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Guidance on Practice for Power System Design

GP 12-01

BP GROUP
ENGINEERING TECHNICAL PRACTICES

Foreword

This is the first issue of Engineering Technical Practice (ETP) GP 12-01. This Guidance on Practice (GP) is based on the following heritage documents from merged BP companies:

Amoco (ACES)

EL-SYS-00-G	Electrical—Systems—Guide
EL-SYS-00-E	Electrical—Systems Design—Specification

BP RPSE

RP 12-3	Electrical Systems and Installations Power System Design
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1. Scope

This GP provides guidance for electrical power distribution system design and should be utilised in conjunction with GP 12-02 and GP 12-03.

2. Normative references

The following normative documents contain requirements that, through reference in this text, constitute requirements of this technical practice. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this technical practice are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

BP Engineering Technical Practices (ETP)

GP 12-02	Guidance on Practice for Power System Installation & Construction
GP 12-03	Guidance on Practice for Power System Protection and Control
GP 12-05	Guidance on Practice for Transformers and Reactors
GP 12-10	Guidance on Practice for Switchgear & Controlgear
GP 12-20	Guidance on Practice for Motors
GP 12-25	Guidance on Practice for Earthing/Grounding
GP 12-35	Guidance on Practice for UPS Systems
GP 12-60	Guidance on Practice for Hazardous Area Electrical Installations
GP 12-80	Guidance on Practice for Power Generators
GP 12-85	Guidance on Practice for Emergency Generators

American National Standards Institute

ANSI C84.1	American National Standard for Electric Power Systems and Equipment Voltage Ratings (60 Hertz)
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Institute of Electrical and Electronic Engineers (IEEE)

IEEE Std C2	National Electrical Safety Code
IEEE Std 399	Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE Brown Book)
IEEE Std 519	Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems

International Electrotechnical Commission (IEC)

IEC 60038	IEC Standard Voltages
IEC 60909-0	Short-circuit currents in three-phase a.c. systems: Part 0 – Calculation of currents

3. System planning

IEEE Std 141, chapter 2 forms the overall basis of this section.



3.1. Basic design considerations

- a. The following points should be considered when establishing a basis for the planning of an electrical power distribution system:
 1. Safety – of personnel and equipment
 2. Reliability of primary electrical power source
 3. Reliability of power distribution system
 4. Simplicity of operation
 5. Voltage regulation throughout the power distribution system
 6. Maintainability
 7. Flexibility – ability to expand and adapt
 8. First cost
- b. The following points are a guide to what should be included in any power distribution system planning process:
 1. Electrical load definition and load forecasting
 2. Selection of an appropriate power distribution system philosophy
 3. Locations of major power distribution equipment – in relation to consumer locations
 4. Utilisation voltages
 5. Primary power utility source
 6. On-site generation – if any
 7. Single line diagram
 8. Power system studies including load flow, short circuit and stability analysis
 9. Power system protection and protective device coordination
 10. Communications – throughout the power distribution system
 11. Maintenance – programming and scheduling
- c. If the primary power utility source is from a public utility company, the following information should be obtained from the utility company:

All negotiations with public utilities should be the sole responsibility of the site operator.

 1. System data – number of phases, nominal voltage, frequency, etc
 2. Voltage regulation.
 3. Short circuit ratings
 4. Reliability of utility company supply
 5. Capacity and ratings of incoming feeders
 6. Number of incoming feeders and whether in parallel operation
 7. If feeders have automatic transfer, or automatic reclose
 8. Protection relay schemes and requirements for coordination with utility company protection system

3.2. Site considerations

- a. Site practices of existing facility should be reviewed and incorporated into design.



- b. Electrical equipment numbering, associated data books, and other references should be coordinated with existing plant numbering system.

3.3. Energy conservation

During the design process associated with power systems attention should be given to the conservation of energy, if there is an economic advantage when lifetime costs are taken into account.

The economic evaluation of alternative arrangements should take into account a lifetime NPV for the project and should include costs for fuel and for any CO2 levy.

4. Power system parameters

4.1. Voltage

IEEE Std 141, chapter 3 forms the overall basis of this sub-section. The clauses in this whole document refer to the nominal system voltage ranges given in chapter 3 and ANSI C84.1, defined as follows:

- *Low voltage 1000V and below*
- *Medium voltage from 1000V to 100kV*
- *High voltage from 100kV to 230kV*

- a. The nominal system (phase-to-phase) voltage should be selected from those detailed in IEC 60038 or ANSI C84.1 as appropriate.
- b. The most economic nominal system voltages should be selected for a power system bearing in mind the possible need to distribute electrical power over considerable distances within the site.

The requirement for having the most economic nominal system voltage is intended to ensure that an economic appraisal of alternatives is undertaken or has been considered. Such appraisals should include consideration of operational costs (including cost of losses) over the expected life of the installation.

- c. In general the nominal system voltages selected should agree with the voltage levels for electrical machines (see GP 12-20).
- d. For 'green-field' sites or offshore locations with a low possibility of interconnection to an outside public utility, the use of non-standard nominal system voltages for low voltage systems should be based on economic considerations.

Selection of a non-standard nominal system voltage (such as 690V) should be based upon specific economic studies, which take full account of the need to hold spares, which may be beyond normal stock levels.

4.2. Frequency

- a. The frequency selected for power systems should be either 50 or 60 Hz depending on the national standards of the site location.
- b. If a site is to be remotely located and powered only from on-site generation, the frequency selected should be compatible with the frequency of supply of the nearest local electrical supply source or public utility, particularly if it is envisaged that future inter-connection may be desirable.
- c. If future inter-connection with other sources of electricity supply is not envisaged as being possible or if economic advantages outweigh the benefits of future possible interconnections, the frequency of supply should be selected on economic considerations and on ease of obtaining suitable equipment.



Offshore experience indicates that selecting 60 Hz frequency tends to offer possible weight, and therefore economic, advantages and since such equipment is widely available this selection becomes more likely.

4.3. Short-circuit rating

The definition of short-circuit terms used in this sub-section can be found in chapter 7 of IEEE Std 399

- a. All switchgear and distribution equipment on a power distribution system should be capable of carrying the prospective rms symmetrical breaking short-circuit current for a specified short-time duration of 1 or 3 seconds without deleterious effect.

The choice between 1 and 3 second durations would be dictated by equipment availability, economics and fault current protection clearing times.

The backup fault current protection clearing times should always be less than the equipment short-time current rating.

Generally 3-second short-time current ratings for switchgear would be preferred to avoid the necessity for rapid protection.

- b. The closure of switchgear on to a short-circuit type fault should not result in mechanical shock load damage to healthy parts of the power system as a result of peak asymmetrical make currents flowing.
- c. Medium voltage power systems should be designed such that the rms, symmetrical breaking short-circuit current of circuit breakers should be selected from rating values readily available from equipment manufacturers.

There are situations (e.g. when on-site generation is provided) when switchgear of higher short circuit capacity (such as 50 kA rms symmetrical) may be necessary, which may only be available from a small number of manufacturers.

- d. The selection of 25 kA rms symmetrical breaking short-circuit current capacity for medium voltage power system, general-purpose applications, may prove to be an economic ceiling for the available fault levels of equipment.

If there is an economic advantage in providing switchgear of higher ratings, such as 40 or 50 kA rms symmetrical, then this should be considered.

- e. In a green field situation, the short circuit capability of the installation should be based on economic grounds.
- f. The short-circuit capability of switchgear should always be proven by type testing before being accepted into full duty service.

Type testing would be particularly important if 'enhanced make', peak short-circuit current or enhanced d.c. content in breaking short-circuit current would be required. See GP 12-10 for testing requirements.

- g. For low voltage power systems the rms symmetrical breaking, short-circuit current of general-purpose circuit breakers should not normally exceed 50 kA rms symmetrical.

If economically viable the selection of 80 kA rms symmetrical or above rated switchgear may be considered for low voltage power systems.

4.4. Methods of limiting short-circuit currents

- a. If the power system design indicates prospective short-circuit levels would exceed the proposed circuit breaker ratings, the following measures should be considered:
 1. Increase the power system reactance, provided this causes no technical problems such as voltage regulation or a commercial problem.



2. Change the power system operating mode by operating with certain circuit breakers open and provide auto-transfer facilities to reinstate the power supply security and quality levels.
3. Purchase switchgear and equipment designed and certified for the higher short-circuit levels if these are available.
4. Provide fault current limiting devices other than fuses.
5. Carry out any combination of the alternatives listed above.

The selection of the most appropriate of the alternatives should be based on least cost.

Saturable reactors (used as resonant links) could offer a good solution for resolving short-circuit limitations for medium voltage systems above 20kV, and high voltage systems and they do not suffer from regulation problems. Their expense generally precludes their use.

- b. The use of Is limiters should be avoided for new installations but could be useful if existing systems are to be expanded or interconnected with new systems.

Care should be taken in designing systems for Is limiters to ensure supply security would not be jeopardised and that cost would be justified.

- c. Fault-limiting (series) reactors used to increase the reactance between the source and potential fault location, should comply the guidance given in GP 12-05.
- d. If fault-limiting reactors are considered to be necessary, they should preferably be installed between busbar sections, to limit potential power system voltage profile problems under normal operating conditions.
- e. The impedance of series reactors should be chosen to limit the fault current passed through the reactor to a level which ensures that total calculated short-circuit levels on either side of the reactor would be no greater than 90% of the selected equipment short-circuit ratings.
- f. Series reactors may be single or three phase, dependent on space and cost considerations. They should have a thermal ability to carry the rated short circuit symmetrical current for at least 2 seconds.

The time rating of the reactor would be dependent upon the protection arrangements.

- g. The voltage drop across series reactors under the motor start, restart or re acceleration conditions should be analysed to ensure that no unacceptable transient under-voltage would occur.
- h. If series reactors are installed between two power systems, the transient stability of the power generator sets should be analysed.

4.5. Frequency and voltage regulation

- a. Power systems should be designed to ensure that the voltage variation experienced at the terminals of any load equipment should not exceed $\pm 5\%$ of the declared system nominal voltage for power system loadings between full load and lightly loaded conditions.

If the system nominal voltage deviates beyond the 5% limit, apart from equipment life expectation being eroded, there is a danger of exceeding the certification limits for equipment installed in a hazardous area. This may not actually cause failures or temperatures likely to cause ignition of a vapour, which may be present, but will increase the likelihood of such occurrences and will therefore infringe the basic safety intention.



- b. The power system should be arranged to be able to withstand without undue stress a transient voltage reduction of up to 20% of nominal for typically a 10 second period or longer.

Motor starting requirements could give rise to such a voltage depression at motor terminals of 20%, and the power system should be able to successfully accept this condition for the starting period. Typical motor starting periods can range from 1 to 10 seconds depending on machine and system ratings and machine inertia.

Starting times beyond 10 seconds are possible for particularly high inertia loads such as fans. These would constitute a special application and should be treated by exception.

- c. Special consideration should be given to power frequency over-voltage effects and the need for power system equipment to withstand higher over-voltages under some circumstances.

This requirement ensures that standard equipment parameters would not be compromised.

Power systems supplied by power generators that have automatic voltage control could experience short-term over-voltages caused, typically by generator over-excitation following a direct-on-line start of a large electrical machine. Significant over-voltage levels may be experienced (120% to 130% of nominal system voltage are not untypical).

This would require special specification of transformers and other equipment to avoid problems caused by over-fluxing or increased current due to magnetic excitation.

- d. Special attention should be paid to voltage and frequency tolerance specifications for generator transformers, which may need to match the run up characteristic of the power generator.

This could require the transformer to be capable of withstanding full rated voltage at 80% of rated frequency.

- e. Site incoming transformers should be equipped with on-load, automatic tap change equipment for voltage regulation purposes. (See GP 12-05)

- f. Automatic voltage regulation equipment of power systems which have both on-site power generation and public utility intakes via transformers, should be designed so that there would be no detrimental inter-action.

Consideration should be given to the deliberate introduction of appropriate operational time constants to prevent unnecessary hunting between transformer tap changers and power generator AVR (automatic voltage regulators).

- g. The excitation systems of synchronous motors should be arranged to ensure no detrimental interactive effects with transformer automatic tap changer equipment.

Synchronous motor excitation could be arranged to maintain a constant power factor to the machine and the transformer tap changer control could be arranged to maintain system voltage within pre set levels.

- h. If a site has no public utility connection, the controls associated with the governors of on-site power generation should be designed so that generator loading should be automatically shared between the operating sets and that the nominal site supply frequency should be maintained within a specified tolerance.

If governor droop control is provided, there should be an operator in attendance who could take action from time to time.



An automatic power system management system could be provided to ensure that the system frequency remains within reasonable limits. Such limits should be $\pm 1\%$ and the output system frequency time should be within 30 seconds of 'standard' time.

A 'standard' clock arrangement should be provided for power plants supplying townships or camp areas. The limit for frequency time may be relaxed for small power plants, and those where frequency time is considered unimportant.

For unmanned power plants or those where constant operator intervention would be undesirable, an isochronous controller designed to provide overall frequency and power generator loadings within prescribed limits should control the system frequency.

- i. The controls associated with the governors of on-site power generation at a site with a public utility connection should be designed for parallel operation with the public utility and should incorporate protection devices which should ensure that under public utility supply disconnection (or unacceptable major disturbance on the local grid network), the site would retain a defined loading condition. The controls should also incorporate means for independent operation, with adequate control of frequency and voltage.

If a facility is interconnected with a public utility, the control of the power system frequency must be under the control of the public utility. Only defined load governor settings or droop load sharing control systems would be possible. The interconnection would be always subject to disconnection under automatic protection system operation, which could leave the on-site power generators supplying the site load. Under these conditions, whatever the original power generator control arrangements, the power generators would have to revert to independent load sharing control.

4.6. Reliability

- a. For each power supply arrangement ('normal', 'maintenance' and 'unplanned outage'), a reliability assessment should be carried out to determine the probability of failure of supply. The results of such an assessment should provide input data for economic analyses.
- b. In the early stages of design, a reliability study should be undertaken as part of the comparison of alternative methods of providing power supplies.

Such studies would also be useful in determining the cost of failures.

- c. The terms of reference of these studies relating to objectives, data gathering, and evaluation should be clearly specified for those undertaking these studies.

These studies may form part of a contractor's work scope or the work scope of a project team.

- d. Assessment of power distribution system reliability should be carried out as part of an overall assessment of plant failure and also as part of a comparison of alternative supplies for new plant. The mean time between failure (MTBF) and the mean time to repair (MTTR) for a power system failure at any particular switchboard should be determined. In addition, the quantitative statement should indicate the probability of failure occurring over a particular timeframe.

For example a value and definition of the probability of zero failures over a 12-month period should be determined.

5. Power system loading

IEEE Std 141, chapter 3 forms part of the basis of this section.



5.1. Equipment rating and diversity factors

- a. A load list should identify all process loads and should further identify the power to be absorbed by the mechanical drive. This should be adjusted for efficiency of the electrical drive to arrive at a value of power to be drawn from the electrical system.
- b. Power system loading estimates should be based on absorbed demands for machine loads with appropriate allowances for efficiency and power factor. In addition the effect of diversity should be assessed using a concept of intermittence or the application of well-proven diversity factors.

In the absence of either of these methods, an average maximum loading expectation may be assessed by adding 50% of the intermittent load (that controlled by level switches or by thermocouples or other control devices) to the continuously running loads.

- c. Assessment of maximum load requirements for an installation should allow for diversity between various loads, drives or plants. Appropriate factors should consider the likelihood of loads, drives, production or process trains coincidentally requiring peak demands and should be based on similar installations.
- d. Aggregated plant loading should be carried out taking account of diversity and any other factors. This 'after diversity' load estimate should only include one allowance for contingency.
- e. In addition to this aggregated load, an assessment should be made of operating standby load.

An estimate of maximum of standby load operation may be obtained by considering such scenarios as boiler outage (insufficient steam for steam turbine drivers) or a maximum product throughput condition.

- f. Power system equipment should be rated to continuously carry the maximum 'after diversity' load associated with peak design production with an additional 10% contingency.
- g. If ambient conditions are likely to exceed 40°C maximum air temperature and an altitude of 1000 m, this should be defined in equipment specifications.

The specification of maximum temperature and elevation should ensure that equipment has sufficient capacity for the most arduous likely conditions. If there is no possibility of reaching the 'standard' 40 °C level at a particular location and there is economic advantage in relaxing the temperature requirement, the actual maximum and minimum temperatures should be specified.

- h. If a total system load is to be estimated and includes a number of individual switchgear loads, care should be taken to ensure there is only one overall estimate for contingency.

5.2. Types of load

All loads should be presented with clear definition of their types in accordance with the following:

5.2.1. Basic loading information

- a. For each identified electrical load, a description of the service should be given together with an indication of whether the device is a machine (a dynamic load) or a static load.

- 1. Dynamic electric motors driving rotating equipment

This type of load is characterised by power being proportional to frequency rather than voltage. Dynamic loads tend to be constant power regardless of voltage deviation.



2. Static non-moving types of electrical equipment such as lighting, heating, capacitor banks, supplies to rectifiers, etc.

Variable speed drives exhibit properties similar to those of dynamic loads viz. constant power demand despite voltage variations. However, power is also independent of supply frequency deviations and their contribution to system fault level is limited by the power electronic system, in some cases to zero contribution.

- b. The bulk of the loads on the majority of petrochemical installations comprise dynamic loads and the proportions of dynamic to static loads are generally in the ratio of 10:1.

5.2.2. Essential loads

- a. These are loads which are important to the safety of the installation or the operational staff, and which require power to permit a controlled shutdown of process plant and facilities in an emergency. They should have a second independent power source and be generally associated with no break supplies.

In certain cases, a short supply break of say 15 minutes may be acceptable if this does not represent a hazard to safety.

Included in the concept of essential loads would be such devices as emergency shutdown systems, lube oil pumps for gas turbines and large compressors, ventilation systems, helipad lighting, emergency lighting, some floodlighting systems, navigational aids, radio systems etc.

- b. Some loads, which are essential by this definition, may require the provision of emergency power supply facilities in order to meet legislative requirements such as NFPA 70 (guidance is available in IEEE Std 446).

5.2.3. Process sensitive loads

- a. These are loads whose loss would affect continuity of plant operation, resulting in loss of revenue but would not result in an unsafe situation arising.

Included in this category would be general lighting systems and process demands.

It would sometimes be possible to include sufficient capacity in an emergency generator to allow some processes to continue on reduced capacity when main power generators or main utility supply source would not be available. The application of such loads should not compromise any emergency services. Each case would be project specific.

- b. Any decision to provide an alternative source of supply for these types of load should be based on economic assessments.

5.2.4. Non-sensitive loads

- a. Non-sensitive loads are those which do not form an important component of a production or process plant and their disconnection could be borne for relatively long periods with minimal or nuisance value. They usually form a small proportion of the total connected load and may have a single power source.

Typical examples of these loads would be the domestic part of accommodation, offices, workshops, some water injection, some potable water systems, etc.

6. Power utility sources

6.1. General

- a. Power supply arrangements are fundamental to any operating site or facility and should feature in any overall project concept. A power supply philosophy document which details

