) \\ i_{cq}(k) \end{bmatrix} + H\begin{bmatrix} -v_d(k)+v_{sd}(k) \\ -v_q(k)+v_{sq}(k) \end{bmatrix} \qquad (3)$$

$$\begin{bmatrix} v_d(k) \\ v_q(k) \end{bmatrix} = H^{1}G\begin{bmatrix} i_{cd}(k) \\ i_{cq}(k) \end{bmatrix} + H^{1}\begin{bmatrix} i_{cd}(k+1) \\ i_{cq}(k+1) \end{bmatrix} + \begin{bmatrix} v_{sd}(k) \\ v_{sq}(k) \end{bmatrix} \qquad (4)$$

,where reference voltage is vector $\vec{v}(k) = [v_d(k), v_q(k)]$.

The Deadbeat Control Algorithm is needed to modify as the sudden change in the waveform will generate error as the assumption of using conventional Deadbeat Control is setting X_{ref}= X(k+1). The pervious period of waveform was recorded and this stored data used as the predicted picture for next period of signal so that the advanced deadbeat control was proposed such as (5), where n is the n^{th} period of fundamental component of waveform at k^{th} sample.

$$\begin{cases} i_{cd}^*(n,k) = -\tilde{i}_{ld}(n-1,k+1) \\ i_{cq}^*(n,k) = -i_{lq}(n-1,k+1) \end{cases} \qquad (5)$$

C. Modified Deadbeat Control and Vector Space PWM Algorithm Error Improvement

According to the simulation results of the Space Vector PWM, the compensated reactive current, i_q, is not equal to zero in Fig. 4 so that reactive power will be given to the load from the source and it is not in optimal case. It is considered that the combined vector in simulation should not generate any error and the error should come from the data sample in $\vec{v}^*(k)$.

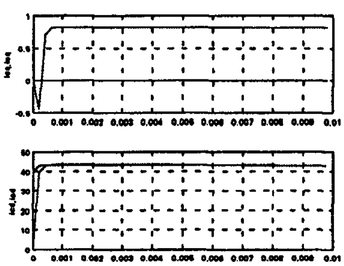

Fig. 4

The improvement can be obtained when a half-sample data inserted into the reference vector.

$$\vec{v}^*(k) = \begin{bmatrix} \cos(wts/2) & -\sin(wts/2) \\ \sin(wts/2) & \cos(wts/2) \end{bmatrix} [v_\alpha(k), v_\beta(k)]^T$$

The error can be improved and shown in Fig.5 which i_q is changed to 0.005 from 0.8.

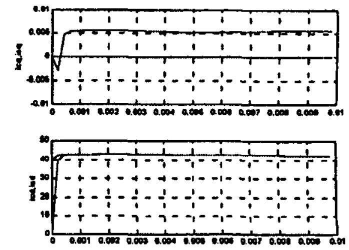

Fig.5

C. Tri-Level Converters and Snubber Circuits

Actually the proposed Unified Custom Power Conditioner (UCPC) are combination of the Unified Power Flow Controller (UPFC), the Unified Power Quality Conditioner (UPQC) and Uninterruptible Power Supply (UPS). UPFC requires a large amount of power rating for power flow control of transmission line. UPQC, which is just a combined system of parallel and series active filters without a BESS system, is focused on the power quality control applied for transmission system. Thus they need for both high voltage-power level and low voltage-power level so that Tri-level converters are employed to the development of Unified Custom Power Conditioner (UCPC) or Distribution System Unified Conditioner (DS-UniCon).

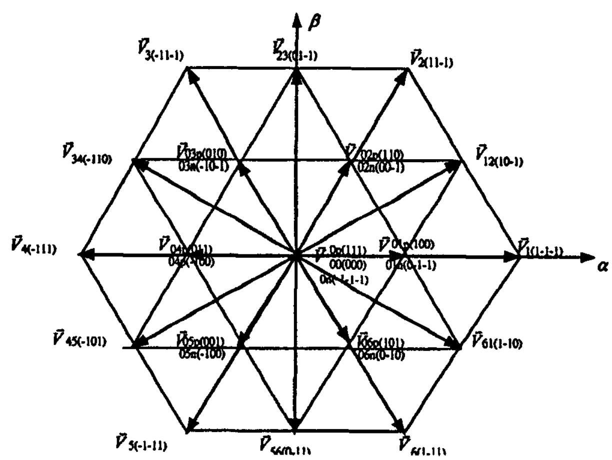

Fig.6

Fig. 6 shows the space vectors distribution. There are 27 types of voltage space vectors distributing from sector I to sector VI in tri-level system. The selection of voltage space vector can be carried out by means of estimating relationship between the actual space vector and the equivalent control voltage vector. However, there is more than one solution in the selection of actual voltage space vector. This degree of freedom can be used to introduce some additional requirements such as the minimization of the switching number or average switching frequency. Therefore, the zero vectors can be injected regularly. Fig. 7 shows the voltage space vectors in sector I. If the equivalent control vector $\vec{V}_{Req}$ is located at square "2" in the area of sector I, it can be decided which voltage space vector should be selected

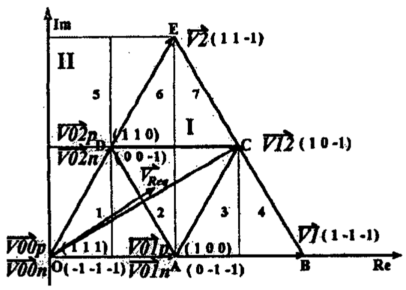

Fig.7

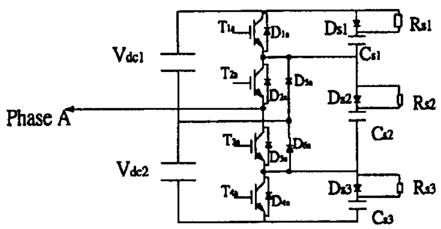

Fig.8

Fig. 8 shows the snubber circuits used in this Tri-level converter. Only one phase is shown as the other two phases are connected the same snubber circuits. The parameters are: $R_{s1}= R_{s2}=R_{s3}= 10\Omega$, $C_{s1}=C_{s2}=C_{s3}=30nF/1600V$ and Ds1~Ds3 in which are the fast recovery diodes with "RFP8120" model.

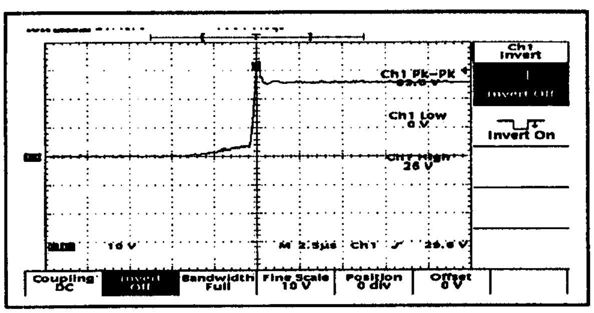

Fig.9

Fig. 9 shows the turn-off voltage of IGBT with dc-linked voltage 500v and peak current 10A.

III. DSP CONTROLLER

The Tri-level or neural point clamped (NPC) PWM converter is the main circuit of the proposed UCPC, this section will focus on the dual-DSPs control of the shunt unit based on tri-level PWM converter as a shunt-connected power quality conditioner. A new control structure based on dual-DSP TMS320C32 and synchronous A/D sampling technology are proposed. Fig. 10 shows the control block diagram of the dual-DSP and synchronous A/D sampling controller. The purpose of 1# DSP is to have the upstream algorithm to get the reference voltage and current from the sampling data to fulfill the closed-loop control target. On the other hand, 2#DSP is to generate the pulses to drive IGBT's and bases on the vector space PWM *method* to calculate the triggered time from the reference vector which is obtained from 1#DSP. 1# DSP will base on the Modified Deadbeat Control and the sampling data to get the reference vector which are already described in section II A and II B. However, 2# DSP will base on the vector space PWM described in section II C to generate the pulse pattern.

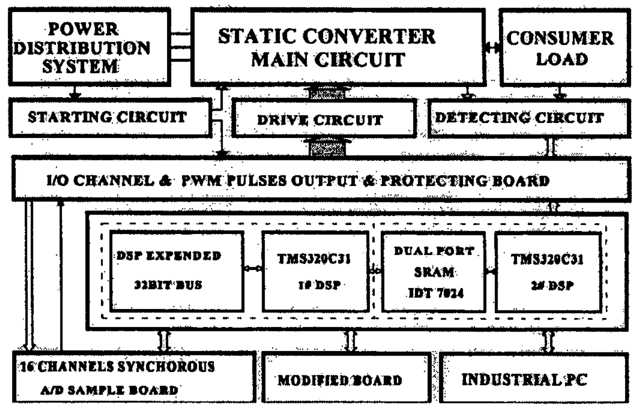

Fig.10

The 16 Channels Synchronous A/D Sample Board is:

1) There are 4 ADC "7874" to be triggered by synchronous pulses from 1# DSP to get the synchronous data, and
2) When ADC 7874 finished their conversion, interrupted signal will send to 1# DSP so that the data can be

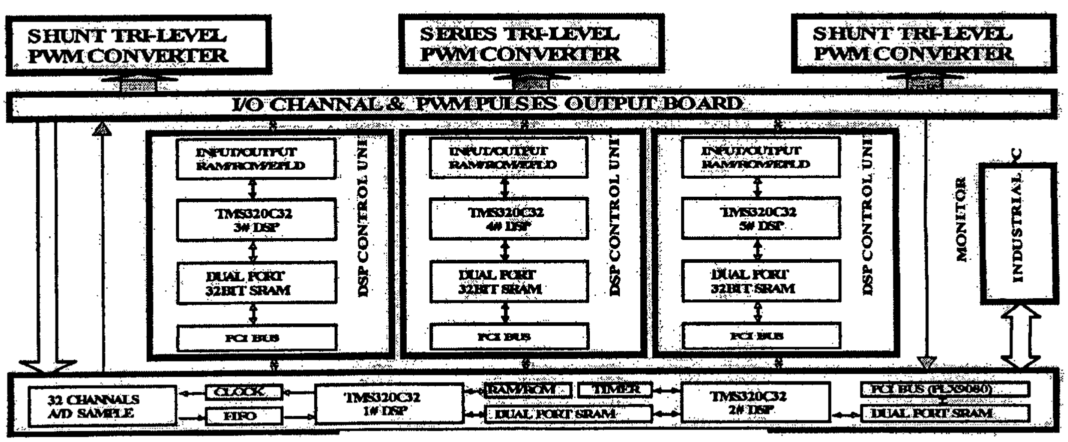

Fig. 11

transferred to data bus. Fig. 11 shows the whole control block diagram. However, 1# DSP and 2# DSP are the upstream control blocks in Fig. 11. The others 3# DSP, 4# DSP and 5# DSP are the final stages to generate the pulses pattern by vector space PWM.

IV. PROTECTION SYSTEM

As we know that IGBT will be broken in a very short time with over-current so that the protection system will be pointed on the characteristics of IGBT components.

1) Upper-Arm and Lower-Arm of the Converter Protection:

For example, consider one arm of the tri-level converter in Fig. 2. The IGBT components such as T_{1a}, T_{2a}, T_{3a} and T_{4a} in phase A cannot conduct at the same time, otherwise, it will short circuit. In the control topology, the dead time among those IBGT's are needed to induce in order to avoid conduction of the upper-arm and lower-arm at the same time.

2) DC-Link Protection:

The current of dc-side of converter is detected. When the over-current lasts longer than 8 microsecond, all the triggered pulses are off.

3) AC-side Protection:

The over-current of ac-side is detected and lasts longer than 8 microsecond, all the triggered pulses are off.

V. RESULTS

Simulation and experimental results are given in this section. Fig. 12 shows the harmonic compensation for the rectifier load. The current i_{la} is the load current in phase a and i_{sa} is the source current in phase a after compensation. V_{dc} in Fig.12 is the waveform of the dc-link voltage of tri-level converter and shows the system that can keep acceptable stable voltage. On the other hand, V_{dc1}-V_{dc2} shows in Fig. 12 that the tri-level converter control algorithm can control the voltage difference between the upper capacitor and lower capacitor within a small region.

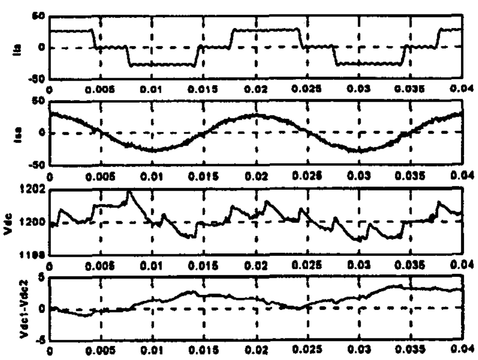

Fig. 12

Fig. 13 shows the compensation results when current in phase A is larger than the current in phase B than 10 %. The combination of Modified Deadbeat Control, Vector Space PWM and Improved Error technique together can compensate the rectified load to improve THD's in each phases. They are 3.61%, 3.69% and 3.67% respectively. Fig. 14 shows the load current in d and q axes. Fig. 15 shows the compensated current in d and q axes respectively.

The experimental results for the inverter mode operation of tri-level converter are given with dc-linked voltage 500v and output 3.2kW. Fig. 16 is the dc-side current waveform of the tri-level converter. There are two waveforms in Fig. 17: one is the line-to-line terminal voltage of the tri-level converter V_{AB} and the other is the line-to-line terminal voltage V_{BC}. These waveforms did not pass through any filter.

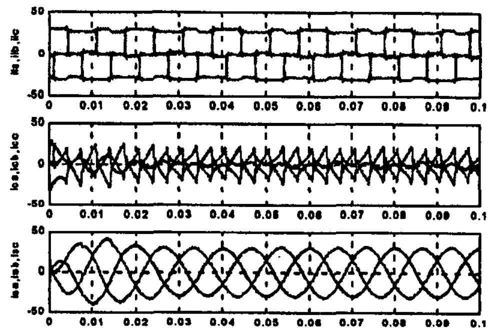

Fig.13

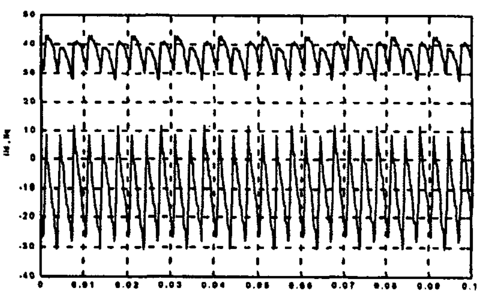

Fig.14

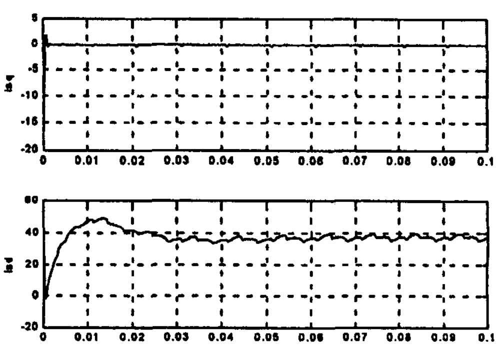

Fig.15

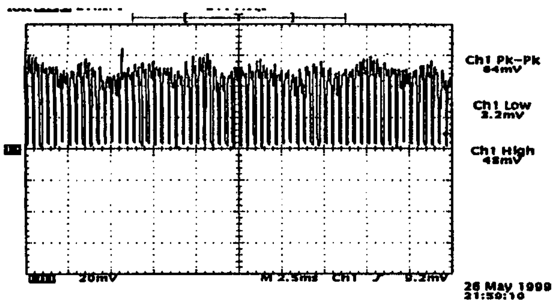

Fig.16

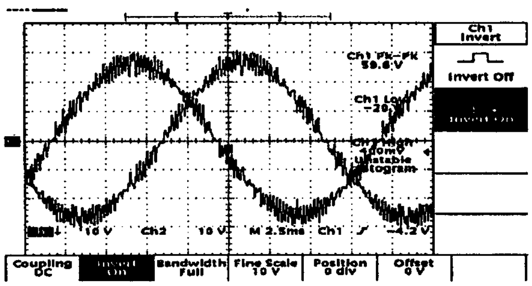

Fig.17

VI. CONCLUSION

A unified approach conditioner for transmission system is proposed and called Universal Custom Power Conditioner (UCPC). The basic circuit scheme and concept of proposed device are addressed. Two shunt and one series converters are proposed to form this new device so that harmonics, imbalance, reactive current, voltage variation, voltage flicker, power interruption, peak load power supply, active and reactive power control can be compensated by one device at the same time. The control strategies are investigated with the modified deadbeat control algorithm and space vector PWM. The hardware of the DSP controller for UCPC is addressed in detail. Some experiments and simulation results are shown to verify that UCPC can synthetically fulfill the unified compensation with multiple-DSP control.

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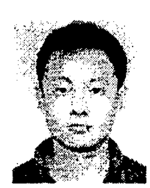
VIII. BIOGRAPIES

Ying-Duo Han, Professor of the Dept. of Electrical Engineering of Tsinghua University, Member of the Chinese Academy of Engineering and Senior Research Center of Tsinghua University.

He was born in 1938 in Liaoning province of China. He received the electrical Engineering degree and Master degree from Tsinghua University in 1962 and in 1965 respectively, Doctor-degree from Erlangen-Nuernberg University, Germany in 1986. From 1986 to 1995 he was vice-chairman and chairman of the E.E. Dept.. From 1989 to 1999, he was the Head of Power Electronic Research Center of Tsinghua University. He has been engaged for more than 35 years in education and research work on electric power system and automation field. He has published 2 books and more than 100 papers. Recent years he is engaged in FACTS, Intelligent Control, Regional Stability Control, Dynamic Security Estimation and Control based on GPS. Now he is working in University of Macau as a Visiting full professor and executive Director of Computer and System Engineering Institute of Macau.



Man-Chung Wong was born in Hong Kong in 1969 and obtained his B.Sc. and M.Sc. degrees in Electrical and Electronics Engineering at 1993 and 1997 respectively in University of Macau. He was a teaching assistant in University of Macau from 1993 to 1997. From 1998 up to now, he is a lecturer in University of Macau for Department of the Electrical and Electronics Engineering. Currently, he is a Ph.D. Student in Tsinghua University. His research interests are the power system, power electronics, power quality and instrumentation.

Zhan Changjiang was born in Hubei province, China in 1970. He received BSc, MSc and PhD from Huazhong University of Science and Technology, Wuhan China in 1991, 1994 and 1997 respectively. From 1997 to 1999, he worked in Tsinghua University on a subject of Distribution System Unified Conditioner (DS_Unicon) as a post-doctor. His research interests include Power Electronics, FACTS and Power quality.

Wang Zhiyong was born in Zhejiang province, China in 1975. He received BSc from Department of Electrical Engineering, Tsinghua University, Beijing China in 1998, now he is reading for MSc in the same university. His research interests include FACTS and Power quality.