KEMA RESPONSES TO APPLICANT'S INTERROGATORIES
November 12

STATE OF CONNECTICUT
CONNECTICUT SITING COUNCIL

NORTHEAST UTILITIES SERVICE COMPANY APPLICATION TO THE CONNECTICUT SITING COUNCIL FOR A CERTIFICATE OF ENVIRONMENTAL COMPATIBILITY AND PUBLIC NEED ("CERTIFICATE") FOR THE CONSTRUCTION OF A NEW 345-KV ELECTRIC TRANSMISSION LINE FACILITY AND ASSOCIATED FACILITIES BETWEEN SCOVILL ROCK SWITCHING STATION IN MIDDLETOWN AND NORWALK SUBSTATION IN NORWALK, INCLUDING THE RECONSTRUCTION OF PORTIONS OF EXISTING 115-KV AND 345-KV ELECTRIC TRANSMISSION LINES, THE CONSTRUCTION OF BESECK SWITCHING STATION IN WALLINGFORD, EAST DEVON SUBSTATION IN MILFORD, AND SINGER SUBSTATION IN BRIDGEPORT, MODIFICATIONS AT SCOVILL ROCK SWITCHING STATION AND NORWALK SUBSTATION, AND THE RECONFIGURATION OF CERTAIN INTERCONNECTIONS	**DOCKET NO. 272** **November 12, 2004**

RESPONSE TO FIRST SET OF INTERROGATORIES
OF THE CONNECTICUT LIGHT AND POWER COMPANY AND
THE UNITED ILLUMINATING COMPANY DIRECTED TO KEMA

"KEMA Report" refers to the report prepared by KEMA, Inc. entitled "Harmonic Impedance Study for Southwest Connecticut Phase II Alternatives," dated October 18, 2004.

INTERROGATORIES

1. Please confirm that KEMA did not study any line-out contingencies. If any study or analysis of line-out contingencies was performed, please provide all results, inputs and work papers.

   A: KEMA has studied line-contingencies in assessing the thermal and voltage performance of various system configurations. We expect that the Connecticut Siting Council will make these results available in the near future. However, line-out contingencies were not evaluated in KEMA's harmonic impedance study, due to its limited scope.

2. Does KEMA agree that it is a widely accepted practice and normal planning criterion to consider contingency conditions in addition to line outages in planning a transmission system?

   A: Yes.

3. *With respect to KEMA's modeling of system loads for the frequency-domain analysis:*

   (a) Please provide all assumptions made regarding the percentage of system load composed of motors, and state how the motor loads were represented;

   A: The System loading was modeled as constant active and reactive power loads, using values in the loadflow base case provided by the Applicant in response to the Data Request of Towns (DR Towns-05--Q-Towns-059). Motor load dynamics were not modeled separately.

   (b) State whether the series inductances between the transmission voltage level and the utilization equipment, provided by substation transformers, distribution feeders, distribution transformers and service cables, are represented in the model, and if not, state whether the damping provided by KEMA's load representation would be greater in the model than would be expected in actual operation.

   A: System loads in the loadflow base case provided by the applicant through the Data Response of Towns (DR Towns-05--Q-Towns-059) were connected to the corresponding busses in the 368-bus system provided by the Applicant in an August 2, 2004's email attachment as "phase1gevers2.olr" in ASPEN OneLiner program format. Transformers and lines/cable models in the supplied 368-bus system model remained unchanged.

4. Please describe the impact of the application of several third-harmonic type-C filters in a system that is resonant near the second harmonic. How would the filters perform if line outages occur?

   A: The effects of line outages on harmonic impedances were not studied, as discussed above. It is however important to note that a third-harmonic C-Type filter does not amplify harmonic voltages, but filters harmonic currents at the third harmonic and damps the parallel resonances above the tuned 3rd harmonic. The system impedance between the busbar on which the filter is connected (e.g. 115 kV substation), and another busbar (e.g. 345 kV substation) will affect the filtering characteristics seen from the distant busbar (345 kV). As seen from the results on page 65 of the report, the combined filtering characteristics of all the filters are shifted from the 3rd harmonic to around 2.6.

5. Assume that the harmonics concern in Southwest Connecticut relates to high magnitude harmonics, injected by severely saturated power transformers following system faults and transformer energization, resulting in severe temporary overvoltages. Is KEMA aware of any applications of type-C filters specifically for the mitigation of high-magnitude low-order harmonics due to transformer saturation?

   A: The effects of system faults and the associated impacts of the saturated transformers on the system were not studied in this report. In previous work by KEMA in this area, the C-Type filters were not specifically designed to compensate the inrush currents from energizing transformers. From the characteristics of the C-Type filter it is however clear that the filters can be designed to filter partly the negative impacts from the energizing transformers. The filter should however be designed in detail in terms of rating and tuned frequency to handle these low-order harmonic transformer inrush currents.

6. Please state whether KEMA has evaluated the equipment ratings to which type-C filters would need to be constructed, in order to be sufficiently robust to mitigate temporary overvoltages under high magnitude harmonic conditions. If so, please provide:

   A: The limited scope of KEMA's study did not permit the development of a detailed design for this filter configuration. For harmonic performance comparison purposes the larger existing capacitor locations were used as basis to assign the C-Type filters. It is not assumed that these are the optimal locations for these filters. The component ratings, filter locations, protection and tuned frequency should be specified in a detailed design study, evaluating the load-flow, voltage profile and harmonic performance of the system as a whole. It should be noted that the filter configuration, operation, system and over-voltage protection are not much different from regular mechanical switched capacitor banks and very similar design practices can be followed.

   (a) The equipment ratings that would be necessary or desirable to mitigate temporary overvoltages such as those following a fault when many power transformers in the system will simultaneously experience magnetic inrush;

A: It was not in the scope of this study to provide a detailed design for this filter configuration. The C-Type filters can however be used to filter the low order harmonic currents associated with the inrush currents from the saturated transformers, but the filter designs would have to be evaluated in a separate design study.

(b) Any other equipment rating evaluations that KEMA has done for type-C filters for this Project.

A: In the limited scope of this study, no detailed design for the filter configuration was done. When designing these filters a detailed specification has to be developed among others including measurements of harmonic current sources, compatibility levels, maximum harmonic voltage amplification levels, steady-state frequency variations, etc., that will determine the ratings of the individual filter components.

7. Please confirm that KEMA did not evaluate the system condition where (a) no capacitors are needed for reactive power support of the system, (b) the minimum generation dispatch (as utilized in the GE studies), and (c) there is a critical line outage If this evaluation was done, please provide all results, inputs and work papers.

A: The effects of critical line outages and their associated impacts on the system harmonic performance were not studied, as discussed earlier. The situation with minimum generator dispatch and all capacitors off did not provide a solved load flow condition in the harmonic study, and no results were generated for this case.

8. Section 2.2.2 (p.14) of the KEMA Report states, "During core saturation, the magnetizing current with large 3rd harmonic levels will rise to a value easily exceeding twice its normal peak." Please clarify whether this is intended to mean that the 3rd harmonic level will exceed twice the normal magnetizing current magnitude, or will exceed twice the rated current magnitude.

A: The exact magnitudes of 2nd or 3rd harmonic components of the magnetizing current during transformer energization, depend on the system configuration, specific transformer transient saturation parameters and point on wave switching timing. The magnetizing current during energization of the transformers, can vary between 2 and 20 times the rated full load current. See references in the answer to question 9 below.

9. *In Section 5 (p. 31), KEMA states that transformer inrush is a short-duration event persisting for 0.1 to 0.3 seconds. Please provide any references, simulations or calculations substantiating that inrush phenomena in EHV systems does not persist longer than 0.3 seconds.*

A: The specific magnitude and duration of the inrush magnetizing current during transformer energization, depend on the system configuration, specific transformer transient saturation parameters and point on wave switching timing. This high level of magnetizing current may persist typically between 0.1 to 0.3 seconds. In EHV systems with highly efficient transformers, the inrush currents may persist for longer *than 0.3 seconds. For further reading on the inrush current issue, consult the following references:*

1. *J. Arrillaga, D.A. Bradley and P.S. Bodger, Power system harmonics, John Wiley & Sons, Norwich, 1985*
2. *L.L. Grigsby (Ed): "Electric Power Engineering Handbook", CRC Press, 2001.*
3. *J.H. Harlow (Ed.): "Electric Power Transformer Engineering", CRC Press, 2004.*

10. KEMA states in Section 2.2.2 (p.14) that harmonics produced by transformer magnetic inrush are "normally well damped and no high overvoltage transient will result." Please state the bases for this conclusion.

A: The details of overvoltages resulting from transformer energization depend on the system configuration, resonance points, specific transformer transient saturation parameters, pre-energization flux levels and point on wave switching timing. In this study the first resonance points were in the 3rd harmonic range for some of substations, but they are very well damped. With increased system strength (from Phase II compared to Phase I), and this increased damping on the system, less severe overvoltages associated with the transformer energization are expected. These conclusions should however be tested with detailed transient calculations, taking the specific transformer saturation, magnetizing models and preferably also transformer inrush current measurements, into account. The transformer inrush problem is one phenomenon that must be dealt with in all power system designs, and it is seldom found to be a non-fixable concern. Natural system damping normally limits the overvoltages in power systems associated with transformer switching. Some ongoing research, development and commercialization of controlled transformer switching algorithms in switchgear, to minimize the inrush currents may be studied and evaluated for this project. Some of these algorithms include switching by delayed pole closing, and simultaneous and rapid closing.

11. Section 2.2.1 of the KEMA Report (p. 13) states, ". . . phase controlled converters form the largest single source of distortion in power systems." Please provide citations to any references that substantiate this statement.

A: The specific distortion source depends on the region studied. It is however well-known that phase-controlled converters are responsible for most of the characteristic 5th , 7th , 11th , 13th etc., current harmonics, and associated voltage distortion at these harmonics. At high voltage and extra high voltage systems, 3rd harmonic current sources may also be present in appreciable magnitude. See references:

1. J. Arrillaga, D.A. Bradley and P.S. Bodger, Power system harmonics, John Wiley & Sons, Norwich, 1985.
2. IEEE Std 519-1992: "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems".

12. KEMA suggests that the preferable means to avoid excessive stimulation of harmonic resonances by transformer magnetic inrush is to retune the system prior to energization, such as by switching capacitor banks in or out. (See section 5 of KEMA Report, p. 3 1)

(a) Is it reasonable to assume that the system operator will be able to anticipate all system faults, and pre-emptively switch capacitors prior to the fault to avoid post-fault transformer inrush stimulation of harmonic resonant conditions?

No, it is not assumed that the system operator will be able to anticipate all system faults. It can however be assumed that the operator could switch off relevant capacitor banks and cables before re-energizing large transformers.

The protection of large mechanically controlled capacitor banks can also be sensitized for abnormal voltage conditions and faults on the system, so that they switch off automatically during these events. This will help to minimize the risks of overvoltage due to low-order resonances.

(b) How would the system operator prevent thermal overloads and/or voltage collapse if other system events were to occur while this equipment was switched out of service?

A: Contingency, transient and voltage stability analyses have to be done in order to determine the best operating procedures under such conditions.

(c) Was any analysis done to demonstrate that the system will be secure with capacitors and cables removed from service in preparation for manually energizing a transformer?

A: No transformer energization, transient or voltage stability analyses were performed within the scope of this study.

13. *Does KEMA agree that transient simulations of fault performance of the Southwest Connecticut transmission system must be performed with the proposed type-C filters in order to determine whether the proposed type-C filters provide a satisfactory mitigation of the harmonic resonance problem shown to result in severe temporary overvoltages following faults?*

A: Yes, as indicated in the report, switching transient calculations have to be done on the chosen configuration to minimize and mitigate possible overvoltages during fault conditions.

14. What are the additional physical space requirements for converting existing shunt capacitor banks to type-C filters, as suggested by KEMA in section 5.2 (p.34) of its report?

A: The final size of the C-Type filter will depend on the detailed design of the filter and selected manufacturer. From other C-Type filter installations it can be indicated that the C-Type filter design may require a 50 – 100% larger footprint when compared with standard, mechanically switched, capacitor banks of the same rating. Some of the C-Type filter components (resistor and reactor) are rated at lower voltages and can thus be stacked vertically if footprint size is limited.

15. Section 7.3.2.2 of the KEMA Report (pp. 47-48) indicates that "light" generation dispatch (more generation units on line than in the minimum dispatch situation), without a line outage, results in a first resonance near the fourth harmonic. Could a significant line outage contingency, combined with a minimum generation dispatch condition, reduce the resonance below the third harmonic?

   A: No line outages have been studied in this report. Therefore, KEMA is unable to comment on the frequency range and damping associated with line outage conditions.

16. A type-C filter, such as suggested by KEMA, has a series-connected inductor and capacitor (L, C2) in parallel with the damping resistor (RI). The combination of L and C2 are tuned to the fundamental frequency (60 Hz) to minimize losses and thermal duty applied to the damping resistor Rl.

   (a) If the system frequency deviates, such as during a major system disturbance, would the damping resistor be exposed to severe and rapid overheating?

   A: This component, as is the case with any equipment designed for a power system, will be designed for a frequency range designated by the utility during the specification phase. The design and quality factor of this filter will be optimized during the detailed design phase.

   (b) Would the protective tripping of the filter be the normal action in the event of a filter component overload?

   A: The protection protocol, as is the case with any equipment designed for a power system, will be designed for a specific overload scenario based on the specification.

   (c) Would the tripping of all the type-C filters in Connecticut during a major system disturbance be necessary to protect the filters from excessive duty caused by frequency variation? If your response is "no", state the basis for this conclusion.

   A: During a disturbance the large frequency variation is of a short duration and would not normally require the filters to be tripped. The protection protocol, as is the case with any equipment designed for a power system, will be designed for a specific overload scenario based on the specification or requirement of the application. The main overload concern would be the power rating of the damping resistor for the maximum frequency range and disturbance time. Normal steady-state frequency variations have to be specified for the design and may have an influence on the rating of the resistor bank.

   (d) If your response to (c) is "yes", please describe the impact of the tripping of all the type-C filters in Connecticut on system security.

   A: See above discussion in (c).

17. If the East Devon - Beseck line is out for maintenance and there is a fault on the Plumtree - Long Mountain line, are the filters at Southington and Frost Bridge effective in mitigating temporary overvoltages on the 345-kV cables? If so, please provide your supporting analysis.

    A: These impacts have to be evaluated in a contingency analysis.

18. Does KEMA believe that a frequency scan alone is sufficient to judge whether a particular configuration is technically feasible?

    A: Frequency scans may provide a reasonable feasibility screening technique. However, system configurations that pass this screening test must also provide acceptable transient performance. If observed transient performance problems cannot be mitigated for a given system configuration, then that configuration could not be judged to be "technically feasible."

19. The KEMA Report (p. 11) states, "The STATCOMs are also sized to replace the shunt reactors required for voltage regulation on the capacitor terminations, as applicable from a loadflow point of view." What shunt reactors are referenced in this statement?

    A: The referenced shunt reactors are the VAr compensating shunt reactors placed at the end of each cable circuit.

20. When the 345-kV variable shunt reactors were included in KEMA's analysis, what setting was assumed, i.e. how many MVARs was each shunt reactor absorbing?

    A: All shunt reactors are fixed in size. No variable shunt reactors were used in KEMA's analysis.

21. *The KEMA Report (p. 14) states, "These second order (2nd) and third (3rd) order harmonic currents results in some harmonic voltages associated with the system impedance at these harmonic numbers, but they are normally well damped and no high overvoltage transient will result."*

    (a) Is this statement supported by any electromagnetic transients analysis?

    A: No

    (b) If not, what is the basis for this statement?

    A: From the harmonic analysis it is clear that the damping of the system at these frequencies are good and much better when compared, under similar conditions, with the Phase I results. It can be expected that if the transient calculations for Phase I provided adequate damping for the system overvoltages, that Phase II with extended undergrounding will provide even better overvoltage performance. It is however important that this be confirmed with transient calculations.

22. The KEMA Report (p. 25) states that the Plumtree to Norwalk - Phase 1 line has 20.5 miles of overhead lines. Please provide the source for the 20.5 mile number.

A: The relevant sentence on page 25 should read "Phase I: 20.5 miles of mixed overhead/cable circuit, including one 9.7 mile cable section with two 2500 kcmil HPFF cable circuits, and two short cable sections using 1750 kcmil XLPE cables."

The 20.5 mile value was calculated from the data shown in "Figure 3-1. Phase 1 Configuration X' 345 kV" excerpted from a GE October 2003 report "Connecticut Cable Transient and Harmonic Design Study for Phase 1" that was included in the July 9, 2004 Data Response provided by the Applicant to KEMA.

23. The parameters described on p. 25 of the KEMA Report include, for the section between Devon and Beseck, "three parallel sections of 1750 kcmil XLPE cables of varying lengths up to 40 miles."

(a) Does KEMA consider 1750 kcmil to be acceptable? If so, what is the basis for the acceptability of 1750 kcmil?

A: Yes. KEMA based this on data provided in the July 9, 2004 and August 6, 2004 Data Responses from the Applicant. Three 1750 kcmil XLPE cable circuits, assuming no more than two circuits in one duct bank, would provide a minimum total rating of 1944 MVA. This is based on the cable current rating of 1084 A provided in the July 9, 2004 Data Response. The 1944 MVA rating is close to the 2038 MVA described in the "Kema-Phase2-Impedance.xls" file of August 6, 2004 Data Response, that a 2-1590 ACSR overhead line would provide. The 1084 A cable current rating provided to KEMA was based on two cable circuits in one duct bank. The rating would be higher if only one cable circuit were placed in each duct.

(b) Are these cables assumed to be in a common duct bank?

A: No. No more than two circuits, preferably one circuit, are assumed to be in each duct bank.

(c) What were the assumed ratings of three 1750 kcmil cables in a common duct bank?

A: Refer to answer (b).

24. The KEMA Report (pp. 58, 60) states, "Also with the filters in and out of service, no large changes in the resonance frequency should be expected." What is the basis for the expectation that with filters out of service, there is no large change in the resonance frequency compared to when the filters are in service? Please quantify "large changes."

A: This is one of the main advantages of using the C-Type filter design. The C-Type filter does not alter the harmonic frequency characteristics of the system. It just *provides added damping at the different resonance frequencies, without amplification of the harmonic voltages at the point of connection.*

25. KEMA has stated that the proposed filters are tuned to the 3rd harmonic. Please state whether the graphs on page 65 of the Report support this proposition.

    A: All the filters, replacing the capacitors on the 115 kV busses, were tuned at the 3rd harmonic. The system impedance between the 115 kV connection points and the measurement point influence the filtering characteristic as seen from the specific 345 kV busbar. As seen in page 65 the series resonance filter characteristic has moved from the 3rd to around the 2.6 harmonic.

Submitted by:

KEMA Inc. T&D Consulting,
3801 Lake Boone Trail, Suite 200
Raleigh, NC 27607