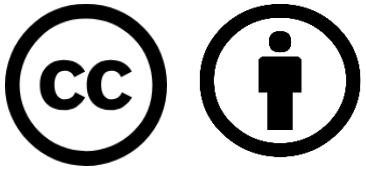
Quality of service analysis

Electric Power Load Analysis (EPLA)

Revision of 8 August 2026

Dr. Norbert Doerry



Essential Questions

What are the different categories of Quality of Service and how do they relate to t1 and t2?	Remember
How does one determine t1 and t2?	Understand
What is a service interruption? What can cause a service interruption?	Understand
How should the MTBSI requirement be established?	Understand
How is Quality of Service Analysis Performed?	Apply

Introduction

- Quality of Service is a reliability metric for the electrical power system
  - Measured at the interface for each load
  - Key metric is the Mean time between service interruption
  - A Service interruption is a service disruption with duration greater than a load can tolerate
- Service interruptions and disruptions are compared to two system metrics
  - T1 = Reconfiguration time – based on choice of circuit protection
  - T2 = Generator start time – based on choice of generator sets

Causes of service disruption (service interruption)

- Fault within user equipment causing voltage to fall below its minimum value before the applicable circuit breaker trips.
- Generator sets tripping off line
- Power distribution equipment failures

Quality of Service categories

- Uninterruptible load
  - Cannot tolerate service disruptions of duration t1
  - Power system designed to minimize service disruptions
  - Usually powered by an uninterruptible power supply (UPS)
- Short-term interrupt load
  - Can tolerate service disruptions of duration t1
  - Cannot tolerate service disruptions of duration t2
  - Power system designed to limit service disruptions to duration t1
- Long-term interrupt load
  - Can tolerate service disruptions of duration t2
  - Power system designed to limit service disruptions to duration t2
- Exempt load
  - Subcategory of long-term interrupt load
  - Need not be restored if surviving generation capacity is insufficient to power all loads

QOS analysis process

- Establish MTBSI requirement
- Determine t1 and t2
- Categorize loads
- Determine reliability of power system equipment
- Estimate load MTBSI

Establish MTBSI requirement

- IEEE Std. 45-3 recommends setting MTBSI between 10,000 hours and 30,000 hours.
- Critical non-redundant loads should generally have a large MTBSI.
- Critical redundant loads may have a smaller MTBSI.
- Non-critical loads may not have an assigned MTBSI.

Determine t1 and t2

- T1 – Reconfiguration Time
  - Should be based on the protective device coordination study
  - Longest time to clear a fault
  - Conventional circuit breakers
    - Typically, between 0.5 s and 2.0 s
  - Solid state circuit breakers
    - Typically, between 1 ms and 100 ms
- T2 – Generator start time
  - Depends on characteristics of the generator sets
  - Usually between 45 seconds and 5 minutes
  - Diesel generator sets usually have t2 on the lower end
  - Twin-spool gas turbine generator sets usually have t2 on the upper end

Categorize loads

- Base on loads tolerance to service disruptions as compared to t1 and t2
- Common guidance:
  - Loads with thermal inertia, such as freezers, refrigerators, HVAC electric heaters, and water heaters should be long term interrupt loads.
  - Non-critical loads should be long-term interrupt loads.
  - Power reserved for electric propulsion operation above a defined minimum speed should be long-term interrupt loads and also designated as exempt load.
  - Power reserved for electric propulsion operation to achieve a defined minimum speed should be designated as a short-term interrupt load
  - Unless required by regulation to be uninterruptible, emergency lighting should be a short-term interrupt load. Other lighting should be long-term interrupt load
  - Most motors (and motor controllers) other than non-critical loads, should be short-term interrupt loads.
  - Computer systems should be studied (and possibly tested) to determine the duration of a service disruption that leads to a service interruption. The QOS category should then be determined by comparing this duration to t1 and t2.

Determine reliability of power system equipment

- Least reliable power system equipment typically …
  - Generator Sets
  - Power electronic converters
- Lack of reliability usually mitigated through
  - Online redundancy
  - Energy storage
  - Load shed strategy
- With mitigation, lack of reliable generation sets and power electronic convers will generally not impact a specific load's MTBSI
  - Only a crude MTBF estimate required.
- Estimating reliability of single-points of failure may be more important for MTBSI calculations (usually very reliable if maintained)
  - Cable
  - Circuit Breakers
  - Load Centers and Power Panels
  - Automatic bus transfers

Estimate load MTBSI

- For each operational condition and ambient condition, identify the loads that would suffer a service interruption upon loss of each power system equipment or component individually. The failure could be due to
  - A loss of power connectivity between the source and the load, or
  - The lack of surviving capacity to serve the load, even after load shedding.
- In determining whether a service interruption occurs due to a loss of a generator set, one assumes that a standby generator set, if available, comes online within time t2; and exempt loads are shed.

Estimate load MTBSI (Continued)

- The failure rate (F_i) for each power system equipment / component i, is given by:

$$F_i = \frac{1}{MTBF_i}$$

- The MTBSI for each load is given by

$$MTBSI = \frac{1}{\sum_{j=1}^{M} \sum_{i=1}^{N} F_i \, p_j \, s_{ij}}$$

Where:

N = number of power system components

M = total number of combinations of operational conditions and ambient conditions

p_j = fraction of time ship operates in each combination of operational conditions and ambient conditions

s_{ij} = 1 if a service interruption occurs due to a failure of component i in the operational condition and ambient condition j; = 0 otherwise. If a load is not operational during the combination of operational condition and ambient condition, then s_{ij} = 0.

- A steady-state simulation or quasi-steady state simulate may be employed to determine s_{ij}
- Calculations assume probability of simultaneous failure of power system components is small
- If loads can fail such that they impact power quality of other loads, and if the rate of such failure can impact MTBSI calculations, then these loads should be considered within the set of power system components.

QOS Mitigation

- Load shedding
- Energy Storage
- Redundant source with automatic bus transfer
- Reliable power system equipment
- Generator set ratings
- Power conversion equipment modularity (N+1 modules)
- Grounding system selection