STATIC COMPENSATION FOR THE IRON AND STEEL COMPANY OF TRINIDAD & TOBAGO (ISCOTT)

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SUMMARY

Some of the problems associated with operation of a large arc furnace installation on a relatively weak supply system are discussed. The solutions adopted by ISCOTT are presented. In particular, a novel real power compensator based on constraining the energy flow to a compensating resistance is developed to minimize frequency excursions and maintain system stability.

1. INTRODUCTION

ISCOTT has embarked on a large project to construct and operate and integrated steel mill in Trinidad. The plant, when completed in early 1980, will be able to transform raw iron ore through all the various stages to the finished product, utilizing direct reduction module, a meltshop and rolling mill facilities. The meltshop will employ 2 x 40 MW UHP arc furnaces with nominal capacity of 90 mt each, and supplied from the grid by the arrangement as shown in Figure 1. In anticipation of the load, the utility company is doubling its generation capacity from the present 365 MW through the addition of local gas turbine generators near the steelworks. The following quality of power services is being offered to ISCOTT:

High voltage supply	:	132 KV ± 6%
Frequency	:	60.0 OHz ± 0.24Hz
Fault level at point	:	1300 MVA for 80% year
of supply	:	1000 MVA for 20% year

The utility company in turn has requested ISCOTT to meet specified technical constraints with respect to power factor and reactive power demand, flicker voltage, permissible real power variations and frequency excursions, and harmonic distortion and unbalance.

The scale of problem that ISCOTT faces is large because of the size of the arc furnaces in relation to the relatively weak supply system. The project presents many technical problems which, though not individually unique, have never been collectively encountered and solved on this scale, and it is recognized that original solutions will have to be provided for successful implementation of the project.

2. SOME PROPOSED SOLUTIONS TO THE PROBLEM

The accepted practice of ensuring relative freedom of the supply network from the dynamic effects of the arc furnace load is to increase the supply short circuit capacity (SCC) to about 50-100 times the rating of the load. In ISCOTT's case, the SCC available even under the best conditions of supply, is only about 10 times the total MVA rating of the two arc furnaces. One immediate solution is to further improve the generation and transmission facilities and upgrade the SCC made available to the steelworks. This solution becomes expensive as major economic expenditures are involved which the power company cannot justify. The problem is aggravated when it is realized that the utility company considers the time available to them to install the new generation eliminates the possibility of using steam generators, even when these are technically preferred because of their better ability to contain power variations by fast steam valving methods. The gas turbines installed near the steelworks are used primarily for regulation to meet the load power

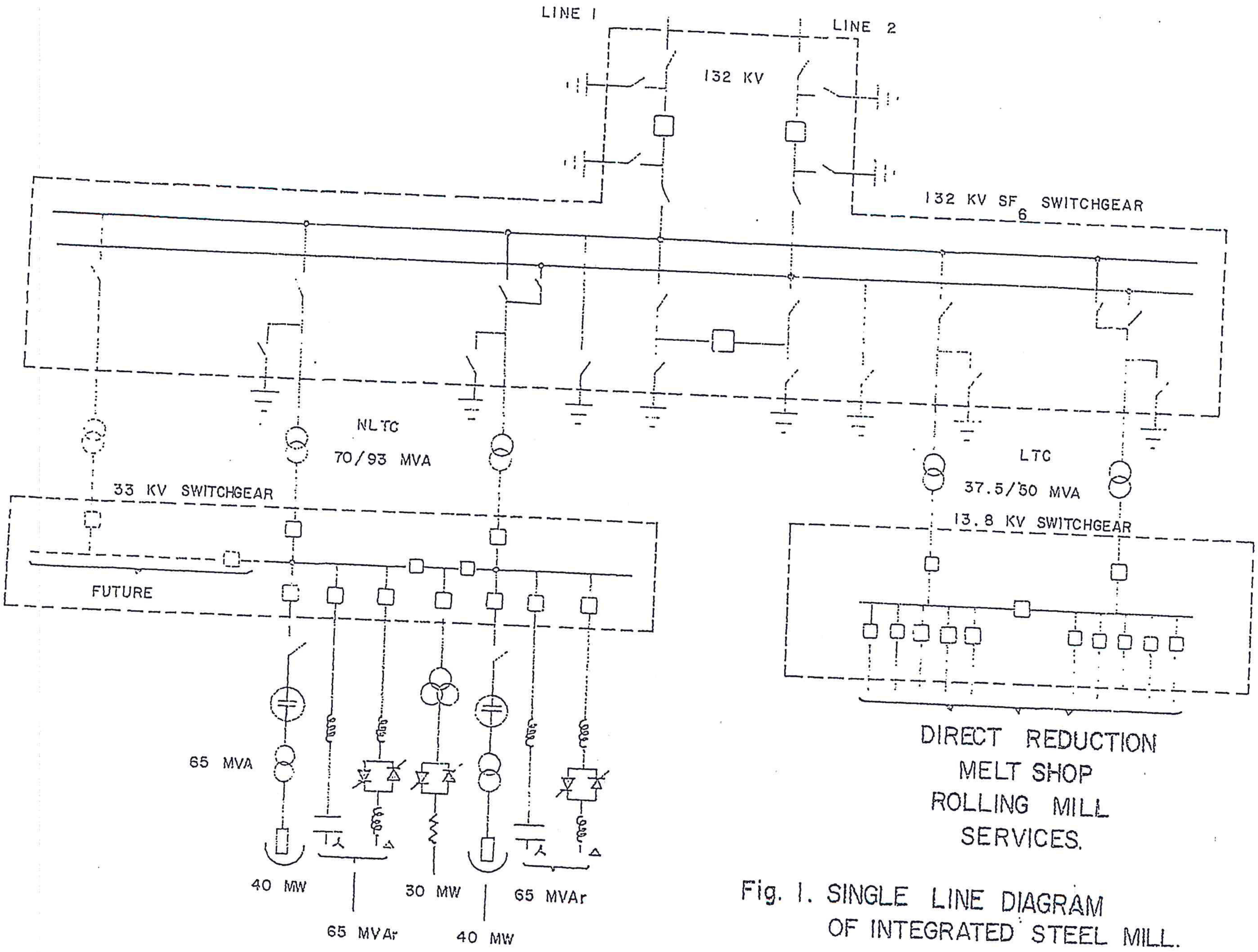

Fig. 1. SINGLE LINE DIAGRAM OF INTEGRATED STEEL MILL.

variations thus minimizing their escape into the rest of the system.

Another solution is to operate a completely isolated system unconnected to the island grid, in which the captive generation plant supplies the entire power requirements of the furnace load. In this case wide variations of the frequency must be anticipated. This solution is clearly unacceptable to the utility company since the large generation capacity still required will be under-utilized and no export of energy or voltage support of the island grid is possible.

A third alternative of shaping the demand profile of the furnaces by imposing constraints on their modes of operation is limited. This requires that the start of the melt down phase of one furnace always coincides with the refining phase of the other. Such practice is unacceptable to ISCOTT since it would severely affect steel production. It becomes imperative for ISCOTT to employ proper load compensation devices to compensate for the dynamic effects of the load.

3. REACTIVE POWER, FLICKER VOLTAGE AND HARMONIC COMPENSATION

Ultra high power (UHP) furnaces operate by the use of short arcs at low power factors near maximum power levels. The high power melts the charge rapidly, while the use of short arcs minimizes roof and shell refactory wear. The arc current is stochastic and can be represented by the summation of the time-dependent fundamental component, and the normal and abnormal harmonic components[1],

$$i_L(t) = \bar{I}_1(t)\,\sin(wt - \phi_1(t)) + \sum_{n=2}^{\infty} \bar{I}_{nh}(t)\,\underline{/\phi_{nh}(t)} + \sum_{a=1}^{\infty} \bar{I}_{ah}(t)\,\underline{/\phi_{ah}(t)} \qquad (1)$$

where $\bar{I}_1(t)\,\sin(wt - \phi_1(t)) = \bar{I}_p(t)\,\sin wt - \bar{I}_r(t)\,\cos wt$ (2)

$$\sum_{n=2}^{\infty} \bar{I}_{nh}(t)\,\underline{/\phi_{nh}(t)} = I_o(t) + \bar{I}_2(t)\,\sin(2\,wt - \phi_2(t)) + \,..\, + \bar{I}_n(t)\,\sin(nwt - \phi_n(t)) \qquad (3)$$

$$\sum_{a=1}^{\infty} \bar{I}_{ah}(t)\,\underline{/\phi_{ah}(t)} = \bar{I}_{S1}(t)\,\sin\left(\frac{wt}{T_o} - \phi_{S1}(t)\right) + \,..\, + \bar{I}_{Sn}(t)\,\sin\left(\frac{nwt}{T_o} - \phi_{Sn}(t)\right) \qquad (4)$$

Expression (2) indicates the time-varying real and reactive components of the fundamental current frequency. The 'normal' harmonics of Equation (3) are due to the distorted shape of the arc current waveform and are integer multiples of the power frequency. The 'abnormal' harmonics of Equation (4) exists whenever current discontinuities exist in the arc current, and are integer multiples of the fundamental subharmonic frequency given by $S1 = \frac{f}{T_o}$ where T_o is the period of the discontinuity[2].

The rapidly varying reactive current component of Equation (2), and the flicker voltages produced by this component flowing through the network supply impedances, as well as the normal harmonic components of Equation (3), are compensated by the use of a static var compensator (SVC). The normal harmonics have well defined frequencies and are best compensated by the use of harmonic filters. The equivalent capacitance of the filter circuits is then fixed and a constant reactive power output is produced. To satisfy the instantaneous reactive current requirements of Equation (2), some type of variable shunt inductance is required and this has been achieved through thyristor control of an inductance, as shown in Figure 1. Such SVC equipment is commercially available[3,4], and control strategies studied by the authors indicate that compensation can be arranged to occur in the same half-cycle of current change, providing very fast compensation of the reactive power requirement and minimizing the generation of flicker voltages[5]. Other schemes have been considered, but were judged inadequate to satisfy the utility's and ISCOTT's technical requirements.

For full flexibility and independent control for each furnace, ISCOTT has ordered two 65 MVAR SVC's capable of continuous variable reactive output 0-65 MVAR, as illustrated in Figure 1. 2nd, 3rd, 4th, 5th and 7th harmonic filter circuits are provided. The equipment is expected to satisfy the requirements for power factor and reactive power demand, flicker voltage, normal harmonic distortion and unbalance.

4. REAL POWER CONTROL

The shock loadings imposed on the island grid and reflected to the generators due to real power variations are of grave concern. Frequency variations outside the established 0.24 Hz limit will operate frequency relays and can even lead to system instability. The normal violent real power fluctuations that occur especially during the boring and meltdown periods are aggravated by scrap collapse, electrode regulation induced short and open circuits, electrode breakage, emergency switching etc. The rapidly fluctuating real power component cannot be instantaneously satisfied by load-frequency control of the generators, and variation of the frequency occurs due to changes in the energy balance of the generators. Governor action will have little effect in reducing frequency variations and can amplify the disturbances, since the load conditions will have changed state many times while the generator is still responding to a previous control signal.

The detrimental effects of large real power variations also include unusual mechanical stresses to both the alternator winding as well as to the gas turbine shaft and blades. Fluctuation of the gas burning rate results in thermal cycling effects causing accelerated metal fatigue, resulting in unacceptable lifetimes for the gas turbines. The magnitudes of power changes expected by furnace operation is frequent enough to require some type of real power compensator.

It is recognized that if a constant real energy flow can be developed in the supply system, then the problems as outlined are eliminated. The generators can then be operated optimally. If the maximum real power of the load is P_T, and its instantaneous power is $P_L(t)$, then a compensator placed in parallel with the load must be made to take the complementary power $P_C(t)$ at all times such that

$$P_T = P_L(t) + P_C(t) \tag{5}$$

This concept is illustrated in Figure 2.

To achieve the complementary power response, the compensator must be a time varying resistive load that can alter its equivalent resistance at will such that Equation (5) is always satisfied. In terms of real current components, Equation (5) can be written

$$\bar{I}_T = \bar{I}_p(t) + \bar{I}_{CP}(t) \tag{6}$$

The time varying resistive compensator can be synthesized through thyristor control of an equivalent resistive load, as illustrated in Figure 3. The compensating resistances used could be actual resistances, or an electrolytic cell, or other devices that can be represented as an equivalent resistance. In these cases the thermal energy or electrochemical energy is used reducing the cost of compensation. Phase angle control of the resistance results in asymmetrical chopped sinusoidal current waveforms. Since the arc furnace current is stochastic, the compensating current is also stochastic and can be represented by expressions similar to Equation (1)-(4). The fundamental reactive component, and the normal harmonic components generated are compensated by the SVC as previously described. Since the real current of Equation (6) is now of constant amplitude, the abnormal harmonic components as well as the DC components are also eliminated.

The magnitude of the compensator real current component depends on the firing angle $\alpha(t)$ and is given by:

$$\bar{I}_{CP}(t) = \frac{\bar{V}}{R_{ab}} (1 - \frac{\alpha(t)}{\pi} + \frac{\sin 2\alpha(t)}{2\pi} \tag{7}$$

$$0^{\circ} \leq \alpha(t) \leq 180^{\circ}$$

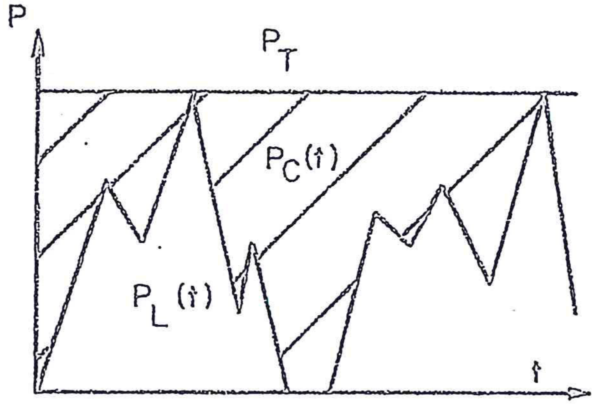

Fig. 2. Complementary power reponse of resistive compensator.

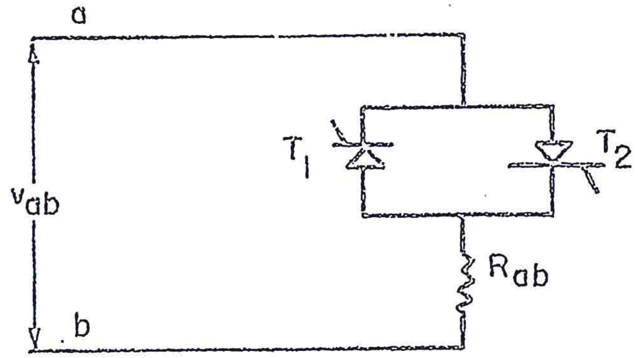

Fig. 3. Thyristor modulated resistive compensator.

For proper compensation the thyristors are controlled with pulse signals derived from the time varying load current, such that Equation (6) and (7) are satisfied. Control schemes have been developed by the authors whereby compensation can be achieved in the same half-cycle of load change[1]. Some experimental waveforms are illustrated in Figures 4(a) and (b), which indicate the complementary response of the compensator. The almost constant supply real current flow is clearly indicated, as well as the half-cycle response time.

When exact compensation is not required eg. for stronger network conditions or for less dynamic loads, or when greater real power changes can be passed on to the power system, the alternative control scheme of integer cycle switching of the resistance could be used. In this method the thyristors are either fully on, or they are completely off. Since the control strategy is essentially on-off switching, no harmonics are generated and no reactive power compensation is required. It be desirable to have a number of individually switched resistances to effect compensation in steps as the load power changes.

ISCOTT has ordered a three-phase 30MW static watt compensator (SWC) for its system as indicated in Figure 1. This compensator is expected to eliminate the abnormal harmonic components, stabilize the real power flow, and minimize system frequency excursions.

5. CONCLUSIONS

The problems associated with operation of an arc furnace installation on a small developing utility system are shown to be different compared with operations on a larger system. Specific solutions are proposed for compensation of the time-varying real and reactive power components. A new static watt compensator based on thyristor modulation of a resistive compensator is presented. It is anticipated that this SWC will find applications in many installations similar to ISCOTT's background.

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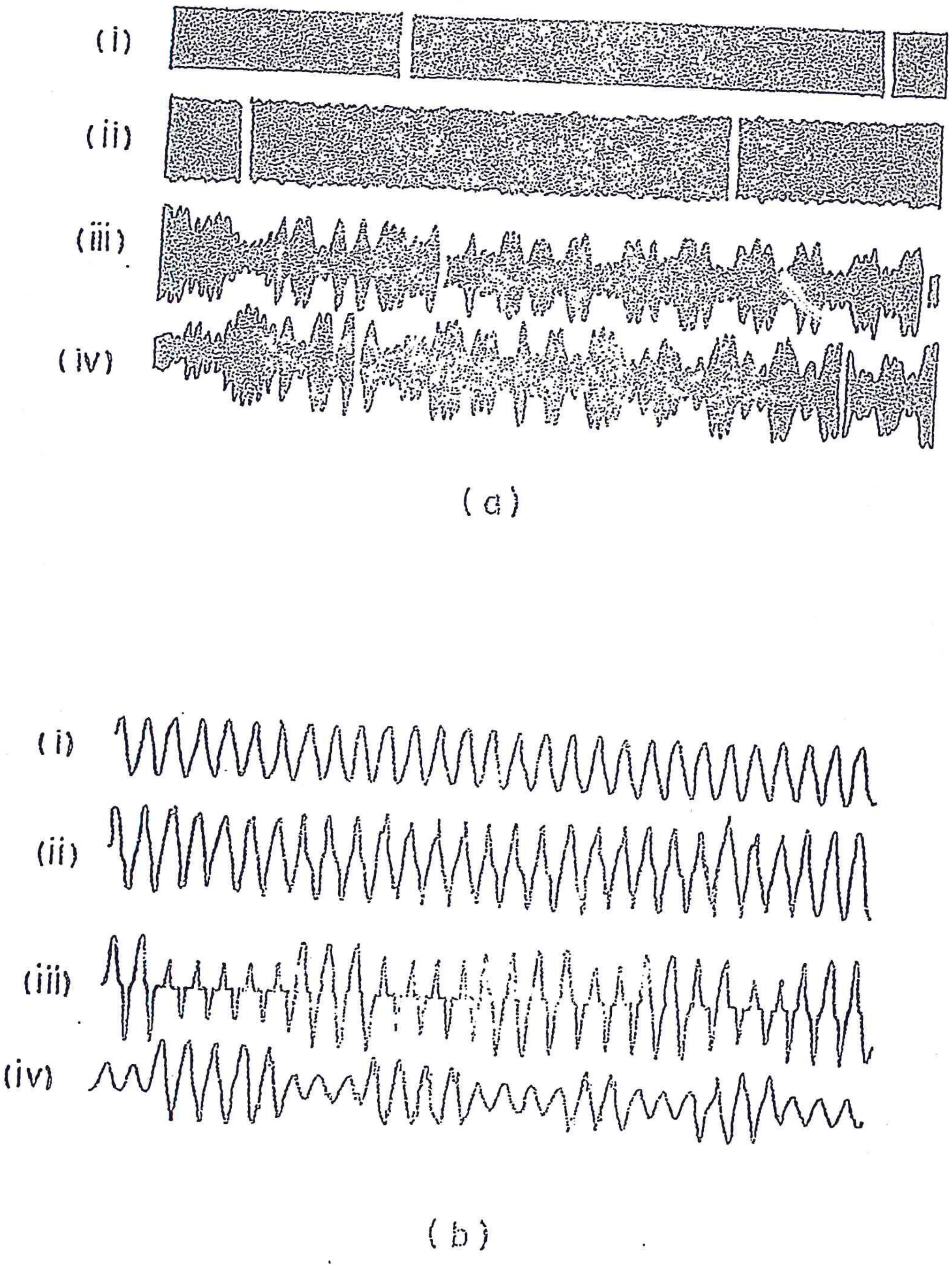

Fig. 4(a) and (b). Experimental waveforms for compensator of Fig. 3.

(i). Supply voltage.

(ii). Resultant supply real current waveform.

(iii). Resistive compensator current.

(iv). Variable main load current waveform.

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