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Guidance on Practice for Power System Protection and Control

GP 12-03

BP GROUP
ENGINEERING TECHNICAL PRACTICES

Foreword

This is the first issue of Engineering Technical Practice (ETP) GP 12-03. This Guidance on Practice (GP) is based on parts of heritage documents from the merged BP companies as follows:

BP RPSE

RP 12-4

Electrical Systems and Installations Power System Protection and Control

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1. Scope

This GP provides guidance for design, installation, and operation of power system protection and control.

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 12-01	Guidance on Practice for Power System Design
GP 12-02	Guidance on Practice for Power System Installation and Construction
GP 12-05	Guidance on Practice for Transformers & 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 12-50	Guidance on Practice for Variable Speed Drives
GP 12-80	Guidance on Practice for Power Generators

Institute of Electrical and Electronic Engineers (IEEE)

IEEE C37.2	IEEE Standard Electrical Power System Device Function Numbers and Contact Designations
IEEE C37.90	IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus
IEEE C37.110	Guide for the Application of Current Transformers Used for Protective Relaying Purposes
IEEE C57.13	IEEE Standard Requirements for Instrument Transformers
IEEE Std 242	IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (Buff book)

International Electrotechnical Commission (IEC)

IEC 60034-11	Rotating electrical machines Part 11: Built-in thermal protection Chapter 1: Rules for protection of rotating electrical machines
IEC 60044-1	Instrument transformers – Part 1: Current transformers
IEC 60044-2	Instrument transformers – Part 2: Voltage transformers
IEC 60255	Electrical relays (all parts)

National Fire Protection Association (NFPA)

NFPA 70	National Electrical Code
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National Electrical Manufacturer Association (NEMA)

MG-1	Motors and Generators
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3. General guidance for power system protection and control

3.1. General

- a. Power system protection and control should generally conform to the guidance provided in IEEE Standard publication 242 (Buff book).
- b. Protection should be provided for each piece of utilization equipment.
- c. Protection relays should comply with the relevant parts of IEC 60255 and/or IEEE C37.90.
- d. The protection relay device numbers referred to in this document relate to IEEE C37.2
- e. Power system protection and control installation should be in accordance with GP 12-02.

3.2. Power system protection application philosophy

- a. Power system protection should be applied to the power system by zones and/or equipment types. Each equipment type shall have their own protection devices to determine the existence of faults and to instruct appropriate circuit switches to isolate the fault in the shortest possible time.
- b. The protection system should be designed to consider the following criteria:
 1. Reliability and Security - Protection should perform correctly when required and avoid unnecessary operation.
 2. Speed - Protection should act to disconnect the fault in the shortest possible time.
 3. Selectivity - Protection should have the ability to locate the fault and trip the minimum number of breakers to isolate only the faulty zone or equipment.

Some protection devices are inherently selective as they only operate for faults within a zone. Others operate for faults outside their primary zone and therefore need to be made selective by current, voltage and/or time delay co-ordination.
 4. Economics - Maximum protection should be provided at minimum cost.
 5. Simplicity - Minimum equipment and circuitry should be provided to give the required protection.
- c. Overlapping of protected zones should always be provided to ensure that no part of the power system is ever unprotected.
- d. Protection device directly upstream of a system fault should clear the fault. Additional upstream devices should be properly coordinated and not be affected.
- e. At least one independent means of back-up protection should be provided to cater for failure of the primary protection system.

3.3. Microprocessor-based protection relays

3.3.1. Advantages

Microprocessor-based protection relays should be used on distribution systems if protection, metering, control, and data recording facilities are required. They can offer a range of benefits namely:

1. Reduced maintenance
2. Simplified commissioning
3. Multiple functions in a single case (reduced panel space requirements)
4. High availability (self-monitoring)
5. Options for remote indications/control/protection settings



6. Fault/event/disturbance records for fault analysis
7. Integral breaker fail protection
8. Options for busbar protection at minimal additional cost
9. Breaker operation/maintenance data
10. Dual powered, either from auxiliary supply or CTs
11. Multiple and composite setting capabilities to cover normal/abnormal operating conditions
12. Low CT burden requirement
13. Versatility in application

3.3.2. Guidelines for use

The following guidelines should be considered when applying microprocessor based relays since there is a need to manage the software for these relays to ensure their safe and reliable operation.

There have been several examples if these relays have failed to operate as designed due to deficiencies in their programming. The causes of these deficiencies generally relate to the initial design and subsequent management of the relay software.

Failure to operate as designed could lead to a hazardous situation. Potential hazards include; failing to safely isolate a fault within the rating of the equipment; failing to provide the required level of back up protection; increased equipment damage, a lack of selectivity, increasing the impact of a fault and resulting in increased commercial loss, a risk of ignition in a hazardous area if the safe operation of the equipment relies on the electrical protection.

- a. The basis of the design should be described in a functional design specification that clearly describes the function of the protection scheme, the settings, the alarms and operator interface. This specification should be a controlled document subject to formal approval by a project.

Traditionally a single line diagram and a protection settings schedule have been sufficient to provide this information. For the more complex applications that these relays can fulfil, these may need to be supplemented by a written description of the protection and control scheme.

- b. The design of the protection scheme should be based on an assessment of the risks being controlled by the protection including risks to personnel, equipment, production and environmental consequences of failure.
- c. This functional design specification should address the need for test facilities such as test blocks, and the data communication and programming facilities.
- d. Consideration should be given to segregation of protection and control features; the need to avoid potential common mode failures between primary and back up protection; the need for hard-wired trip facilities; and the handling of watchdog alarms.
- e. The design of the overall system should consider communications with remote locations, the required level of redundancy and any special requirements for fibre optic cables, screened cables, twisted pairs, and interposing relays to avoid noise and pick-up.
- f. The programming of the relay should be carried out by competent persons and subject to review to ensure that it meets the design intent. Good software management should be used with an auditable trail of any changes and clear version control.
- g. The software should be self-documenting with paper and electronic masters and back ups maintained.



There may be benefits in maximising the use of standard programming of relays to aid operation and maintenance and the provision of spares.

- h. The use of front panel, multifunction pushbuttons to programme the relays and programming via individual bits within a binary stream should be avoided if possible due to the increased possibility of error.

3.3.3. Guidelines for commissioning

- a. Detailed factory and site acceptance test procedures should be prepared and approved by a project in advance of testing. These test procedures should exhaustively test all combinations of functions and also provide assurance that functions that are not required have been de-activated.
- b. Those involved in witnessing of the tests and the acceptance of the system should be trained in the use of the relay and its programming prior to the tests.
- c. Prior to commissioning a set of operations and maintenance manuals for the relays and the application should be available on site. These manuals should include a full description of the scheme; logic diagrams; details of settings, and a master copy of the software.
- d. Tests should be by primary current injection with the relays mounted in their panels with the permanent secondary and control wiring.
- e. If it is necessary to temporarily defeat a function to allow the testing to take place, these should be logged and a record kept that the functions have been restored after the test.
- f. The tests should be fully documented and copies of the test results and software recorded.
- g. Information on the fault codes that may arise in the event of a relay or communication failure and the actions to be taken in response to these alarms should be provided.

3.3.4. Guidelines for operation and maintenance

- a. A back-up copy of the software should be kept in a secure location and a log of changes and software versions kept. A recovery plan should be prepared to allow the relays to be replaced and reprogrammed in the event of the failure.
- b. System software provided by the manufacturer should comply with the following:
 - 1. The manufacturer should inform the user if software bugs are detected and provide advice on the need to upgrade the system software.
 - 2. The manufacturer should provide confirmation that the application software will run satisfactorily on a new version of the system software if the relay is upgraded or replaced.
 - 3. The manufacturer should advise if there is a need to re-test the application on the new system software.
- c. Relays which may remain in service for 20-30 years should consider the following:
 - 1. The manufacturer's ability to provide spares and technical support for the life of the relay, given the shortening life cycle of these products.
 - 2. How to ensure that personnel on site are trained in these relays and maintain their level of competence.
- d. The relay manufacturer's recommended routine maintenance and testing of the relays should be obtained and used as the basis for routine testing.
- e. These relays should be function checked by secondary current injection at regular intervals to prove digital inputs, outputs, and measuring circuits.



The potential failure modes of a programmable device are significantly different from an electro-mechanical relay and the routine testing schedule needs to recognise this. The potential for drift and mechanical mal-operation are reduced but several potentially hazardous failure modes remain such as damage to the secondary wiring and the failure of the circuit breaker trip circuit.

4. Current Transformers (CTs) and Voltage Transformers (VTs) for Protection

- a. CTs should comply with IEC 60044-1 or IEEE C57.13, as appropriate.
- b. VTs should comply with IEC 60044-2 or IEEE C57.13, as appropriate.
- c. CTs should have either a 1 Amp or 5 Amp secondary rating as appropriate for the particular protection application.
- d. CTs for phase or earth/ground fault differential protection should be exclusively used for that purpose.

CTs for phase or earth/ground fault differential protection should, have similar characteristics and be in accordance with the relay manufacturer's recommendations. This is necessary to ensure that through faults do not create an imbalance and cause the unit protection to operate (for additional guidance see IEEE C37.110).

- e. If high accuracy metering is required, separate instruments connected to separate CTs should be used.

Microprocessor based multi-function relays often use common CTs for protection and metering purposes. If the metering accuracy provided is not acceptable, separate meters fed from separate CTs should be used.

There is a clear distinction between the requirements of CTs for protection and metering duties. For metering the accuracy within, and a little above, the normal working range is important, but accuracy in the overcurrent and fault ranges of current does not matter. A protective CT must deliver accurate currents in the fault range, whereas accuracy in the working range is unimportant. This gives rise to two different design concepts.

5. Main Incomer (Service Supply Line) Protection

5.1. General

- a. All negotiations with public utilities on protection schemes for main incomers (service supply lines) shall be the sole responsibility of site owners. Many public utilities have standardised protection arrangements that should be taken into account together with these recommendations.
- b. Main incomer protection trips should be by manual reset lockout relays (Device 86), which may already be provided for busbar, or transformer protection as described in section 7 and section 8 respectively.
- c. Special consideration should be given to the responsibility for procurement of all items of equipment in the protection scheme, especially CTs, cabling, glanding, etc. Location of CTs also should be addressed and adequate provision should be made.



5.2. Single public utility supply and no on-site generation**5.2.1. Cable feeder**

- a. If the only power feed to a site is via a single cable feeder from a public utility there should be no other main incomer protection relay requirements than that which may be required for busbar protection. Phase overcurrent and earth/ground fault protection relays (Device 51/50 and 51N/50N or 51G/50G) should be provided by the public utility. If there is unit protection (Device 87F) on the cable feeder this should be supplied and installed by the public utility.
- b. If cable feeders are procured and installed by the public utility, protection devices should be at the sending end and utility substation, and installation and procurement of protection devices should be by the public utility. Duplication of protection devices at the receiving end (service entrance) cannot normally be justified. Public utility overcurrent and earth fault protection settings must consider site operation and co-ordination requirements.

5.2.2. Transformer feeder

- a. If public utility connections to a site are at primary terminations of a transformer, but otherwise as described in clause 5.2.1 the main incomer relay protection requirements should be as specified in section 7 and section 8. transformer primary overcurrent and earth/ground fault protection (Device 51/50 and 51N/50N) should be provided by the public utility and an intertrip scheme as specified in clause 8.8 may be required to be negotiated by site owner with public utility.
- b. Public utility overcurrent and earth/ground fault protection settings should consider site operational, co-ordination and transformer protection requirements.

5.3. Parallel public utility supply and no on-site generation**5.3.1. Cable feeder**

Protection requirements should be as described in clause 5.2.1 with the addition of directional overcurrent and directional earth/ground fault protection (Device 67 and 67N) for each service entrance supply line. If the public utility is supplying and installing unit feeder protection (Device 87F), then directional protection may not be required.

Provision of directional protection, in addition to conventional overcurrent and earth fault protection, allows selective tripping of parallel feeders in the event of a fault on one of the public utility feeders. (Unit feeder protection similarly allows selective tripping).

5.3.2. Transformer feeder

Protection requirements should be as described in clause 5.2.2 with the addition of directional overcurrent protection (Device 67) for each site main incomer for selective tripping.

5.4. Public utility supply in parallel with on-site generation

- a. Consideration needs to be given to the Public Utility's protection requirements for the connection of on-site generating plant embedded within their distribution system. The protection required depends on factors such as: permanent or short-term (test) parallel operation, import or export of power, generator voltage level, generator size, system earthing/grounding, etc.

Fault level and stability studies in accordance with GP 12-01 should help to determine specific protection requirements.



- b. The public utility may require protection to comply with their safety, technical and legal requirements in addition to generator protection specified in section 6. Protection may be required to address the following issues.
 - 1. Synchronising
 - 2. Stability considerations
 - 3. Fault current contribution
 - 4. Islanded operation
- c. The public utility protection requirements could be as follows:
 - 1. Under/over voltage (Device 27/59)
 - 2. Under/over frequency (Device 81)
 - 3. Loss of mains
 - 4. Voltage restrained or controlled overcurrent (Device 51V)
 - 5. Directional overcurrent (Device 67)
 - 6. Earth fault (Device 51N/50N or 51G/50G)
 - 7. Reverse power (Device 32)
 - 8. Neutral voltage displacement (Device 59N)
 - 9. Check synchronising. (Device 25)

6. Generator protection

6.1. General

Consideration needs to be given to the generator service conditions, as a protection scheme for parallel operations (with other generators and/or public utility) will differ from that required for isolated operation.

6.2. Method of neutral earthing/grounding

- a. The recommended neutral earthing/grounding system for generators of both the direct and unit connected type should be in accordance with GP 12-25.
- b. The method of connection of a generator to the electrical power system dictates the type of neutral earthing/grounding and protection requirements. There are two methods of connection:

- 1. Direct Connected

In this case, some of the generated power is distributed to loads at the generator voltage from a direct connected busbar.

- 2. Unit Connected

Here all the generated power is supplied through a transformer this being known as the Unit or Generator Transformer.

6.3. General generator protection philosophy

- a. Generators should be protected against the following internal faults:
 - 1. Stator phase-to-phase.
 - 2. Stator phase-to-earth/ground.
 - 3. Rotor-earth/ground fault.

