SECURITY AND RELIABILITY CRITERIA FOR DEMAND CONNECTION PLANNING AND DESIGN

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INTRODUCTION

There has been a considerable increase in electricity demand [1]-[3] in many countries. This requires power system expansion planning [4] to cope with the growing demand considering security and reliability criteria [5], [6] of the system including renewable energy resources [7], [8]. An invited tutorial on electricity transmission system security standard has been presented in [9]. Security and reliability criteria for electricity generation and transmission system planning is presented in [10].

This article describes the main security and reliability criteria for demand connection planning through substations. The objective is to provide the basic information on the technical design specifications and criteria, technical terms and equipment parameters for planning of demand side substations, in addition to the requirements of normal case (N), contingency cases (N-1). Additional criteria, that covering aspects of quality of supply which are often contained in the grid code [11-13], should be considered in conjunction with the security standards [5, 6, 14].

This article is structured as follows. Section 1 presents definitions of technical terms used in this security standards. Section 2 explains system instability measures. Section 3 discusses the maximum short circuit levels of switchgear. Section 4 describes the demand connection design criteria. Section 5 presents substation configurations and design examples. Section 6 describes the equipment thermal loading. Section 7 presents the dynamic criteria. Finally, Section 8 summaries the main recommendations for the technical requirements and criteria for planning and design of demand connections to electricity transmission systems through substations.

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1- DEFINITIONS [14]

FAULT OUTAGE: An outage of one or more items of system equipment, generation units and/or Transmission System Operator (TSO) connection circuits initiated by automatic action, unplanned at that time, which may or may not involve the passage of fault current.

PLANNED OUTAGE: An outage or one or more items of system equipment, generation units and/or substation demand grid connections, initiated by manually instructed action which shall be confined to the maintenance period; and planned at least seven (7) days in advance of the event, or as prescribed by the grid code.

UNPLANNED OUTAGE: An outage of one or more items of system equipment, generation units and/or TSO connections by manually instructed action which has not been subject to the recognised outage planning process of the grid code.

SECURED EVENT: A contingency on the transmission system, or any part thereof, which shall be considered for the purposes of assessing system security and which, should it occur, must not result in the remaining parts of the transmission system being in breach of the Transmission Security Standard (TSS) criteria. Secured events are individually specified throughout the TSS. A secured event may be caused by, but it is not limited to, any of the fault initiation events.

INSUFFICIENT PERFORMANCE MARGINS: For all time periods, and in particular during post-fault periods, there are insufficient performance margins when the voltage on any relevant portion of the transmission system has values within the range of unacceptable voltage conditions and occurs under any one of the following conditions:

*Based on international best practise, a 5% increase in group demand above the level prevailing prior to the occurrence of the relevant secured event; or

* The unavailability of any single reactive compensator or other reactive power provider; or

* The loss of any one automatic switching system or any automatic voltage control system for on-load tap changing.

RESTRICTED PERIOD: Means the period other than the maintenance period, occurring between 00:00 on 1st April and 24:00 on 30th September of any year and is the period during which:

* No planned outage shall occur

*Unplanned outages may only be permitted as prescribed in the grid code

* The summer peak demand will occur

TECHNICAL LIMITS: These represent the values of technical parameters usually specified in type test certificates, which set out the manufacturer specified rating for the relevant equipment, usually classified as:

* Continuous rating

* Short duration, or

* Peak rating

Values may also be adjusted on the basis of environmental conditions such as, but not limited to, ambient temperature and humidity.

UNACCEPTABLE CONDITIONS: Unacceptable conditions either voltage, or frequency, or both

* Unacceptable frequency conditions are conditions where the transmission system frequency does not meet the criteria for either high frequency limits, or low frequency limits.

* Unacceptable voltage conditions occur when the values of voltage fall in the unacceptable conditions range of values.

TRANSMISSION SYSTEM OPERATOR (TSO): Means a grid system operator and may mean either an international connected party or an internal connected party, or both of them, as required by the context. A TSO is capable of importing power from and exporting power to the transmission system.

BACKGROUND CONDITION: For system study purposes, this will include, but not limited to, any parameters that are relevant to the behaviour and dynamics of the licensed transmission system, such as:

* Transmission system configuration

* The electrical location and duration of planned outages and/or unplanned outages

* Voltage levels at demand substations

* Forecast demand at grid supply points

* Transfer capacity between demand groups that may not make use of circuits within the transmission system

* Connected production facilities

* Dispatched generation units

* Available generation units which have not been dispatched

* Energised TSO connection circuits

Specific background conditions required for particular secured events are specified throughout the TSS.

2- SYSTEM INSTABILITY: System instability may occur as a result of poor damping or pole slipping. These are explained as follows:

* Poor damping, where electromechanical oscillations of generation units are such that the resultant peak deviations in machine rotor angle and/or speed at the end of a 20 second period remain in excess of 15% of the peak deviations at the outset (i.e. the time constant of the slowest mode of oscillation exceeds 12 seconds); or

* Pole slipping, where one or more transmission connected synchronous generation units lose synchronism with the remainder of the system to which it is connected.

A- SYSTEM DAMPING: The stability curves describing a transiently-limited time domain system trajectory, will be visually inspected to ensure that the oscillations are damped or at least are as close to 5% damping ratio as is possible. This value, in fact, is internationally adopted to ensure an acceptable operating condition of the system. A stability simulation is deemed to exhibit positive damping if a line defined by the peak of the machine relative rotor angle swing curve will intersect a second line connecting the valley of the curve with an increase in time. Corresponding lines on bus voltage swing curves will also intersect with an increase in time. A simulation, which satisfies these conditions, will be defined as stable. A simulation, which appears to have zero% damping ratio with acceptable voltage, will be defined as marginally stable.

Eigenvalue Analysis:

$$\lambda_{1,2} = -\sigma \pm j\omega_d$$
$$= -\xi\omega_n \pm j\omega_n\sqrt{1-\xi^2}$$

Damping Ratio:

$$\xi = \frac{\sigma}{\sqrt{\sigma^2+\omega_d{}^2}}$$

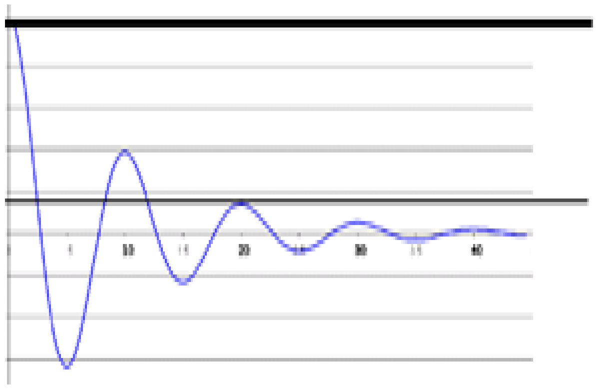

Fig. 1- System response

B- INSTABILITY: For the purpose of assessing the existence of system instability, a fault outage is taken to include a solid three phase to earth fault (or faults) anywhere on the transmission system with an appropriate clearance time. Clearance times used should be consistent with the fault location and appropriate to the actual protection, signalling equipment, trip and interposing relays, and circuit breakers involved in clearing the fault.

C- POLE SLIPPING: When the rotor angle increases from an initial value δ to (δ+2π), the rotor is said to be slipped one pair of poles. Figure 2 shows a simplified structure of a 3-phase synchronous generator with two poles.

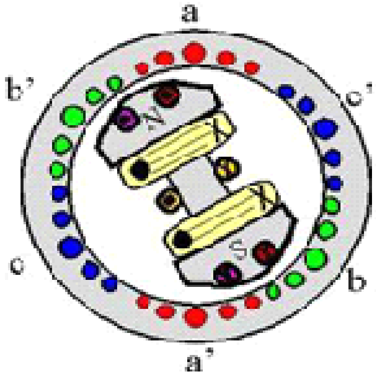

Fig. 2- Two-pole synchronous generator

Figure 3 shows simulation record of a case study resulting in 13 pole-slips of a real 120 MW synchronous generator when it was subjected to a solid 3-phase fault [15].

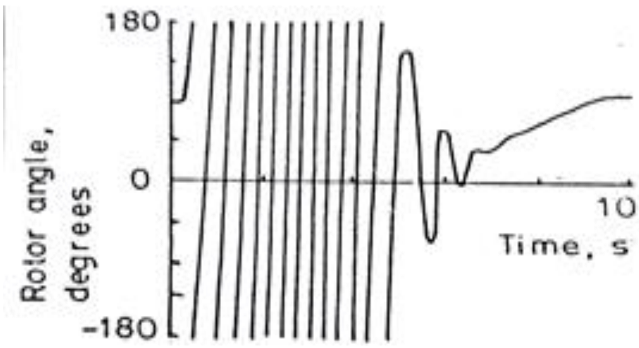

Fig. 3- Pole slipping (13 slips)

3- SHORT CIRCUIT LEVELS: The maximum short circuit levels of equipment should be calculated for three phase and single phase to earth faults based on the following assumptions:

* 1.1 p.u. pre-fault voltage (according to IEC 60909 Standards)

* Calculated figures should not exceed 100% of switchgear rating

*All generating units and transmission elements are in service during peak conditions

Table 4 shows the short circuit levels in kA at various voltages in the Egyptian power system [11], [3]. Figure 4 shows a typical short-circuit current shape.

The power system fault current levels shall not exceed the values listed in the Table 4. The short-circuit fault ratings for equipment shall not be less than these values.

Table 4- Short Circuit Levels [16]

Nominal System Voltage (kV, rms)	Short-Circuit Level	
	Short Time Withstand Current (kA)	Peak Withstand Current (kA)
11	25 (3 sec.)	63
22	25 (3 sec.)	63
66	31.5 (1 sec.)	80
132	31.5 (1 sec.)	80
220	40/50 (1 sec.)	125/100
500	40/50 (1 sec.)	125/100

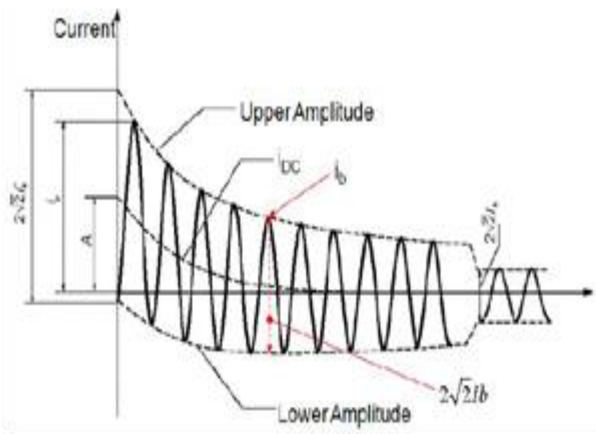

Fig. 4- Short-circuit current

The short circuit levels given above are for a three-phase symmetrical fault. Fault level calculations shall be based on the highest voltages at each system voltage level, as defined before. Applications of fault current limitation techniques in a transmission system are discussed in [17].

4- DEMAND CONNECTION DESIGN CRITERIA: Demand Group is a site or group of sites which collectively take power from the remainder of the transmission system through a substation.

Group Demand means the demand, expressed in MW or MVA, associated with the relevant demand group. Table 2 shows the demand class definitions and the time required for supply restoration [14], [18].

A -BACKGROUND CONDITIONS FOR DEMAND CONNECTION: When there are neither planned outages nor unplanned outages, the group demand shall be set equal the value at the time of peak demand;

When there is a planned outage local to the demand group, the group demand shall be set equal to the relevant maintenance period demand;

Any transfer capacity (i.e. the ability to transfer demand from one demand group to another) declared by distribution licensees shall be represented taking account of any restrictions on the timescales in which the transfer capacity applies. Any transfer capacity declared by the distribution licensees to be available for use in planning timescales must be available for use in such planning timescales. Also, any generation available within a demand group shall be taken into account by considering its forecast generation as provided by the relevant generation unit.

B - DEMAND CLASS AND SUPPLY RESTORATION TIMES: Table 2 shows the demand class definitions and the time required for supply restoration in both normal operation and in maintenance period. The momentary interruption means a loss of power that lasts for no more than one minute from the start of the relevant fault initiation event, with the restoration of power intended to be performed by automatic equipment.

Table 3 shows the intact system design requirements for peak demand values. Table 4 shows the outcomes following a maintenance period fault outage. Table 5 shows the outcomes following an unplanned outage at peak demand values.

C - ADDITIONAL DEMAND CONNECTION REQUIREMENTS: In addition to the requirements mentioned before and for the background conditions described the system shall be planned such that operational switching does not cause unacceptable voltage conditions.

D – INVESTMENT ANALYSIS: Where necessary to satisfy the above demand connection design criteria during the maintenance period, and unless operational measures can be applied to ensure adequate transmission capacity, investment analysis shall be applied.

Table: 2- Demand class definitions and the time required for supply restoration

<table>
<tr><th rowspan="2">Demand Class</th><th colspan="2">Demand class boundaries</th><th colspan="2">Following a system outage during the restricted period</th><th colspan="2">A planned outage followed by a single fault outage during the maintenance period</th></tr>
<tr><th>Low MW ></th><th>High MW ≤</th><th>Required level of served demand (MW)</th><th>Time to restore served demand</th><th>Required level of served demand (MW)</th><th>Time to restore served demand</th></tr>
<tr><td>A</td><td>0</td><td>2</td><td rowspan="5">Total Group Demand</td><td>Repair time of faulted circuit</td><td rowspan="5">Maintenance Period Demand for the Demand Group</td><td>No requirement</td></tr>
<tr><td>B</td><td>2</td><td>6</td><td>3 hours</td><td>No requirement</td></tr>
<tr><td>C</td><td>6</td><td>20</td><td>15 minutes</td><td>Return time of planned outage</td></tr>
<tr><td>D</td><td>20</td><td>115</td><td>Momentary interruption allowed</td><td>Return time of planned outage</td></tr>
<tr><td>E</td><td>115</td><td>300</td><td>Momentary interruption allowed</td><td>Momentary interruption allowed</td></tr>
<tr><td>F</td><td>300</td><td></td><td colspan="4">No loss of supply for the secured events of MITS design criteria</td></tr>
</table>

Table: 3- Intact system design requirements for peak demand

System equipment loading	a) System equipment shall not exceed pre-fault rating levels b) System equipment shall be within the relevant technical limits c) Circuit-breakers shall not be subjected to predicted fault current in excess of their technical limits
System parameters	d) For the licensed transmission system there shall be: e) No unacceptable frequency conditions f) Voltage levels within normal conditions g) No insufficient performance margins
System stability	There shall be no system instability

Table 4- Outcomes following a maintenance period fault outage

During the planned outage of either:	And following a further:	These outcomes shall be met:
A single Transmission Circuit; or A single Generation Unit	Fault outage of a single transmission circuit	a) No loss of supply to grid supply points such that the provisions set out in the demand table are not met b) System equipment shall be within the relevant technical limits c) No unacceptable frequency conditions d) The transmission system voltage levels within normal conditions e) No insufficient performance margins f) No system instability

Table 5- Outcomes following an unplanned outage at peak demand values

After any one of the following:	These outcomes shall be met:
1) An unplanned outage of a single transmission circuit 2) An unplanned outage of a single section of busbar	a) No loss of supply to grid supply points for a demand group of greater than 2 MW b) System equipment shall be within the relevant technical limits c) No unacceptable frequency conditions d) The transmission system voltage levels within normal conditions e) No insufficient performance margins f) No system instability

5 – SUBSTATION CONFIGURATIONS AND DESIGN EXAMPLES:

Figure 6 shows the connection of a typical 132/33 kV two transformer substation. Figure 7 shows a typical 220 kV feeder connection for a large industrial customer requiring a 220kV connection. The customer's assets begin at the cable connection to the 220 kV GIS circuit breaker and isolator section.

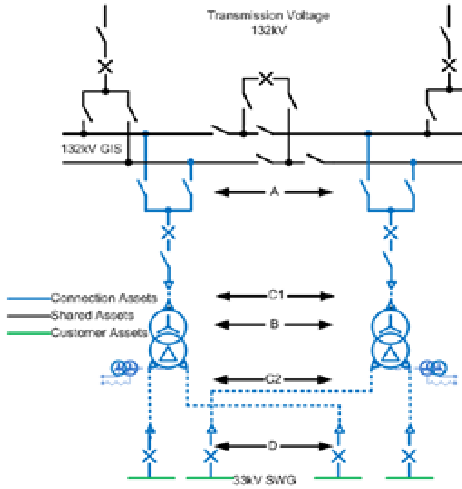

Fig. 6- Two-transformers substation

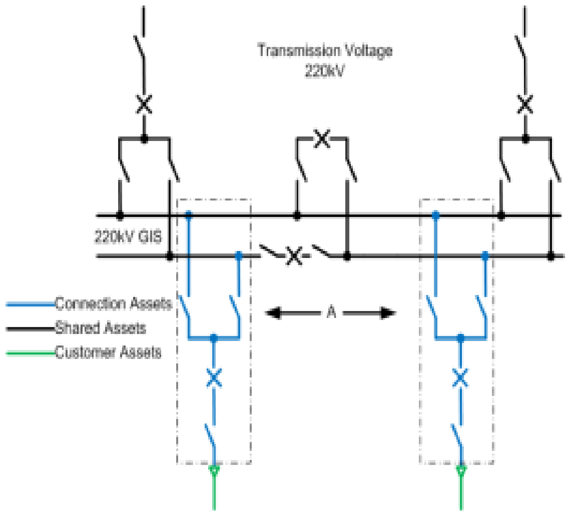

Fig. 7- Typical 220 kV feeder connection for a large industrial customer

6- EQUIPMENT THERMAL LOADING:

Normal operating condition allows a long-term overload of transformers up to 10% of nominal current (or MVA). A temporary (short term) overload (less than 15 minutes) of transformers is allowed up to 20%. In normal operating conditions no overload of the transmission lines is allowed. A temporary overload of the transmission lines generally is allowed up to 20% for 30 minutes. For old lines no overloads are allowed. Calculations of ampacity of overhead transmission lines is described in [19].

7- DYNAMIC CRITERIA: The system will be considered stable if the following conditions are met: generator synchronism, system damping and transient voltage and frequency performance.

A - GENERATOR SYNCHRONISM: All generators in the system have to remain in synchronism as demonstrated by the relative rotor angles. Neither sustained nor increasing oscillations of the rotor angle is generated for any generator of the system. No loss of synchronism among machines should be detected. No sustained voltage oscillations should be detected on any node.

B - SYSTEM DAMPING: The stability curves describing a transiently-limited time domain system trajectory will be visually inspected to ensure that the oscillations are damped or at least are as close to 5% damping ratio as is possible. This value, in fact, is internationally adopted to ensure an acceptable operating condition of the system. A stability simulation is deemed to exhibit positive damping if a line defined by the peak of the machine relative rotor angle swing curve will intersect a second line connecting the valley of the curve with an increase in time. Corresponding lines on bus voltage swing curves will also intersect with an increase in time. A simulation, which satisfies these conditions, will be defined as stable. A simulation, which appears to have zero% damping ratio with acceptable voltage, will be defined as marginally stable.; however, in practice this oscillatory behavior is unacceptable.

C – TRANSIENT VOLTAGE & FREQUENCY PERFORMANCE: Minimum transient frequency and duration, maximum transient voltage dips and duration, and post transient voltage deviations should be considered for each of the simulated scenarios. These parameters will be measured at load buses. The minimum frequency and the transient voltage dip should be investigated for each case in order to evaluate the needs for eventually emergency actions.

8 - RECOMMENDATIONS

* The article has presented and explained basic information on the technical design specifications, criteria, technical terms and equipment parameters required to connect demands (loads) to electrical networks through substations.

* Successful demand connections should satisfy the requirements of demand supply security standard and the related parts in grid code / distribution code.

* Academic researchers should take into consideration the requirements of utility security standards and grid / distribution codes in performing research works.

* Electrical engineers in the field of designing, specifying, installing, testing, commissioning and operation of substations need to clearly

acquire details and technical background of the demand connection security standard and grid code / distribution code.

* It is worth acquiring information on key performance indicators of electricity transmission systems available in [20].

* The references listed at the end of this article provide more detailed information on the transmission security standards, grid codes and electricity distribution codes.

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