EFFECTIVENESS OF LOAD-SHIFTING RESOURCES FOR RELIEF OF CABLE-CONSTRAINED TRANSMISSION LIMITATIONS

Reigh Walling
Walling Energy Systems Consulting, LLC
April 2, 2016 (Revised April 5, 2016)

BACKGROUND

Load demand has a pattern of diurnal variation that results in an inefficient utilization of some resources, and load-shifting resources are a means to achieve a more level load. The load-shifting resources are particularly valuable for addressing generation constraints and transmission constraints where the limitation of transmission capacity is due to the loading limits of overhead lines. Transmission capacity limits, particularly in an urban environment, are constrained by the maximum allowable temperatures of the lines and equipment. The temperatures of the equipment do not follow the load level instantaneously, but rather lag behind according to the equipment's thermal time constant.

Unlike overhead transmission lines, for which the thermal time constant is typically less than 20 minutes, the thermal time constants of underground transmission cables are typically in the range of 30 to 100 hours.[1] The long time constants have a very substantial smoothing, or filtering, effect that makes the peak temperature more dependent on the overall energy delivered each day, rather than the peak of the load demand. Figure 1 shows the daily load cycle, during peak season conditions, for the Buell plus East Hampton load of the LIPA system. Also shown in this figure are the relative temperatures of an overhead line with a typical 20-minute time constant, and an underground cable having a typical 48-hour time constant.

As a result of the thermal filtering effect of cable thermal time constants, the effectiveness of load-shifting resources to resolve cable transmission capacity constraints are severely reduced because they do not limit the total energy consumed as their primary objective. Battery storage resources actually increase the total energy because they absorb more energy to recharge than they deliver during discharge. Demand response can reduce energy requirements, or it may only displace the demand.

Because the South Fork of Long Island is constrained by transmission cable capacity, more specifically the peak temperatures of cables, the evaluation of proposed resource solutions should specifically consider the relative effectiveness of load-shifting resources compared to energy supply resources.

---

[1] E. Bascom, V. Antoniello, "Underground Power Cable Considerations: Alternatives to Overhead", 47th Minnesota Power Systems Conference, November, 2011.

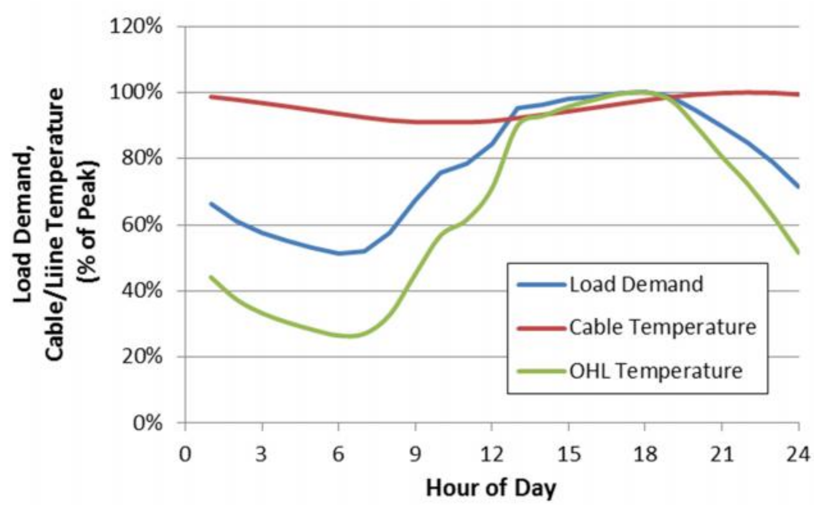

Figure 1 – Buell + East Hampton load curve and associated cable temperature.

ANALYSIS RESULTS

Using the load curve shown in Figure 1, the effectiveness of load shifting has been analyzed by use of numerical thermal modeling. Load shifting was modeled as a constant reduction of load between the hours of 1 pm and 8 pm, and an equal increase of load between the hours of 1 am and 8 am.[2] Losses were not considered; the load shifting was modeled to be energy-neutral.

Figure 2 shows the results for a 10% load increase combined with a load shift of 10%, assuming a cable thermal time constant of 48 hours. While the load shift keeps the load peak from exceeding the peak of the reference load curve (load curve without growth), the peak cable temperature is increased. Clearly, the load shift does not provide one-for-one effectiveness in resolving the constraint.

The amount of load increase allowable for a given amount of peak load reduction has been determined for cable time constants of 24 and 48 hours. The allowable load increase is that which causes the maximum cable or line temperature to be equal to the peak temperature without the load growth. In addition, as a reference, the allowable increase is also determined for the 20-minute time constant of an overhead line. The results of this analysis are summarized in Figure 3. If the cable has a 48-hour time constant, the load shifting resource is only 23% as effective as a generation resource. This means that if load demand increases 3%, the magnitude of the load shift needed to maintain constant peak cable temperature would need to be 13% of the peak demand. For a 24-hour time constant the effectiveness is 32%. The actual thermal time constants of the cables constraining the South Fork of the LIPA system should be determined and used in the evaluation of resources.

[2] The 2 pm to 9 pm peak reduction period in the RFP was not used for the analysis because the unmitigated 1 pm load becomes the peak for only a small amount of load displacement. The 1 pm to 8 pm period provides a more effective limitation of peak load.

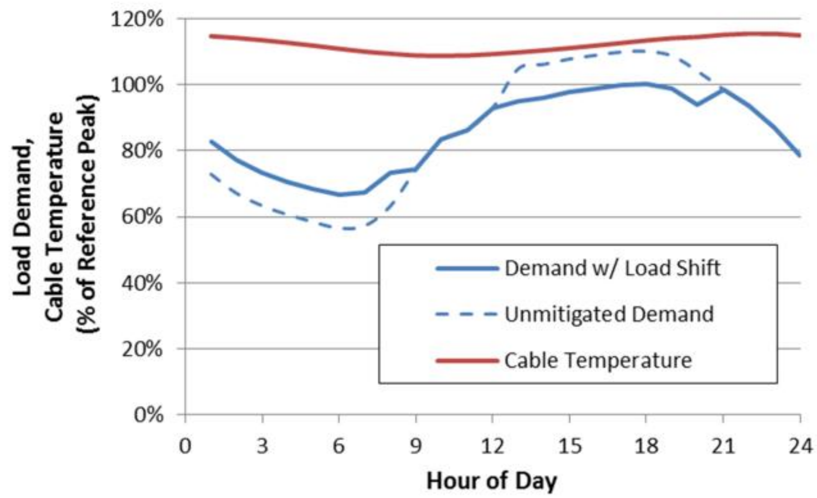

Figure 2 – 10% load growth with 10% load shifting.

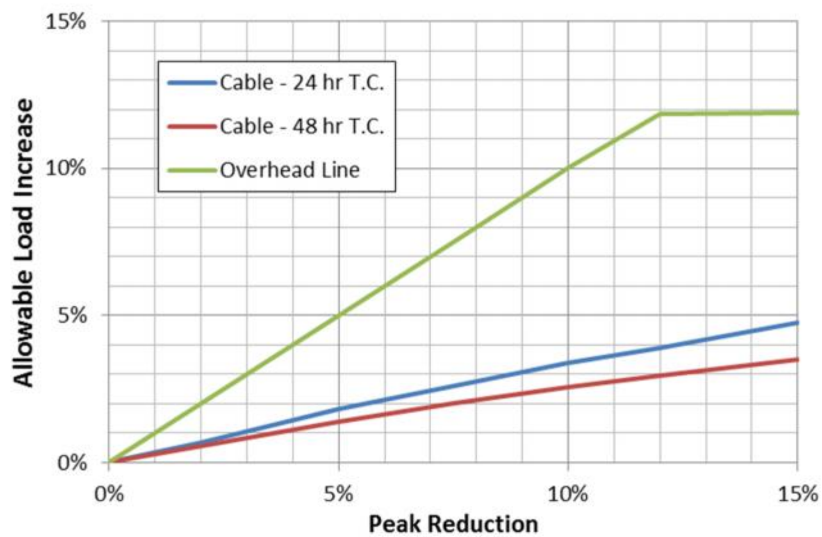

Figure 3 – Allowable load growth versus peak reduction (percent on the base of the peak load without growth) for cables with 24 and 48 hour time constants and a typical overhead line.

As a comparison, the allowable load increase is also shown for the case where overhead lines are the transmission limitation. Here, load shifting is nearly 100% effective until the load growth causes demand in the hours outside of the target demand reduction hours to exceed the line thermal capability.

Analysis was also made of a scenario where net load is limited to a certain value and demand shifted to the preceding such that the demand is increased to the value of the cap for as many hours necessary to deliver the same energy. The results were nearly identical.

Demand Limitation

The previous analysis considered energy-neutral shifting of load from the afternoon to early morning hours. Some forms of demand response act to limit demand during high-load hours without the demand being displaced to other hour, resulting in a decrease of energy delivered. Analysis was also performed to evaluate the effectiveness of this type of demand modification on underground cable loading constraints. In this analysis, the reference demand curve is scaled up, and a cap applied to the demand. The magnitude of this cap was adjusted such that the peak cable temperature is the same as the peak temperature of the reference loading condition. With the load curve scaled up, the load cap must necessarily be less than the peak of the reference load curve. The magnitude of demand reduction is thus the difference between the peak of the scaled-up load curve and the loading cap. Figure 4 illustrates this demand modification for a 10% increase in load demand. In this case, the demand is capped at 90.2% of the reference peak in order to hold the maximum cable temperature (48 hour thermal time constant assumed) to the reference peak cable temperature. Thus the magnitude of demand reduction is 19.8% in order to accommodate a 10% increase in load demand. The effectiveness of demand capping is compared with load time shifting in Figure 5. The effectiveness of load shifting levels off when the load demand is essentially made flat. Peak curtailment has equal effectiveness for lower levels of load growth, but is more effective as the load cap digs more deeply into the demand of the off-peak hours.

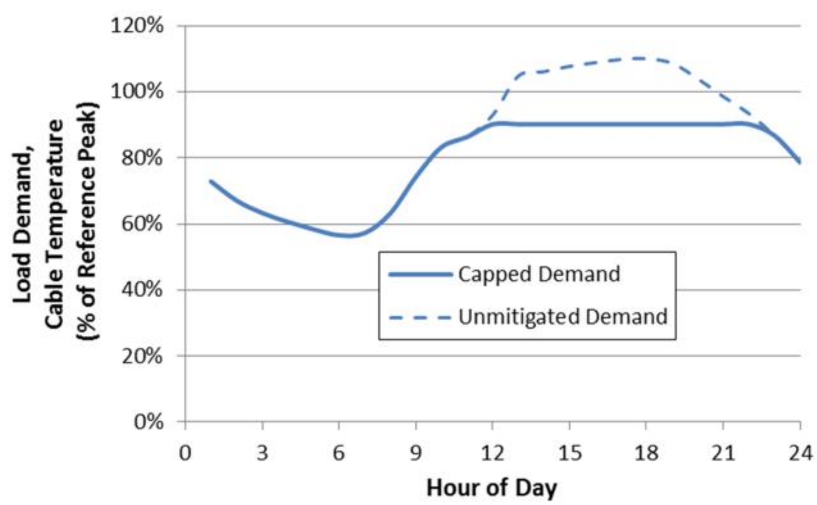

Figure 4 – Demand limitation to accommodate a 10% load curve growth.

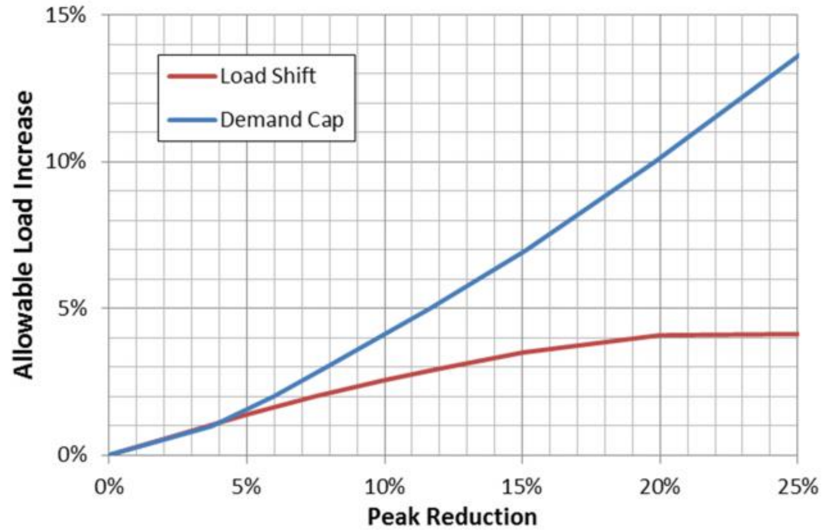

Figure 5 – Comparison of load shifting and demand limitation (capping) to accommodate a 10% load curve growth. Assumed cable thermal time constant is 48 hours.

Conclusion

Load shifting, while highly effective in addressing generation capacity and overhead transmission capacity constraints, is substantially less effective when underground cables constrain transmission capacity. Demand reduction that simply caps the peak demand does not provide a one-for-one increase in load serving capability when cables with long thermal time constants constrain the system. Evaluation of the South Fork resource proposal needs to consider this.