

ENGINEERING RECOMMENDATION P29

MARCH 1990

THE ELECTRICITY COUNCIL

PLANNING LIMITS FOR VOLTAGE UNBALANCE  
IN THE UNITED KINGDOM

## CONTENTS

- 1 SCOPE
- 2 DEFINITIONS
- 3 INTRODUCTION
  - 3.1 Description of the Disturbance
  - 3.2 Effects on Equipment
  - 3.3 Estimation of Unbalance
  - 3.4 Measurement of Unbalance
  - 3.5 Reduction of Unbalance
- 4 LIMITS
  - 4.1 Basis of Limits
  - 4.2 Influence of System Impedance
  - 4.3 Limits
- 5 REFERENCES

1 SCOPE

This Engineering Recommendation provides limits for voltage unbalance in public distribution networks operating at 132kV and below, to be used in the technical evaluation of proposed new loads which may give rise to voltage unbalance. The limits relate specifically to the voltage unbalance attributable to the proposed new load and are not intended to be applied as generalised network limits. In assessing requirements for the connection of the load, account will be taken of significant sources of unbalance already known to be connected in order to maintain an acceptable quality of supply.

Unbalance due to faults is not covered by this Engineering Recommendation and the levels that occur are likely to exceed the specified limits. Equipment which is likely to be damaged by such a situation should be protected by loss-of-phase, out-of-balance or negative phase sequence protection as appropriate.

Other aspects of the connection of potentially disturbing loads are discussed in the relevant Engineering Recommendations, eg harmonics in ER G5/3, voltage fluctuations in ER P28.

2 DEFINITIONS

Voltage unbalance

In a three-phase system, the degree of voltage unbalance is expressed by the ratio (in per cent) between the rms values of the negative sequence component and the positive sequence component of the voltage.

This ratio may be approximated (for values of voltage unbalance of a few per cent) as:

$$\text{Voltage unbalance (\%)} = \frac{\text{Maximum deviation from the average of the three-phase voltages}}{\text{average of the three-phase voltages}} \times 100\%$$

Point of Common Coupling (p.c.c.)

The point on a public electricity supply system electrically nearest to a customer's installation at which other customers' loads are, or may be connected.

3 INTRODUCTION

3.1 Description of the Disturbance

The voltage measured at the terminals of a generator is almost perfectly sinusoidal in shape and with the three phases equal in magnitude and separated by 120°. If the impedances of the various system components were linear and identical for each phase and if all loads were balanced and three-phase in nature the voltages would remain balanced. However, low voltage supplies and loads are predominantly single phase, and at higher voltages some very large single-phase loads are connected such as traction loads and single phase furnaces.

Currents to unbalanced three-phase loads and single-phase loads give rise to dissimilar voltage drops on the three phases of the supply system and consequently the phase voltages within the supply system will be unbalanced, because the voltage at any point is the difference between the generated voltage and these voltage drops due to load current.

In addition the impedance of some system components is not the same in each of the three phases, particularly overhead lines. Hence the current taken by a balanced three-phase load will also produce unbalance which will form part of the background voltage unbalance.

Unbalanced voltages caused at lower voltage levels on the supply system are not transferred upwards through the various voltage levels of the system to a very significant extent, because of the reduction in source impedance. Unbalance caused at a higher voltage is however transferred down to lower voltages, though for example three-phase rotating plant and voltage stabilising equipment at the lower voltages may reduce the transferred unbalance.

Under certain fault conditions extreme levels of unbalance can occur, these conditions can be of short term or intermediate duration. Short term conditions arise during the flow of fault current, prior to the disconnection of the fault by an automatic circuit breaker or fuse. Generally such events last no more than a few seconds. Events of intermediate duration arise typically from the loss of one of the three phases supplying an installation or within an installation following a break in a phase conductor or the operation of a protective device such as a fuse in one phase only. These latter events may persist for a few hours, until they are reported by consumers and repair or replacement is undertaken.

### 3.2 Effects on Equipment

Experience has shown that provided the limits of unbalance specified for individual loads or groups of loads in this document are observed, equipment will not generally be affected by unbalance. Some types of three-phase equipment are potentially more sensitive to unbalance than others and it is the sensitivity of such equipment which has been used as the basis for the limits.

Of prime concern in this respect are three-phase rotating electrical machines and three-phase rectifier and inverter equipments. A thorough technical background to the problems is given in ETR 116 - Report on Voltage Unbalance due to British Rail AC Traction Supplies.

For three-phase rotating plant the predominant effects are rotor and stator heating. Synchronous machines are the most sensitive. It has been shown that since it is heating effects that are the main concern, short term levels of unbalance a little above the limits in this document do not normally cause damage. Where Negative Phase Sequence protection is provided (on large machines for example) nuisance tripping can occur if the protection settings are exceeded, even for short periods.

Rectifier and inverter equipment generates additional harmonics current in both the ac and dc circuits when subjected to unbalanced voltage. However such equipment should be designed to tolerate 2% unbalance (see IEC publ 146). As far as is known at present other electronic control equipment does not appear to be particularly sensitive to voltage unbalance.

### 3.3 Estimation of Unbalance

The voltage unbalance arising at the pcc due to a combination of unbalanced three-phase loads or phase to phase loads may be evaluated by the following expression:

$$\text{Voltage unbalance (\%)} = \frac{\sqrt{3} \times \text{negative phase sequence component of the loads (A)} \times \text{Line voltage}}{\text{three-phase short circuit level at pcc (MVA)}} \times 100\%$$

An accurate assessment of unbalance is provided by phase sequence analysis techniques, as described, for example, in ETR 116 Appendix A and D. In carrying out detailed assessments or simplified assessments as described below, lv infeed from motors is ignored, although their effect has been taken into account in producing the limits in section 4.

The accurate addition of the negative phase sequence components requires a knowledge of the phase and amplitude for each source of unbalance. A simple worst case solution is given by direct addition of the amplitudes.

The above expression can also be used to provide a simplified assessment of the combined effect of such loads with different pcc's if the lowest of the short circuit levels at the pcc's is used in the denominator, in general, however, complex calculations are best carried out by means of a computer study.

The voltage unbalance caused by a single phase load connected between phases may be calculated as:-

$$\text{Voltage unbalance (\%)} = \frac{\text{single phase load (MVA)}}{\text{three-phase short circuit level (MVA) at pcc}} \times 100\%$$

### 3.4 Measurement of Unbalance

Measurement of unbalance requires the use of negative phase sequence recording equipment, and at hv this is generally carried out on a convenient three-phase voltage transformer (VT).

Attention must be given to the burden as the VT windings and to the integrity of the VT fuses to ensure that the measured unbalance relates to the hv system. Where the results of measurements are to be used in assessing the connection of a proposed load, care must be taken to relate the phase and amplitude values measured through the VT to the equivalent values which would occur at the point of concern on the system (eg pcc). Guidance on these aspects is given in ETR 116 Section 2.3 and Appendix D.

### 3.5 Reduction of Unbalance

A number of technical options are available in planning a reduction in voltage unbalance, the chosen solution may involve a trade-off between conflicting requirements for other disturbances or aspects of supply and it is important not to look at any one aspect in isolation.

The most commonly available options are:-

- connection to a different supply point
- rearrangement of phase connections
- connection at a higher voltage level
- provision of phase balancing or filtering equipment.

4 LIMITS

4.1 Basis of Limits

It is in the interests of Supply Undertakings to operate with a low level of voltage unbalance in order to avoid increased losses and to maintain the supply voltage within statutory limits. However, the Supply Undertaking has only limited control of short-term variations in voltage unbalance which are caused by the unco-ordinated switching of loads by customers. A background voltage unbalance may exist due to unbalance of the system impedance. This rarely exceeds 0.5% but higher levels, in excess of 1%, may be experienced at times of high load and when outages occur at voltage levels above 11kV.

ETR 116 established that three-phase machines can withstand voltage unbalance in excess of 2% for short periods, but that the long-term mean voltage unbalance should not exceed 1%. This implies that voltage unbalance levels between 1% and 2% are unlikely to give rise to unacceptable degradation of equipment provided the frequency and duration of such occurrences are suitably controlled. In addition account can be taken of the neutralising effect of rotating plant, particularly at 11kV and below.

4.2 Influence of System Impedance

Calculation or measurement of voltage unbalance requires a knowledge of the system impedance. The values used should give a realistic maximum value of unbalance over the period of operation of three-phase rotating plant which is likely to be affected. In general for distribution networks this could require the full annual cycle of loading to be considered.

The following factors may need to be considered:

- a Local Generation - Unless there are long-term guarantees that this will be running at the time of operation of the disturbing load it should be ignored.
- b Routine Switching - This is usually employed for fault level control and reactive compensation purposes. The condition which gives the highest system impedance should be used unless it is tied in directly with the operation of local generation. In this case the condition with the generation running should be used if this has the higher impedance.
- c System Outage - The short-circuit level corresponding to single-circuit outage conditions - fault or maintenance - should be assumed. Where the short-circuit level for normal operation is lower than the single-circuit outage condition, the lower level should be assumed.
- d Future System Changes - Planned system alterations which will increase the system impedance during the lifetime of the disturbing load should always be taken into account.

- e Supergrid Impedance - At 132 kV and above, consideration of supergrid impedance is normally necessary. The operating conditions giving rise to the highest level of unbalance should be used.

#### 4.3 Limits

Taking into account the system configuration which gives rise to the maximum value of voltage unbalance as discussed in 4.2 above, the following limits should be applied at the p.c.c. in respect of the unbalance caused by the proposed load;

- a voltage unbalance should not exceed 2% when assessed over any one minute period, and
- b based on the conditions within the customer's installation which will give rise to the worst sustained voltage unbalance at the p.c.c, the voltage unbalance should not exceed (assuming that the supply system is symmetrical at the p.c.c);
  - 1.3% for systems with a nominal voltage below 33kV, or
  - 1% for other systems with a nominal voltage no greater than 132kV.

Where a balancer is used, the limits in (b) above may be exceeded for no more than 5 minutes in every 30 minutes in order to accommodate temporary mismatch due to changing load conditions.

These limits shall be replaced in respect of traction load by the limits in the Addendum to ER P24 which takes account of the particular cyclic variations that arise in this case.

Due regard should be given to existing levels of unbalance voltage where such levels when combined with the proposed new load may be excessive. In such cases it may be necessary to reduce the limits given above after a more detailed assessment has been made of the combined unbalance.

5        REFERENCES

- Engineering Recommendation G5/3    -    Limits for Harmonics in the UK  
Electricity Supply System
  
- Engineering Recommendation P24    -    AC Traction Supplies to British Rail
  
- Engineering Recommendation P28    -    Planning Limits for Voltage Fluctuations  
Caused by Industrial, Commercial and  
Domestic Equipment in the United Kingdom
  
- Engineering Technical Report 116 -    Report on Voltage Unbalance due to  
British Rail AC Traction Supplies
  
- I E C Publication 146            -    Semi-conductor Converters