PPL EU REQUIREMENTS FOR TRANSMISSION CONNECTED FACILITIES TO BE OWNED AND OPERATED BY PPL EU

Attachment 2
Bulk Electric System and Non- Bulk Electric System Facilities

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1	9/1/17	GJ	NJM	**SUBSTATION ENGINEERING INSTRUCTION** **PPL ELECTRIC UTILITIES CORPORATION**
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Record of All Issued Revisions

Revision	Page(s)	Section(s)	Description	Issue Date
0	All	All	Initial Issue	9/19/2014
1	All	All	Minor grammatical fixes	9/1/2017
2	8, 10 and 11	3.4.1, 3.4.5, 3.5.2	Revised 230kV Switchyard minimum design and substation layout requirements. Also revised preferred order of station service supplies.	10/30/2018
3	9	3.4.4, 3.5.2	Revised 500kV Switchyard minimum design.	3/1/2019
4	8 and 11	3.4.1 and 3.5.2	Revised minimum requirements for 230 kV switchyards.	3/8/2019

Distribution:
1. RC 0880 – T&S Standards
2. RC 0883 – Substation Engineering
3. RC 0601 – T&S Asset Management
4. RC 0878 – T&S System Engineering

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1. Overview

The Bulk Electric System (BES) includes 500 kV, 230 kV, and 138 kV lines, 500 kV,230 kV and 138 kV switchyards, 500 kV-230 kV substations, 500-138 kV Substations, 230-138 kV Substations, and 500 kV, 230 kV and 138 kV interconnections to generating facilities. The non-Bulk Electric System (non-BES) includes facilities include 69 kV lines, 69 kV switchyards, 230-69 kV and 138-69 kV substations, and 69 kV interconnections to generating facilities. The BES and non-BES transmission system shall be planned and developed to meet the criteria designated herein. These criteria are based on the North American Electric Reliability Corporation Reliability Standards. The Planning Principles and Practices described herein are compatible with the PPL EU Reliability Principles and Practices as well as the Reliability Planning Criteria of the PJM Interconnection.

2. Planning Principles

The BES and non-BES shall be planned to be operated at all load levels and during normal scheduled outages to withstand specific unscheduled contingencies without: exceeding equipment capability; causing instability or cascade tripping; or exceeding voltage tolerances.

The BES and non-BES facilities shall have adequate capability so that the system can withstand the following unscheduled contingencies:

- The outage of any single generating unit, transmission line, transformer, bus or one pole of bipolar DC line or the opening of a circuit breaker. Following the disturbance, no facility loading shall exceed the applicable emergency rating and the system shall be capable of readjustment to restore equipment loadings to within applicable normal ratings.

- After the outage and readjustment specified above, the subsequent outage of any remaining generator or line shall not cause loadings on remaining facilities to exceed applicable emergency ratings. After this subsequent outage, the system must be capable of readjustment to restore loadings to within applicable emergency ratings for the expected duration of the outage.

- The loss of any double circuit line, or the combination of a line fault and stuck breaker, or a fault with an overtrip and a successful reclosing of the overtripped terminal. Tripping of a unit or automatic runback will be considered acceptable to prevent facility loadings in excess of applicable emergency ratings. In addition, manual runback of generation is acceptable to restore facility loadings to within applicable emergency ratings for the expected duration of the outage.

Reactive Supply sources shall be provided on the BES to maintain acceptable normal and post-contingency voltage levels.

- Adequate reactive reserve will be installed to maintain scheduled bulk power transmission voltages at regulated buses for the loss of the largest reactive supply to the study area.

Stability of the system shall be maintained without significant loss of generation for the following types of faults occurring at the most critical location at any load level:

- A permanent three phase fault cleared by normal primary relay action, including reclosing.
- A permanent single phase to ground fault and the failure of a protective device to operate properly causing a stuck circuit breaker, delayed clearing, or events having a similar probability of occurrence.
- A permanent three-phase fault cleared by Zone 2 relay action, including reclosing.

Certain tests of abnormal contingencies will be conducted to measure the ability of the system to withstand disturbances beyond those that can reasonably be expected. The following list of abnormal contingencies shall be evaluated.

- Sudden loss of the entire generating capability at a station.
- Simultaneous loss of two critical transmission lines with no system readjustment between outages.
- Sudden loss of all lines emanating from a single switching station.
- Simultaneous loss of all lines on a given right of way.
- Occurrence of a three phase fault with delayed clearing.

In testing the system for these types of contingencies, only one contingency shall be considered to occur at a time. The decision regarding the action to be taken, if any, will be based on the following fundamental considerations:

- Consequences of the disturbance.
- Probability of the disturbance.
- Cost of significantly changing the consequences or the probability.

PPL EU projects identified to reinforce the BES and non-BES system for the aforementioned contingencies must be coordinated with the PJM Regional Transmission Expansion Plan (RTEP). In general, these projects will include installation of new facilities and reinforcement of existing facilities.

3. Practices

3.1. General

The practices are used to develop the necessary facilities to achieve the principles described in the previous section. The practices are based on PPL and industry wide experience with failures of facilities and equipment in the past and the expectation that performance of facilities and equipment in the future will be at least as good as it was in the past.

Experience indicates that the following practices for the PPL EU BES are reasonable and acceptable.

3.2. Planning Procedures

System load-flow studies are performed to determine the steady-state operational response of the electric power system. Planners are assigned the responsibility to determine the best overall reinforcement considering long term and economic impacts to system deficiencies identifiedfrom the system load flow study. A model of the electric power system, including any previously proposed upgrades, shall be used to determine whether a proposed reinforcement resolves the system deficiency or introduces additional thermal and/or voltage violations.

3.2.1. Short Range Plans

Short range plans are those to be implemented within the next 2 years. Studies for this time frame are more likely to involve the solution of possible operating problems. These problems are caused by delays in facilities going in service, complex interrelationships of various projects, permanent equipment failures, and facility outages to accommodate construction, etc.

3.2.2. Medium Range Plans

Because of the lead times required to construct and install new facilities, studies forthe early portion of this period may be similar to those of the short range period but typically study out to 5 years from the current year. PJM/PPL planning studies shall determine detailed plans and associated costs for an orderly, economic development of the BES and non-BES to meet load growth. The plans shall consider, as much as possible, the effects of longer range plans of PPL and neighboring transmission zones and, according to planning principles, shall specify:

- Initial and ultimate development of BES and non-BES switchyards and substations.
- Equipment capability and operating characteristics to provide for the safe and stable operation of the system.

- Voltage levels to be maintained on the BES and non-BES systems.
- Reactive requirements to maintain satisfactory voltage levels during normal and emergency conditions.
- Requirements for future line rights of way, transmission facilities, substations, and switchyard sites.

3.2.3. Long Range Plans

Long range plans, which typically study out to 15 years from the present year, shall be directed towards defining the general pattern of development for the PPL EU Transmission System in the following areas:

- Trend of future voltage design levels, both AC and DC system expansion.
- Need and timing for conversion of existing lower voltage facilities to 500 kV, 230kV or 138kV operation.
- Development of the BES system to accommodate both load growth and generation changes.
- Right of way requirements for transmission lines, switchyards, and substation sites considering possible joint use of right of way corridors by two or more utilities.

3.3. Transmission Line Standards and Ratings

All new 500 kV lines shall be equipped with triple bundle 1590 ACSR conductor or equivalent as determined by PPL EU Transmission Engineering Department.

230 kV lines are typically constructed with 1590 kcmil ACSR conductor or equivalent and operated at a design temperature of 125°C.

138 kV lines are typically constructed with 556.5 kcmil ACSR conductor or equivalent and operated at a design temperature of 125°C.

In general, new 500 kV lines shall be designed for ultimate single-circuit construction. Double circuit 500 kV line design will be considered on a case by case basis with input from appropriate departments and concurrence with PJM. New 230 kV and 138 kV lines shall be designed for ultimate double circuit construction. Ultimate double-circuit capability maximizes the future use of the right-of-way.

Ratings for existing circuits are reviewed and revised periodically, considering conductor, relay settings and terminal equipment limitations.

All new or modernized 230 kV and 500 kV line construction shall be adaptable to "hot line" maintenance methods. Exceptions may be made where prohibited by physical limitations, such as narrow right of way. In addition, new and modernized line construction is assumed to meet the more stringent requirements for hurricane winds or the usual sleet formation loads for the territory traversed.

3.4. Switchyard Functional Development

In planning the PJM/PPL bulk power system to meet reliability commitments under the NERC transmission planning standards (TPL-001 through TPL-004), various switchyard arrangements must be evaluated to determine: (1) the initial arrangement of new 230 kV and 500 kV switchyards, (2) the step-by-step development of new 230 kV or 500 kV switchyards, and (3) the step-by-step expansion of existing 230 kV and 500 kV switchyards.

Consideration must be given to the following factors when evaluating switchyard arrangements:

- Proposed arrangements must take into account the number of lines to be terminated at the switchyard, the relative importance of the switchyard as part of the BES, and the possible physical limitations that prohibit further expansion.
- Flexibility for breaker maintenance and maximum use of transmission lines. Provisions should be made to perform breaker maintenance without removing critical lines from service.
- Consequences of line faults during breaker maintenance. Breaker switching configuration to permit breaker maintenance without removing a line from service.
- Consequences of delayed clearing of a line fault.

3.4.1. New 230kV Switchyards

All new 230 kV switchyards shall, at a minimum, be fully built out 2 bay double bus double breaker layout with provisions to tap the bus for future transformation. If future build out is expected or due to reliability studies it is determined that local reinforcement is required, a breaker and a half design or a double bus double breaker layout with spacing for breaker and a half design may be required as part of the initial interconnection review.

If double bus double breaker (ultimate breaker and a half) arrangement is initially required, provisions for conversion of a double bus switchyard to a breaker and a half arrangement will generally be provided.

3.4.2. Existing 230kV Single Bus Switchyards

Existing single bus 230 kV switchyards cannot readily be expanded to the breaker and a half arrangement due to the limited space available at these locations. These and will be considered on a case by case basis.

3.4.3. Existing 230kV Double Bus Switchyard

Existing double bus switchyards that cannot readily be expanded to breaker and a half arrangement pose additional engineering challenges. Should new transmission lines be proposed at existing double bus switchyards, connection through single breakers on one of the buses may be possible if sufficient space is available.

Existing double bus switchyards should have at least two bus tie bays when these bays also terminate a line. This will prevent splitting the bus for a line fault. If the minimum consequences of a line fault with a stuck breaker cannot be tolerated, a single breaker terminal must be converted to a double breaker, at additional cost, resulting in three or more bus tie bays.

3.4.4. 500kV Switchyard Development

All new 500kV switchyards shall, at a minimum, be fully built out 2 bay double bus double breaker layout with provisions to tap the bus for future transformation. If future build out is expected or due to reliability studies it is determined that local reinforcement is required, a breaker and a half design or a double bus double breaker layout with spacing for breaker and a half design maybe required as part of the initial interconnection review.

If double bus double breaker (ultimate breaker and a half) arrangement is initially required, provisions for conversion of a double bus switchyard to a breaker and a half arrangement will generallybe provided.

3.4.5. Station Service

The preferred method of station service supplies in order are: power transformer tertiary (if 3 or more power transformers are installed), bus-connected power voltage transformers, external three-phase 12 kV source, external single-phase 12 kV source with phase converter.

At stations where three or more forced cooled transformers are installed, three permanent AC station service supplies shall be installed utilizing a cascading design with two automatic transfer switches.

3.5. 500kV and 230kV Switchyard Standards

3.5.1. Existing Switchyards

At existing switchyards, facility ratings, short circuit capabilities, breaker interrupting times, etc., used in planning studies shall be those determined by Planning & Engineering for theparticular equipment installed in each station.

3.5.2. New Switchyards

All new switchyards shall be assumed to have the following design characteristics for planning purposes:

- At new locations the bus, circuit breakers and associated facilities shall bedesigned for a maximum short circuit duty of 40,000 Amps at 500 kV switchyards, and 50,000 Amps at 230 kV switchyards.
- All new 500 kV circuit breaker installations shall have two cycle interrupting times.
- Existing circuit breakers with longer interrupting times shall be replaced with two cycle circuit breakers if system stability conditions require faster fault clearing times than are possible with existing breakers at a given location.
- Supervisory control shall be provided with equipment adequate for future expansion as follows:

From the Transmission Control Center to 500 kV switchyards and substations to open, close and indicate position of each 500 kV circuit breaker, motor operated disconnect and FILBAB. Provide station alarms and tap changing and tap position indication on 500-230 kV transformers.

From the Regional T&D Operations Office to 230 kV switchyards and substations to open, close and indicate position of each 230 kV circuit breaker and motor operated disconnect switch and to provide station alarms and TCUL tap position indication on regional supply transformers (500-138 kV, 230-138 kV, 230-69 kV, etc.).

Telemetering of the following information with equipment adequate for future expansion shall be provided.

At all 500 kV Switchyards and 500-230 kV Substations
to the Transmission Control Center

- 500 kV line and bus 3 phase voltages
- 500 kV lines - MW and MVAR
- 500 kV lines - 3 phase amperes
- 500-230 kV Transformers - MW, MVAR, 3 phase amperes

At all 230 kV Switchyards to the Regional T&D Operations Office

- 230 kV bus 3 phase voltage
- 230 kV lines - MW and MVAR
- 230 kV lines - 3 phase amperes

- Relays and protective equipment shall be provided at all 500 kV and 230 kV switchyards in accordance with PJM standards. The design standards listed in the above document, relaying and protective equipment shall be installed at all 500 kV switchyards to detect impending failure of live tank circuit breakers.

- A 500 kV fully built out 2 bay double bus double breaker layout shall be installed at 500 kV switchyards with provisions to tap the bus for future transformation (as a minimum). Two double bus double breaker bays (ultimate breaker and a half design) or more than 2 bays may be required to be installed at 500 kV switchyards.

- A 230 kV fully built out 2 bay double bus double breaker layout shall be installed at 230kV switchyards with provisions to tap the bus for future transformation (as a minimum). Two double bus double breaker bays (ultimate breaker and a half design) or more than 2 bays may be required to be installed at 230 kV switchyards.

- All new 500 and 230 kV breakers shall have motor-operated disconnects installed on both sides of the breaker. Breaker failure schemes with automatic isolation of the failed breaker and automatic restoration shall be installed where a breaker failure could interrupt two or more elements.

- Underfrequency relaying shall be installed throughout the system toprovide automatic load shedding to facilitate matching load and generation in the unlikely event of a system separation.

- These relays shall be installed at a sufficient number of appropriate locations on the distribution system to permit not less than thirty (30) percent of the Company's peak load to be interrupted automatically in three levels of ten (10) percent each.

3.6. Voltage Control

Voltage schedules for PJM/PPL bulk power buses are coordinated with the bulk power bus voltage schedules of the other PJM transmission zones. The guidelines used to establish bulk power voltage levels are:

- Voltage gradients throughout the PJM system should be minimized. Unusually large voltage gradients generally reflect an improperly balanced system condition.

- During heavy load periods, transmission system voltages should be maintained as high as feasible taking into account equipment limitations.

- Voltage deviations are generally indicators of the adequacy of reactive support available in the area. Voltage deviations at 230-69 kV and 230-138 kV substations with primarily regional supply responsibilities are usually well defined and non-cascading. Generally voltages as low as 90% of nominal can be tolerated without mis-operation of PPL protective equipment or customer equipment.

- Voltage deviations at major 500 kV and 230 kV switchyards with bulk power transfer responsibilities can impact large areas with undefined bounds. PJM has a voltage deviation threshold of 5% for buses that remain networked post-contingency, and 7.5% for buses that become radially connected post-contingency. Voltage deviations beyond these values will significantly increase exposure to widespread voltage collapse.

3.7. Reactive Supply

Certain non-PPL bulk power policies affect the location and amount of PPL bulk power reactive supply. Prior to determining the bulk power reactive requirements the following are assumed:

- Approximately unity power factor will be achieved on the high voltage side of 138-12 kV and 69-12 kV transformers.
- The normal reactive requirements of each region will be supplied locally within that region. This is usually accomplished by balancing the VAR flow within the regional 500-138 kV, 230-138 kV and 230-69 kV transformers.
- Transmission voltage levels will continue to be coordinated among PJM member companies to prevent large inadvertent VAR interchange.

With these assumptions the following procedure determines compliance to the reactive supply requirement:

Reactive Power resources to ensure that adequate reactive resources are available to meet system performance. Bus voltages will be scheduled such that transformer tap changers operating slightly below the midpoint of their range during heavy load periods.

3.8. Synchronous Stability

Stability of the multi-generator bulk power system must be given consideration to the following listed below; is evaluated for each major generation addition. Stability studies may be performed for conditions other than generation additions as deemed necessary. The results of the stability studies are used to determine:

- the effectiveness of alternative transmission plans,
- the operating restrictions of a transmission configuration,
- the required normal primary and backup clearing times,
- the protective relay functional requirements, and
- any additional equipment or precautions that are necessary to ensure that the system meets the bulk power system planning principles.

3.8.1. Tests

The following stability tests shall normally be made in the course of the particular study:

- A permanent three phase fault cleared by normal primary relay action, including reclosing, if applicable.
- A permanent single phase to ground fault and the failure of a protective device to operate properly causing a stuck circuit breaker, delayed clearing, or events having asimilar probability of occurrence.
- A permanent three-phase fault cleared by Zone 2 relay action, including reclosing, if applicable. Zone 2 tests are not required for lines with dual pilot protection.