REACTIONS OF INDUSTRIAL LOADS AND THEIR COMPENSATION SCHEMES

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ABSTRACT

Industrial loads which draw power from the grid network of a utility cause repercussions in the network which lead to additional losses in the generation and transmission systems and interfere with the supply of energy to other customers. Such loads have low power factor, produce voltage fluctuations, create unbalances in the system, generate harmonics and produce flicker problems. . Interference due to power system reaction has become greater with the increased use of power electronics, especially to the variable speed converter drives. Compensating equipment which included: switched shunt capacitors, filter banks and static compensators are used to reduce these reactions. The paper analyses the different reactions of various industrial loads and suggests compensation schemes by which these can be reduced to acceptable levels.

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1. INTRODUCTION

Industrial loads which draw power from the grid network of a utility cause repercussions in the network which lead to additional losses in the generation and transmission systems and interfere with the supply of energy to other customers. Such loads have low power factor, produce voltage fluctuations, create unbalances in the system, generate harmonics and produce flicker problems. Some of these loads are metal industries having arc furnaces, foundries and rolling mills, cement industries, mining industries, paper mills, chemical plants involving electrolysis process. Interference due to power system reaction has become greater with the increased use of power electronics, especially to the variable speed converter drives.

As per the utility regulations the reactions of industrial load on the utility supply had to be reduced to acceptable level. This job is done by compensating equipment which includes: switched shunt capacitors, filter banks and static compensators.

The paper analyses the different reactions of various industrial loads and suggests compensation schemes by which these can be reduced to acceptable levels.

2. POWER SYSTEM REACTIONS OF REACTIONS.

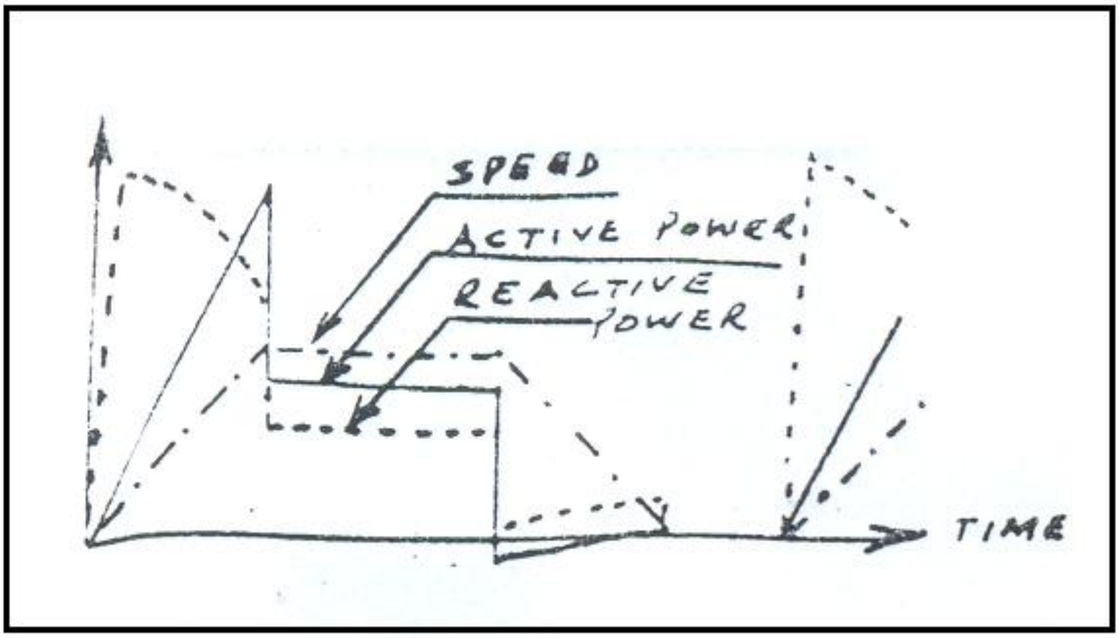
A distinction has been made between the different types of reactions

2.1 Deterioration in the power factor due to reactive loads

Large varying loads have large and abrupt changes in the profile of real and reactive power. The reactive power consumed by the loads cause additional losses in power generation and transmission systems. The utilities, therefore, impose the restriction of power factor limit on the industrial load and charge penalty if the average power factor over a prespecified period falls below a fixed value(usually 0.9 lag).

The changes in the real and reactive power in an arc furnace are caused by variation in the operating points which is defined by arc voltage and the electrode current. The phenomenon makes the reactive load vary between zero and furnace short circuit power and give rise to flicker. The power factor of an arc furnace varies within a range of 0.65 to 0.9.

In a rolling mill, during acceleration and deceleration periods of the mill which lasts between 5 to 20 seconds approximately, the reactive power consumption vary greatly while during period of constant speed, the active and reactive power consumption remains constant as depicted in Fig 1.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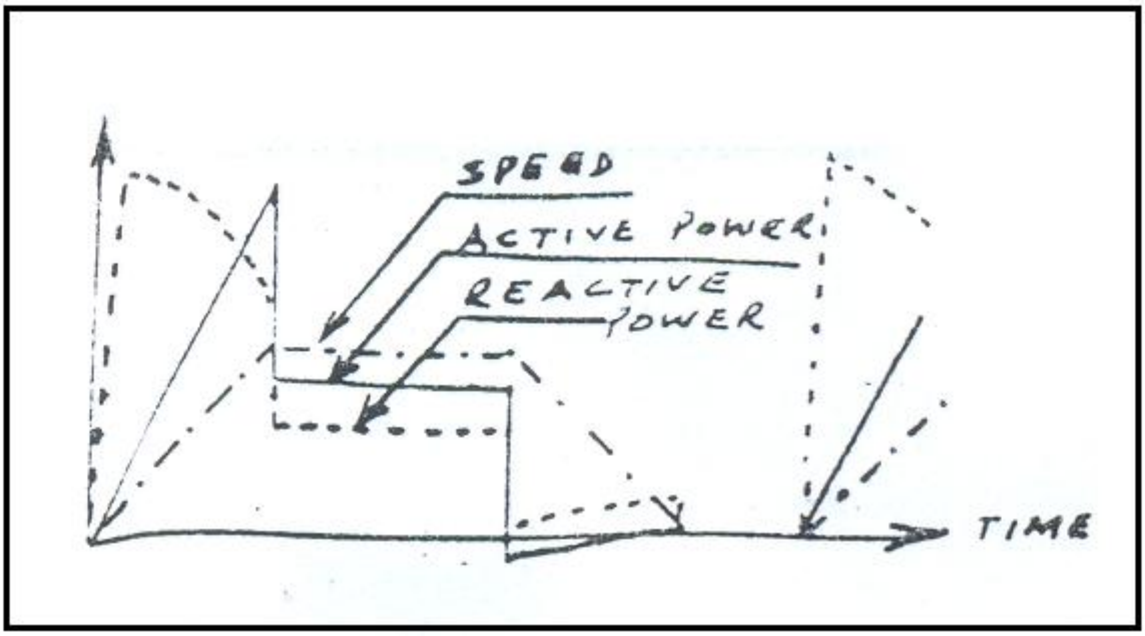
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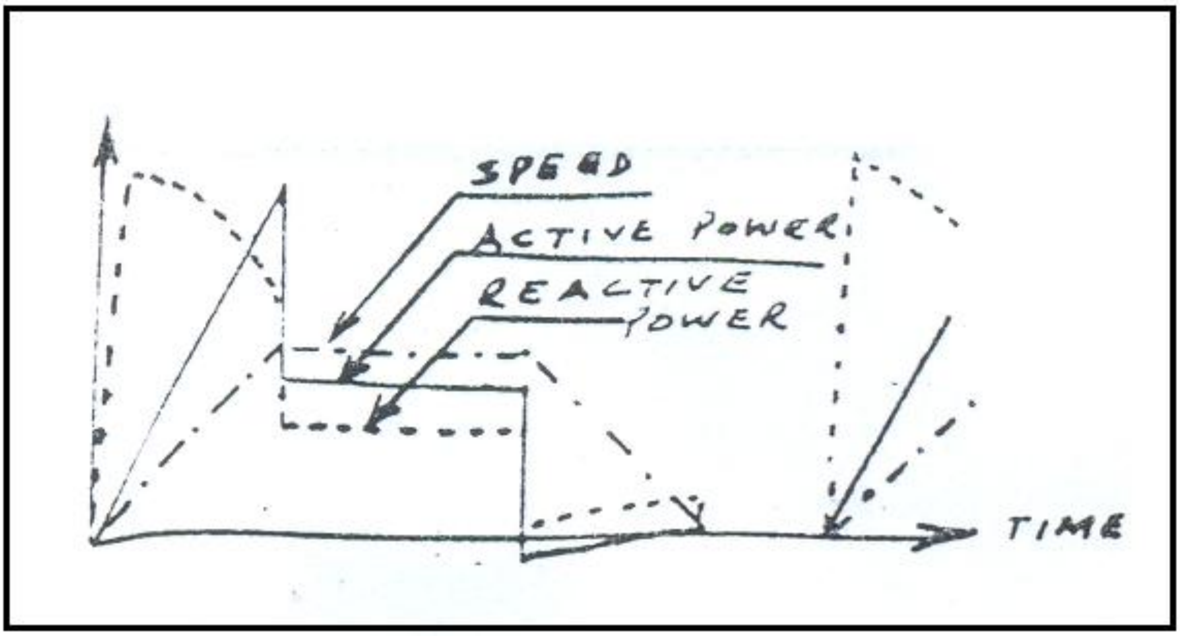


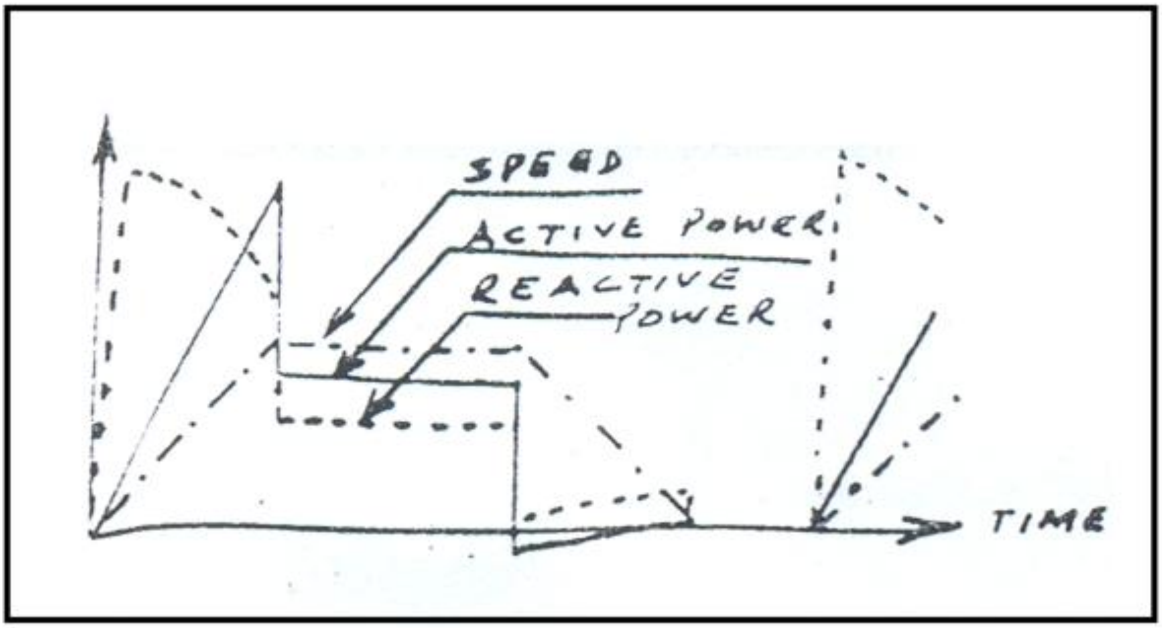
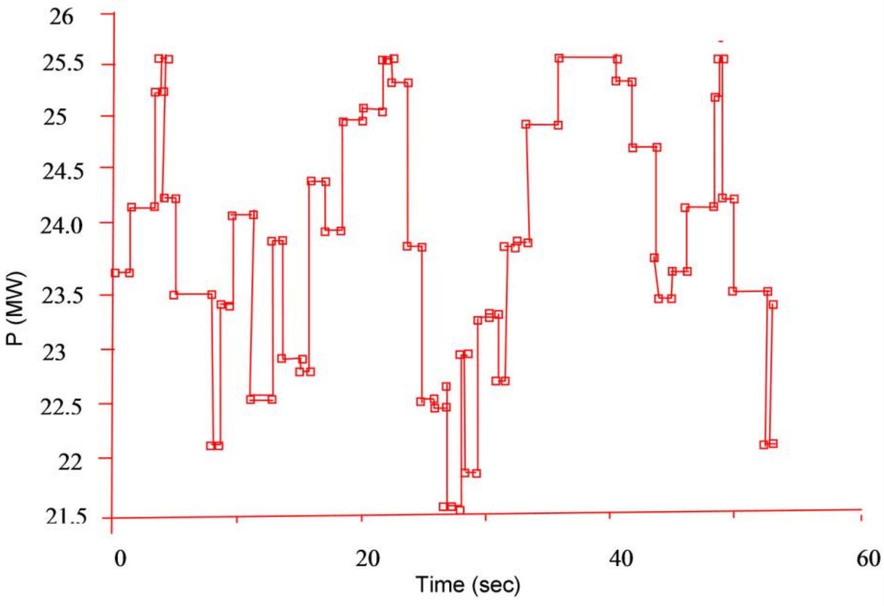
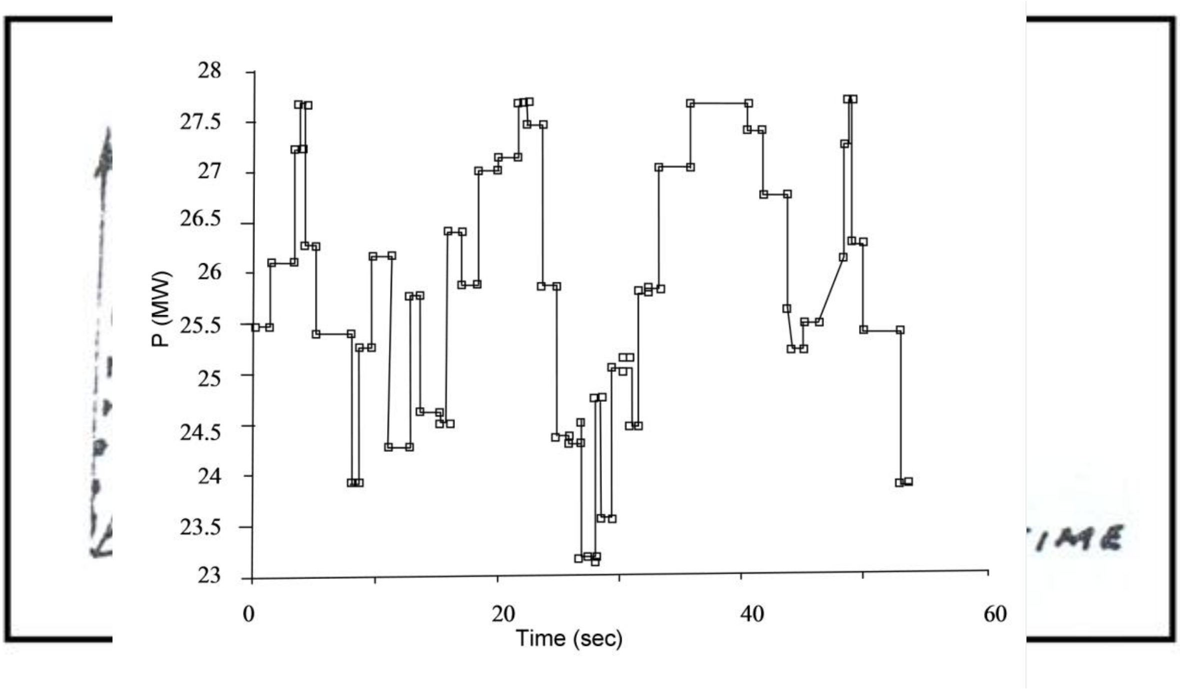


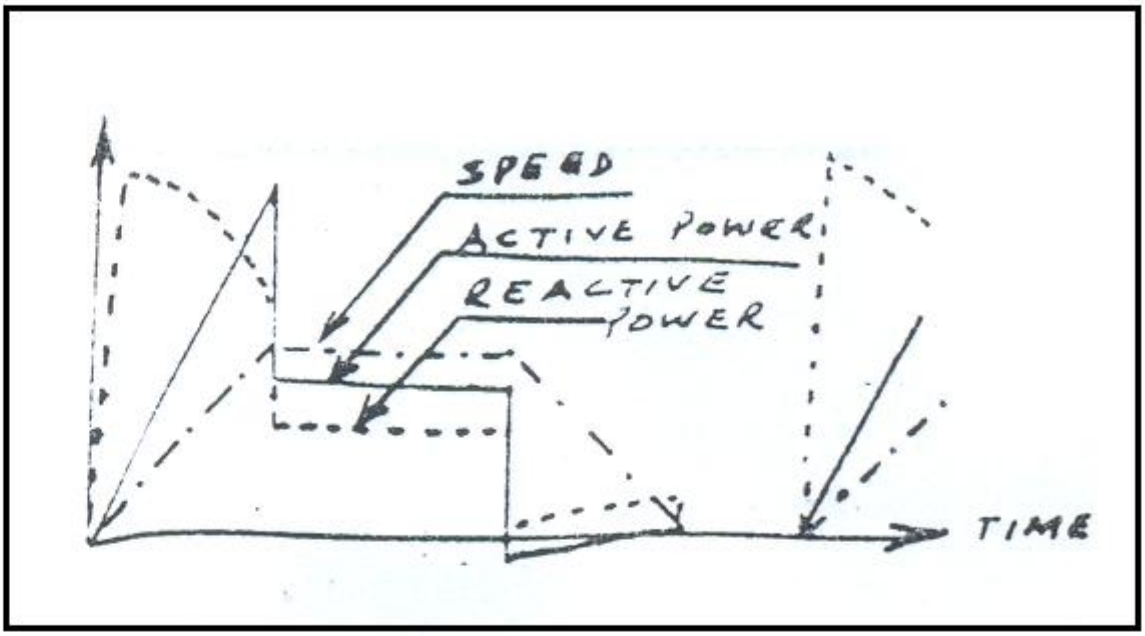
Fig 1 Active and Reactive power variation of a typical rolling mill

Large static converters are used in chemical industry and in electrolysis. Variable speed drives are the most important area of application of power electronics in the light and heavy manufacturing industries, trend being toward ac drives. Converters and ac drives consume large reactive power causing low power factor. Asynchronous motors, which constitute the vast majority of motor drives in industrial plants are responsible for large reactive power demands. Motors running at low loads have poorer power factor. The situation can be improved by using synchronous motors which can be operated at unity power factor or with the slightly leading lower factor. However, only drives with medium to high rating are of any real practical use. Typical examples are of large blowers, rotary and reciprocating compressors, pumps and wood grinding machines in paper and pulp plants.

Power factor correction usually relates to balancing of the reactive power drawn by the load from the supply system to an acceptable level on an average basis. The reactive power requirement of most loads is usually slowly variable and can be corrected by a balanced three phase compensator.







A typical load cycle curves for the active and the reactive power requirement of a modern steel mill are shown in fig 2(a) and 2(b), respectively. If such a system is left uncompensated, it will lead to very poor power factor and voltage regulation. Under such circumstances a combination of a static capacitor and a static compensator is required. A scheme for such compensation is discussed later.

2.2 Voltage Fluctuations

Voltage fluctuations typically result from the connection of a load, or combination of Loads, which is relatively large compared with the strength of the supply system, and whose current varies rapidly at the low power factor. Examples are electrical arc furnaces, motor starting, cyclic loads such as mine winders/ rolling mills and reversing drives, in metal and mining industries.

For the purpose of simple analysis, any supply system can be reduced to a constant voltage behind single equivalent impedance, fig 3. The maximum voltage change ΔV, due to a disturbing load, is an approximate function of system reactance and reactive component of current change, i.e., per unit voltage change can be predicted as:

$$\Delta V/V = I_q X/V = VI_q X/V^2 = Q/S$$

Where $Q(=VI_q)$ is the maximum reactive power change of load and $S(=V^2/X)$ is the maximum short circuit level of the supply system at the point of common coupling (pcc) with other consumers, which is where utilities tend to access voltage fluctuation disturbances.

For thyristor converter drives, ΔV can be predicted using equation (1) from the Q of the converter or combination of the converters, as the case may be.In electrical arc furnaces, the voltage fluctuations are caused by the unstable nature of the arc furnaces. Changes in impedance are continuous and predominantly sudden and random; the resultant ‘modulation’ of 50 Hz voltage, when applied to electrical lamps causes ‘flicker’ in their light output.

Voltage fluctuations have unpleasant consequences both for the plant operator’s own installation and for the others connected to the same network.

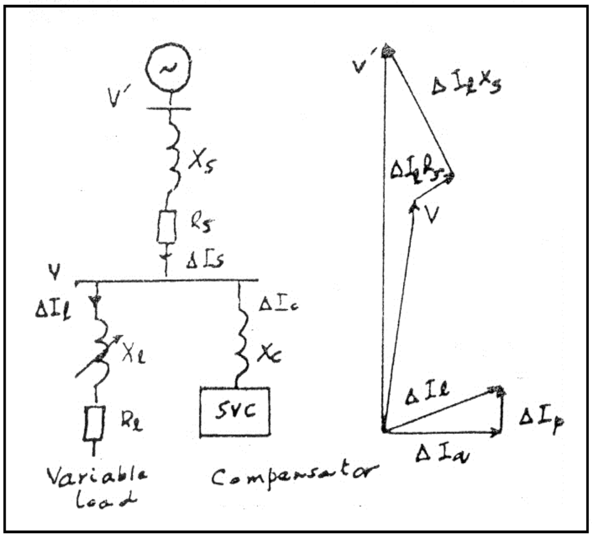


Fig 2Equivalentcicuit and phasor diagram of a supply network of an industrial load

2.2.1 Voltage Fluctuation Limits

Electrical plant such as control equipment, is usually affected by the step type of voltage fluctuation, and limits can be defined in terms of absolute voltage change. In UK, the step type of fluctuations (rise time less than 100 m/s) due to colliery winders and rolling mills are limited to 1 %,but 3% is permissible if the voltage change is ramped over a period of two seconds. These limits apply when the pcc is 66kV or lower; they are reduced at higher voltages, 0.7% and 0.5% at 132 kV and 220kV, respectively. In case of welders the acceptable voltage fluctuation level lies between 0.25% and 1% depending on the frequency of fluctuations. In case of random fluctuations due to the arc furnaces the criteria of acceptability is by cumulative effect gauge point value. The short circuit voltage depression (scvd) at the pcc should be less than 0.02 at 132kV and below, or 0.016 at 220 kV and above [2]

2.2.2 Reduction of voltage fluctuations

For a given installation, ΔV can be reduced by reducing either load current variations or system reactance, Fig3. System reactance can be reduced by transferring the pcc to a higher short-circuit level (usually at higher voltage) or by strengthening the existing pcc with additional lines, transformers and/or generation.

Alternatively, the reactive current drawn from the supply can be reduced by changes to, or compensation of, the load itself. Examples of the first method are reducing the rated power or increasing the reactance of the arc furnace, and applying current limit to, or deliberately ramping the current demand of a thyristor converter. The disadvantage of such a method is an increase in cycle time and corresponding decrease in production. The second method, that of 'compensating' the var demand of the load rapidly, is the use of static compensation better controlled reactors with fixed capacitors or thyristor switched capacitors.

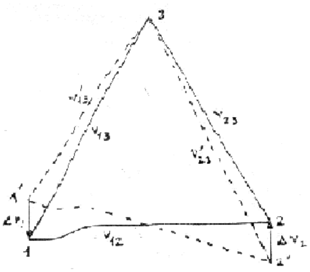
2.3 Unbalanced loads

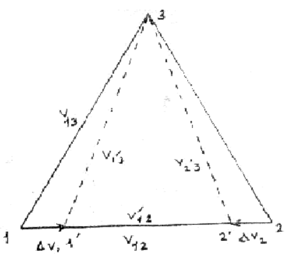
Most A.C power systems are three phase and are designed for balanced operation. However, some loads, like single phase traction loads and arc furnace loads lad to unbalanced operation of the power system. Unbalanced loads result in different voltage drops across the power system reactances and therefore unequal voltages in the network.

A single phase active power causes the value of the phase- to- phase voltage to which the loaded phase is connected to only change insignificantly ; however, it causes the other phase-to-phase voltages to either increase or decrease, fig4(a). In contrast to this a single phase reactive load results in a corresponding drop in the phase-to-phase voltage which the loaded phase is connected, and a much lower drop in two other phase-to-phase voltages, fig 4(b).

Unbalanced loads have to be balanced in order to obtain once more a voltage delta with both the sides at the coupling point. This job of balancing is done by a compensator.

Excess reactive load in a phase can be balanced by additional capacitor in that phase. Excess active load in a phase balanced by connecting a capacitive load to one of the two remaining phase-to- phase system voltages and an inductive load to the other(voltage increase in one phase and voltage decrease in the other). The load compensation is provided in such a manner that the system does not experience any unbalance load effects.





Harmonics

The connection of non-linear loads to the supply system leads to the production of harmonic currents which may cause current and voltage distortion throughout the network. Fourier analysis can be used to describe distortion in terms of fundamental frequency and harmonic components. In industrial loads, controlled converters (e.g. rolling mills and mill winders) or uncontrolled converters (e.g. aluminium smelters), traction loads and discharge lighting, etc. generate harmonics.

In converters, the switching action of the diodes/thyristors causes a current to be driven from the supply system which is distorted from the desired sine wave. In the steady state the typical harmonics occurring in an ac/dc converter and $n=k.\ p\pm1$, where $k=1,2,3\ldots..$and p is the pulse number, which depends on the rectifier circuit(usually $p=6$, although for higher ratings p may be equal or greater than 12). The amplitude of a harmonic is given by

$$I_n = [1/n]\ I_1 F_n$$

Where $I_{1=}$ amplitude of fundamental wave, n= harmonic number, and F_n = correction factor and depend upon both the control angle and overlap angle. These harmonics are called the characteristic harmonics. Transient conditions and unbalanced operation of the system also causes non-characteristic harmonics- multiples of 3. Fig 5 shows the magnitudes of harmonics of a six-pulse converter.

The arc furnaces are non-linear loads and the presence of erratic non-conductive half cycles explains the appearance of even and odd harmonic currents with lower order and higher magnitude. Assuming an arc furnace to be a current generator of harmonics, the harmonics generated will comprise of line spectrum and a continuous spectrum. Fig 6 shows the harmonic spectrum for a typical furnace.

Harmonic measurements done or six different arc furnace loads in Madhya Pradesh indicated the following type and magnitude of harmonics [2]: 2[2-14]%; 3[4.4-14.9]%; 4[0.2-1.6]%; 5[4.5-12.6]%; 6[0.5-2.8]%; 7[0.3-5.7]%; 8[0.3-0.8]%; 9[0.5-1.1]%.

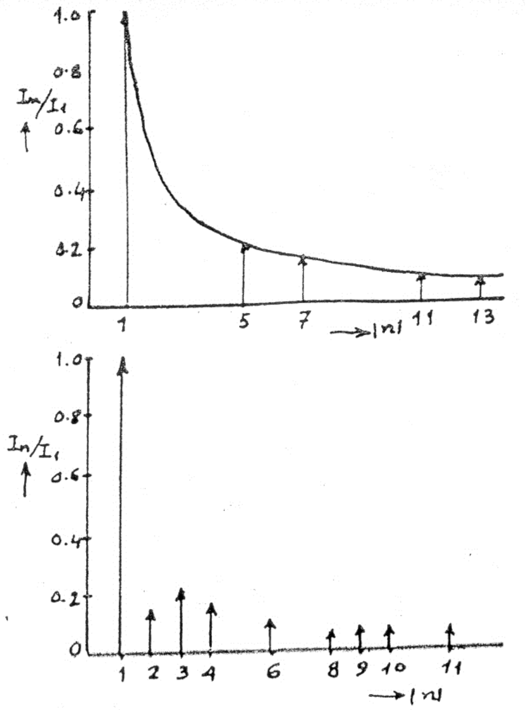


Fig5 Harmonic spectra of a six pulse converter

(a) characteristics harmonics, and (b) non characteristics harmonics,

3 . STATIC COMPENSATING SYSTEMS AND FILTER BANKS

Modern static compensators employ static equipment such as capacitors. Reactors and thyristor controlled elements with high speed, electronic measurement and controlled devices as their main components. The two types of compensators normally employed for the industrial applications are: thyristor controlled reactors + fixed capacitors, and thyristor switched capacitors. Depending on the type of requirements of compensation, single phase or three phase (average) control may be used. Some details of these compensators are given in references [1, 3].

In combination with the compensators or otherwise, filter banks are used to provide capacitive reactive power and eliminate harmonics. In filter, an inductive coil (reactor)is put in series with a capacitor, which is tuned to a harmonic frequency. The harmonic current flow into the filters and does not affect the other parts of the plant or network. A filter bank is normally designed so that each of lower harmonic has an individual circuit and the higher harmonics a common high pass filter[3].

The network reactions described do not necessarily infer the need for compensation. The determinant factor is the extent of these reactions, which depends largely upon the ratio of power rating of the load causing the disturbance to the Short-Circuit level of the network at the point of common coupling. In case, an industry installs a separate transformer for their loads, the secondary of this transformer is then isolated from the other transformers and the disturbance effect is reduced due to much higher short circuit reactance at the higher mains voltage level.

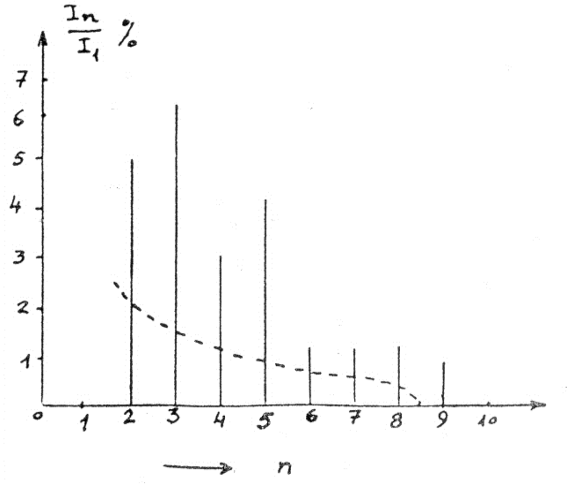


Fig 6 Harmonics spectra of atypical arc furnance

4. TYPICAL LOADS, REACTIONS AND TYPES OF COMPENSATION

Electrical steel plants-

Arc furnace reaction: low pf, voltage fluctuations, unbalance and harmonics

Compensation: filters and static compensators

Rolling mills-

Converter fed d.c. drives

Reaction: low pf, voltage fluctuations, harmonics

Compensation: filters and static compensators

Cement works –

All types of drives

Reaction: low pf and harmonics

Compensation: switched capacitors and filters

Paper mills-

Converter fed drives and asynchronous motors

Reaction: low pf and harmonics

Compensation: switched capacitors and filters

Chemical plants-

Converters

Reaction: low pf, voltage fluctuation and harmonics

Compensation: filters and static compensators

Mining industry-

All types of drives

Reaction: low pf and harmonics

Compensation: switched capacitors and filters

5. STATIC COMPENSATOR FOR VSP

Visakhapatnam steel plant(vsp) is an integrated steel plant in Andhra Pradesh, and is connected to APSEB grid at 220 kV, but it has its own generation of about 200MW, sufficient for its own demand. In one of the areas, called Medium Merchant and Structural Mill(MMSM), there are two types of loads- fluctuating and non-fluctuating. The fluctuating loads comprise thyristor converter fed d.c. main motor drives, and the non-fluctuating loads are auxiliary drives, ventilation and others. Both the loads are supplied separately at 11kV from a 220 kV/11 kV transformer. The load cycles, P and Q of one of the operation of the fluctuating load are shown in Fig 2(a) and 2(b). To get an overall pf of 0.9 under all operating conditions, and to limit the voltage fluctuations and harmonics within limit, a fixed capacitor bank of 10 MVAr on non-fluctuating load bus and a static compensator of 10 MVAr(cap)/5MVAr(ind) on the fluctuating load bus have been provided. The capacitive part of the compensator has been provided in the form of four filter banks, tuned to 5th,7th , 11th, and 13th harmonics. The compensator scheme is shown in fig 7. The compensator limits the voltage fluctuations within 2% for slow change of 2 per 50 seconds and within 0.7% for fast changes of 2 per second. The filters limit the individual harmonic voltage distortion to 3% and total harmonic voltage distortion to 4%.

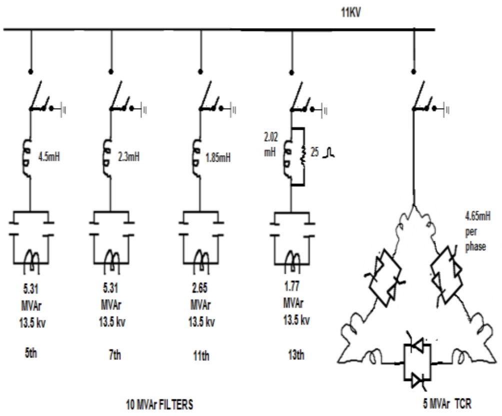


Fig7 Static compensator at VSP network

6. FILTER BANKS FOR SALEM STEEL PLANT

When a load consumes nearly constant reactive power, but at the same time produces harmonics, giving rise to voltage distortion, the use of filter bank is the most desirable method of compensation. A filter banks combination of 10MVAr at 11 kV was installed at salem steel power plant. The filter bank consists of 5th, 7th, 11th, and 13th harmonic filters, Fig 8. With these filter banks , the power factor was improved from 0.3 to 0.9 and the voltage harmonic distortion was reduced from 3.4% to 0.8 %. The voltage wave form at 11kv bus with and without filter bank is shown in fig. 9.

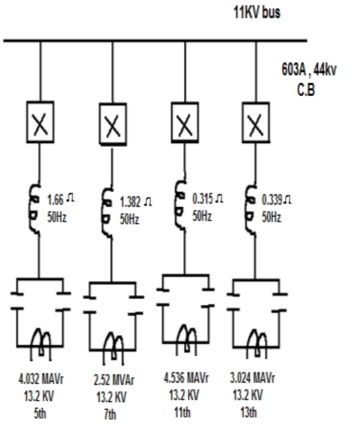


Fig8 Filter banks at salem steel plant

SUMMARY

It is desirable to be aware of the disturbing effects of different types of industrial loads. The major reactions of considerations are, deterioration in the power factor due to reactive loads, voltage changes due to reactive power, flicker, unbalanced loads and harmonics. For new loads, an advanced planning be made to install the compensation equipment if needed, which can be predicted with reasonable accuracy applying simple rules.

When acceptable limits are exceeded, it is uneconomical to connect the load to strong supply system, reactive power compensation and / or harmonic filtering equipments are well established as alternate solutions.

Several types of static compensators are currently available and suitable for most applications; however, care must be taken concerning the type of compensator, its proper design and cost.

Static compensator may also be employed for load balancing in cases where, in addition to being asymmetrical, the load is rapidly variable. Harmonic filters, when properly integrated with a supply system, provide a safe and effective solution the problem of excessive harmonic distortion. Since an harmonic filter inherently generates vars, it can usually be designed additionally to meet power factor correction requirement

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3. SP Seth, ‘Arc Furnace Loads and Their Compensation by Static Compensators’, IEEMA workshop on Capacitors for Industrial Furnaces, Sept. 1991, Indore.