MULTIFUNCTIONAL POWER LINE COMPENSATOR FOR DISTRIBUTION POWER LINES

M.Ichihara*, T.Akiyama*, H.Nara*, K.Tamura*, F.Ichikawa**

* Development Department 1
Product Development Laboratory
MEIDENSHA CORPORATION
2-1-17, Ohsaki, Shinagawa-ku,
Tokyo 141-8565 JAPAN
Phone +81- 3- 5487- 1585 Fax +81- 3- 5487- 1598

** Power Electronics Group
Power Engineering R&D Center
TOKYO ELECTRIC POWER COMPANY
4-1, Egasaki-cho, Tsurumi-ku, Yokohama-City,
Kanagawa 230-8510, JAPAN
Phone +81- 45- 585- 8507 Fax +81- 45- 585- 8520

ABSTRACT - We propose a multifunctional power line compensator (PLC) which can individually compensate multiple impediments at the same time. The PLC has the flexibility to share power to each compensation according to commands, this improving the working rate. We constructed a 100 kVA PLC model including a controller with digital signal processor (DSP) to realize a multifunctional compensation. The PLC was connected to a power receiving facility, and experimental results of multifunctional compensation were obtained.

1. INTRODUCTION

Many compensators for distribution power lines have been developed to reduce reactive power, which lowers the efficiency of power transmission; to suppress harmonics current which may create problems such as heating; and to reduce unbalanced current, which decreases the capacity of three-phase transformers. Moreover, voltage drops can occur in power lines, resulting in abnormalities in electrical equipment.

Generally, these impedimental currents and phenomena are reduced by specific compensators. For example, reactive power is compensated by a static var compensator (SVC), harmonics current and unbalanced current are compensated by an active filters (AF), and voltage drop is compensated by a step voltage regulator (SVR). However, the working rate of such a compensation system tends to be low and the cost performance will be poor, because the maximum capacities of these compensators are designed for compensation in the worst case.

We are developing a multifunctional power line compensator that can compensate these obstacle currents and maintain the line voltage at the same time. This system has functions to compensate reactive power, harmonics current and unbalanced current of the loads, as well as the ability to change the line voltage by outputting reactive power. The power for each compensation, including the line voltage control function, can be varied within the range of the capacity of the main circuit of the compensator.

We constructed a 100 kVA model of the PLC and connected it to a power receiving station. The PLC was equipped with a fully digital controller using a DSP. We conducted various experiments including multifunctional compensation. In this paper, we describe the control system of the PLC and the experimental results obtained.

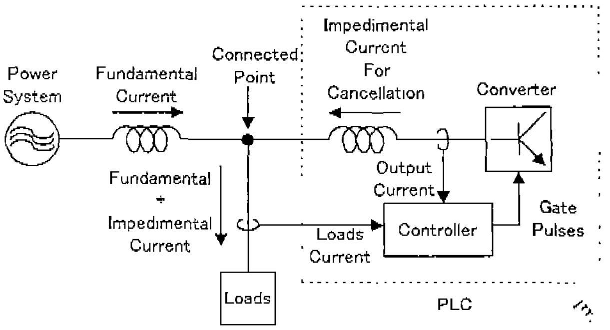

Fig.1 General concept of the PLC

2. COMPENSATION METHOD

Fig. 1 shows the general concept of the PLC. The PLC is connected upstream from the load. The PLC controller detects the currents of the load and makes current references to compensate them using the multifunctional compensation method. The main circuit of the PLC is very similar to that of a standard AF and the controller controls its output current so as to cancel impedimental currents of the load. The source must supply not only the fundamental current but also the impedimental currents of the load without the PLC. With the PLC, however the PLC supplies these impedimental currents instead of the source and the source needs to supply only the fundamental current. At the same time, the PLC can control the line voltage. The PLC controller detects the line voltage and compares it to the reference level. The

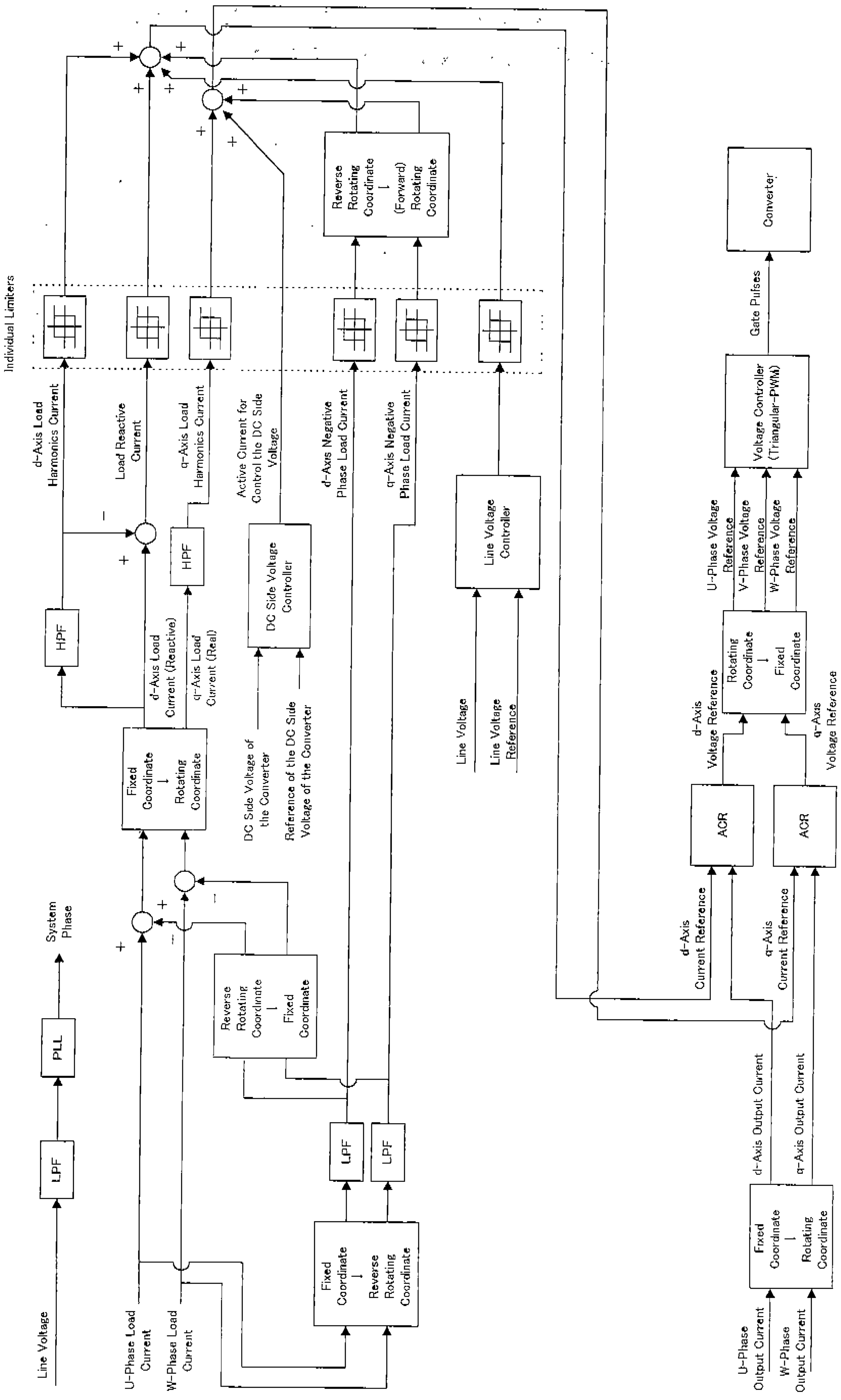

Fig. 2 Controller block diagram

controller then determines the output reactive power to set the line voltage to the reference level, using the PI control method. The reactive current reference is mixed with the other references and the line voltage is controlled.

A block diagram of the controller is shown in Fig. 2. The controller detects the line voltage for line phase detection and line voltage control. The detected value for phase detection is filtered and sent to the digital phase lock logic (PLL). The output of the PLL is used for rotating coordinate conversions. The detected value for line voltage control is sent to the line voltage controller and converted to the reactive power current reference. The detected load currents are separated into negative phase current and others by reverse rotating coordinate transformation. The currents without negative phase are separated into reactive current and harmonics by low pass filters (LPF) and high pass filters (HPF). By these processes, the controller obtains each impedimental current. All compensation currents are sent to individual limiters. The parameters of these limiters can be changed by commands. Finally, these current references are gathered and sent to an auto current regulator (ACR). The ACRs make voltage references and these are converted to gate pulses by the triangular pulse width modulation (PWM) method.

3. REALIZATION OF CONTROLLER WITH DSP

The control system is shown in Fig. 3. The system is a DSP-based digital controller in which most of the control functions are implemented by the software of the DSP. In addition, there are interfaces with the input and output devices.

The system works with the frequency of the triangular PWM wave. When the phase of the triangular wave becomes zero, the PWM controller sends a sampling start signal to the A/D converters. The values detected by the current sensors and voltage sensors are then sent to the A/D converters. When the conversion is completed the A/D converter controller sends an interrupt signal to the DSP. The DSP then starts a program for PLC control. Finally the moduration rated of the PWM calculated by the program from the voltage references are send to the PWM controller.

The DSP has an interface with the host computer. The host computer sends the program and the commands which determine the parameters of each limiter to the DSP. At the same time, the DSP sends trend values in the control system to the host computer.

The control program consists of a real time control block and a non-real time host communication block. The control block, which is started by the interrupt signal from the A/D converter, has the PLC control program that includes functions for sensing data from the A/D converter, calculating the PLC control method, and establishing the PWM parameters, as well as the software PLL. The host communication block works in the foreground of the DSP process and reads or writes to the memory of the DSP according to commands from the host computer.

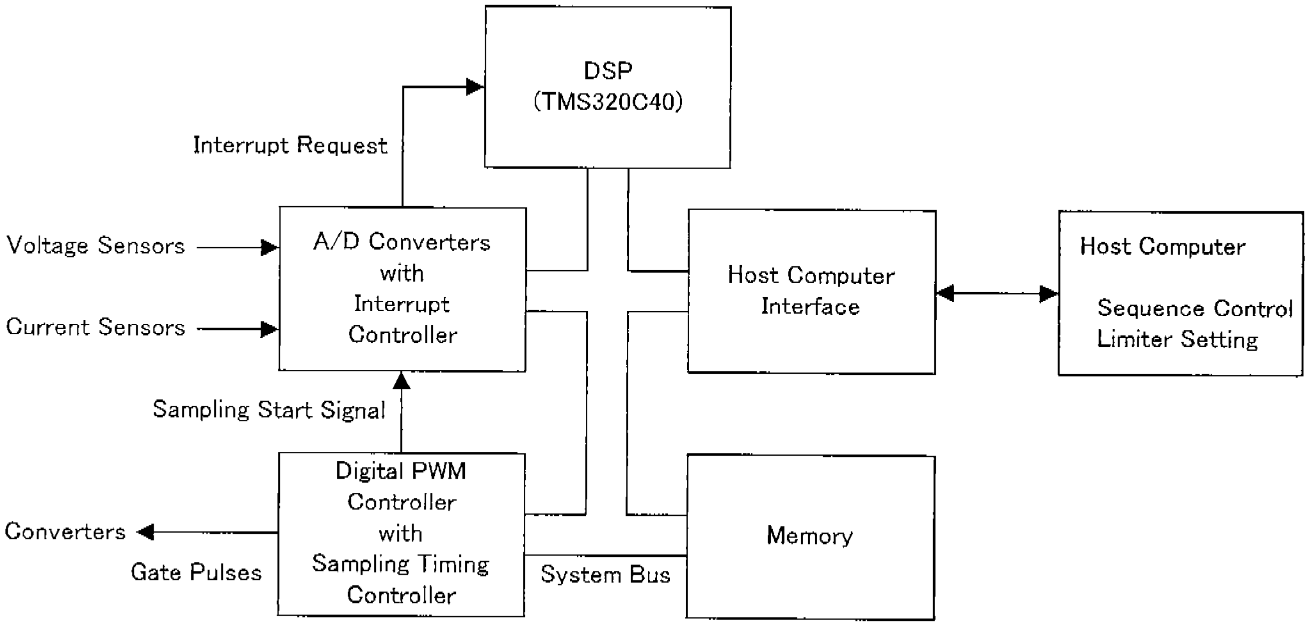

Fig.3 The Structure of the controller

4. EXPERIMENTS AT RECEIVING FACILITY

We conducted experiments to verify the performance of the controller. To obtain results in real operation, we used a power receiving facility in actual use. The connection of the facility and the PLC model is shown in Fig. 4. The facility has two 1500 kVA receiving transformers which convert the voltage from 22 kV to 6600 V. There are two three-phase transformers which convert the voltage from 6600 V to 200 V for three-phase loads (air conditioners and other experimental facilities) in the 6600 V line. Three single-phase transformers which supply the power for single-phase loads (lights and computers) are each connected line-to-line, and convert the voltage from 6600 V to 100 V.

The PLC model is constituted by two 50 kVA converters incorporating IGBTs for the main circuit device. Each output of the converter is gathered by the three winding transformer and its 400 V output is connected to 6600 V line by a transformer which converts the voltage of 400 V to 6600 V.

The load transformers have current sensors at the 6600 V side, so these sensors are used to detect the load currents that will be compensated. The voltage of the 6600 V line is sent to the line voltage controller and PLL in the PLC controller, and the PLC controls the voltage of the 6600 V line. Receiving current sensors are installed on the 6600 V side of the receiving transformers, and we measured the detected currents to check the compensation by the PLC.

In experiments to share the power of the PLC for line voltage control, one of the receiving transformers was opened because the PLC did not have sufficient power to change the line voltage widely when both receiving transformers were in operation.

5. EXPERIMENTAL RESULTS

Many results of compensation by the PLC were obtained. Here, we describe some results which show the merits of the PLC compared with ordinary compensators.

The first result is for compensation with the following:
(1) load reactive power compensation
(2) load harmonics current compensation
(3) load negative phase current compensation

The PLC has the ability to compensate all of these functions, although its capacity is finite. We therefore shared its capacity among each of the functions in various patterns as shown in Table 1, and measured the received currents when the PLC was operated and not operated, respectively.

Table 2 shows the results of reactive power and negative phase current compensation. The received reactive power was decreased by the PLC compensation, and the decrease rates matched the allocated capacities. This result indicates that reactive power compensation

Table 1 Compensation patterns

Compensation Patterns	Power for Compensation (kVA)		
	Reactive Power	Harmonics Current	Unbalanced Current
Pattern 1	30kVA	30kVA	30kVA
Pattern 2	10kVA	40kVA	40kVA
Pattern 3	40kVA	10kVA	40kVA
Pattern 4	40kVA	40kVA	10kVA

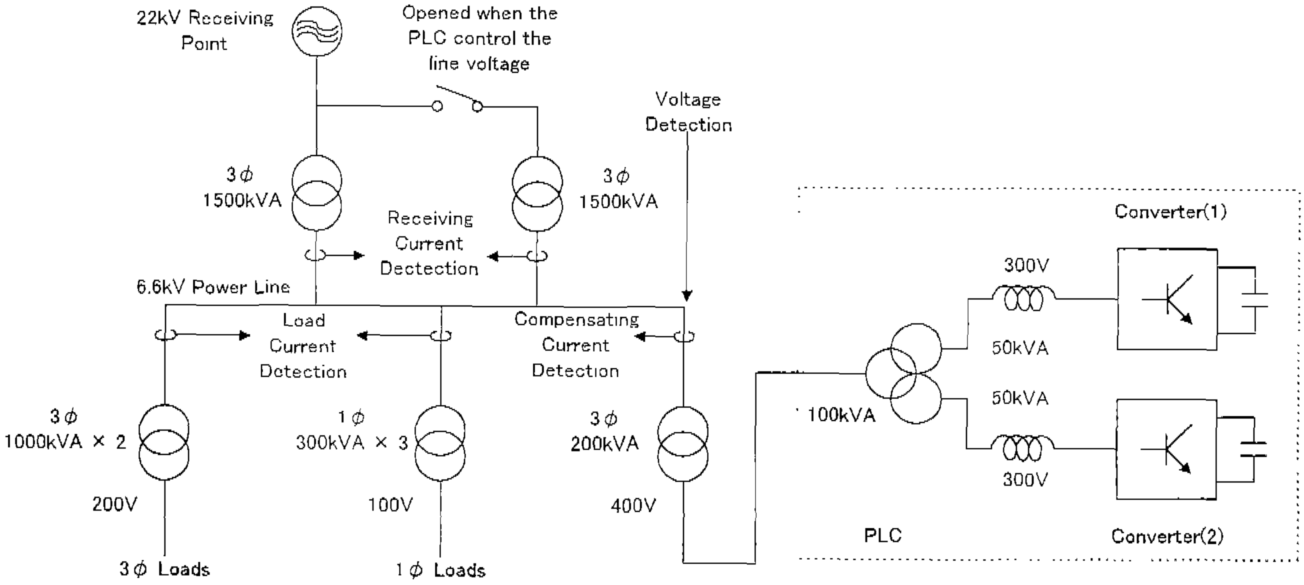

Fig.4 The connection to the power receiving facility

Table 2 Results of reactive power and negative phase compensations

	Reactive Power (kVar)	Unbalanced Current Rate (%)
Without Compensation	46	26.9
Pattern 1 (Change)	19 (-27)	14.5
Pattern 2 (Change)	39 (-7)	11.6
Pattern 3 (Change)	10 (-36)	10.9
Pattern 4 (Change)	10 (-36)	25.7

function worked well. The rate of unbalanced current was also decreased in a similar manner to the results for reactive power compensation.

Fig. 5 shows results of the harmonics compensation. The received current included several harmonics without compensation. When the PLC was operated, the harmonics were suppressed and the rate of suppression corresponded to the capacity allocated to harmonics compensation. For example, in pattern 3 the capacity allocated to harmonics compensation was only 10 kVA, so the harmonics were virtually uncompensated. On the other hand, in patterns 2 and 4 the capacity was 40 kVA and the harmonics were compensated well.

From these results, it can be said that the PLC is able to compensate each impediment individually and that there is no interference between each function.

The capacity allocated to each function can be changed while the PLC is in operation. We carried out compensation experiments with changing the capacity distribution in what we termed it "time scheduling operation". Fig. 7 shows the results of the experiments. The term was about 40 minutes. Each impediment was reduced by the PLC, and the rate of reduction matched the allocated capacities.

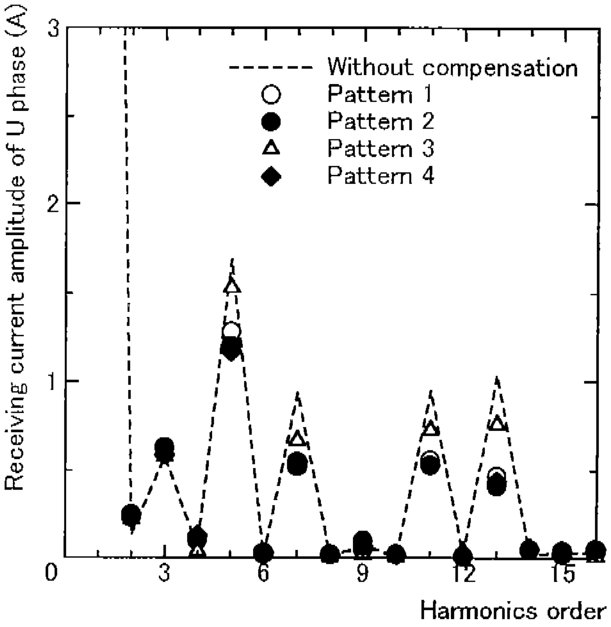

Fig.5 Results of the harmonics current compensation

The PLC can also regulate the line voltage by controlling the output reactive power. Fig. 6 shows the result of line voltage regulation. The line voltage was controlled to the reference level, thus confirming the voltage control ability of the PLC.

6. CONCLUSION

We constructed a multifunctional PLC model which has the ability to compensate several types of impedimental power and current by means of a fully digital controller, and carried out experiments on the system.

A DSP-based controller was configured and we were able to realize the multifunctional compensation method by the software of the DSP. This software control also made it possible to easily change the parameters of the controller while the controller was in operation. The experimental results showed that the PLC compensated each impediment corresponding to the allocated capacities, and that there was no interference between them. The line voltage control function also worked well, and stabilized the line voltage.

We will research techniques for the construction of a large-scale converter in order to realize larger PLCs with good cost performance.

7. REFERENCES

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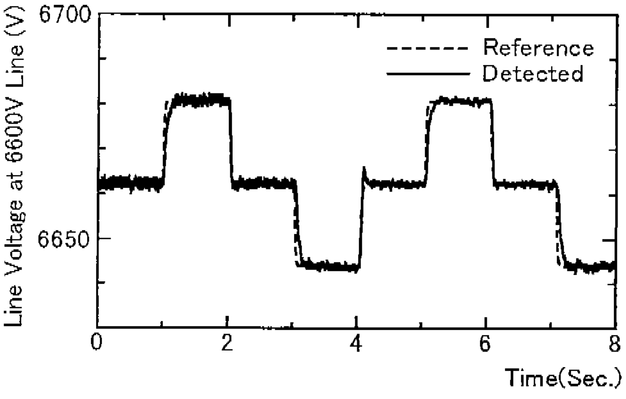

Fig.6 A result of the line voltage regulation

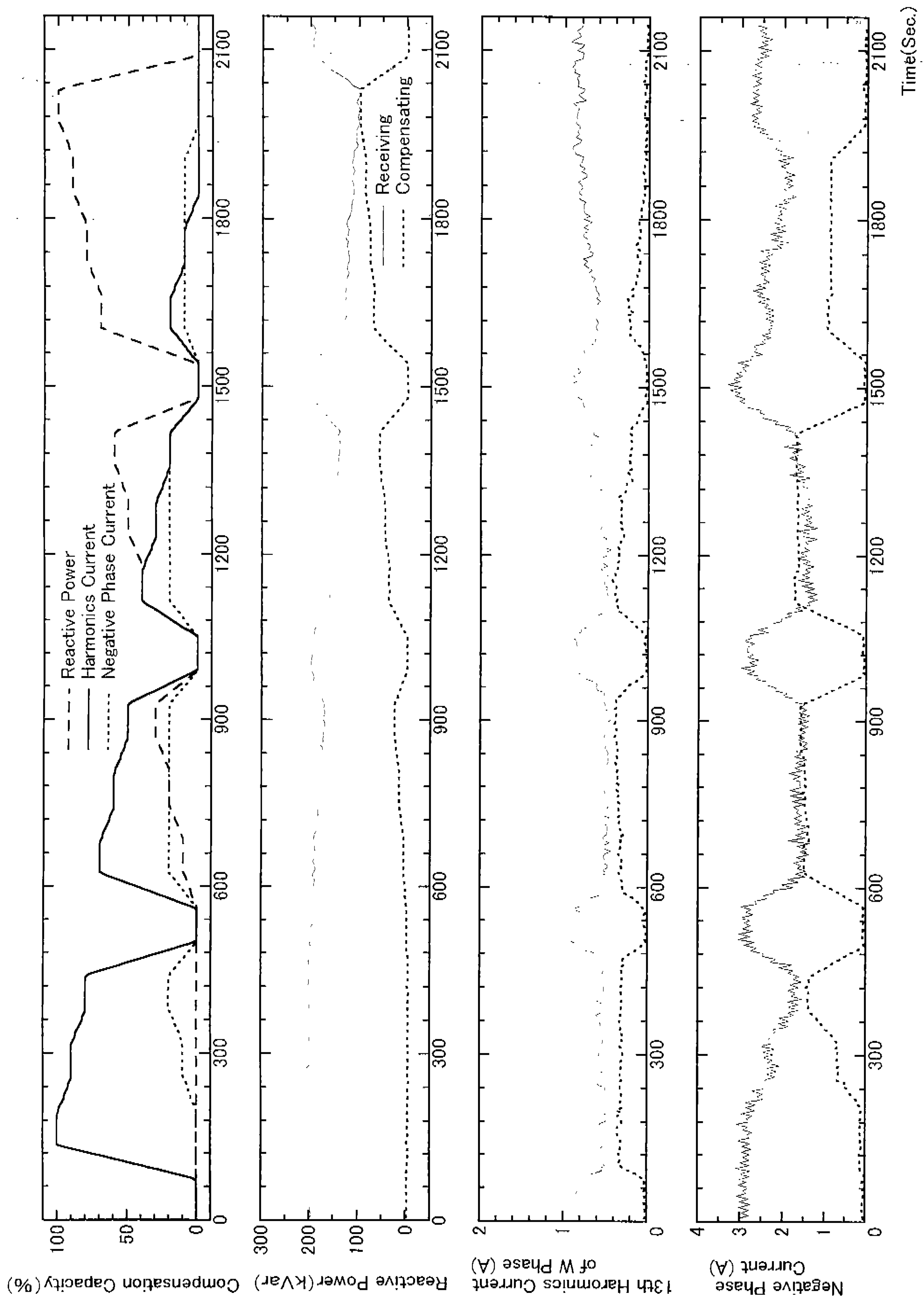

Fig. 7 Results of the time scheduling operation