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Value of the Distributed Energy Resources to Distribution Grid

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SUMMARY

This paper describes the theoretical and practical development of an analytical tool for evaluating the Value of Distributed Energy Resources (DER) to the Distribution Grid as a function of time and location; that is, hours of the year and nodal location on a distribution circuit. The work is unique in that it can value both DER's real and reactive power contributions to the distribution grid on a temporal and locational basis. The framework developed incorporates familiar concepts of Locational Marginal Pricing applied to distribution circuits in the form of Distribution Locational Marginal Pricing (DLMP), but extends them to incorporate a locational Marginal Cost of Capacity (MCC) and a Locational Marginal Value (LMV) of DER.

KEYWORDS

Value of Distributed Energy Resources, Locational Value, Temporal Value, Locational Marginal Pricing, Locational Marginal Cost of Capacity, Locational Marginal Value, Non-wire Alternative.

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1. BACKGROUND

As the penetration of DER increases in response to the growing understanding of the various value streams that it provides, there are efforts to recognize the value that this technology can also provide to the grid. The state of New York has the Reforming the Energy Vision or NY REV [1] which has required regulated utilities to propose tariff based compensation to DER for the value they provide to the grid in terms of avoided cost. California has an active working group [2] looking at the value of DER. In Illinois, the Future Energy Jobs Act legislation has a goal of recognizing the Value of DER to the Grid « at the location at which it is interconnected, taking into account the geographic, time-based, and performance-based benefits.» [3]

This paper develops a methodology that would aim to meet the policy goals of fairly compensating the contributions that DER provides to the grid so as to support a sustainable market.

2. VALUE OF DER TO THE GRID PRINCIPLES

The first principle in determining the Value of DER to the distribution grid in terms of avoided costs is that all DER value is *locational.* This is because upgrades to the grid are planned based on issues that emerge at specific locations. A projected overload on a particular circuit would not be mitigated by an upgrade to the adjacent circuit.

Even within a given circuit, the ability of DER to avoid capacity or voltage costs by providing real or reactive power depends very much upon the DER's nodal location relative to the grid constraint to be addressed. For instance, if a new warehouse is planned in the last half mile of a two-mile long circuit such that the first mile of the circuit would then be overloaded, DER in the first mile would only help resolve the loading issue in the first mile, but it would have no effect whatsoever on the loading issue in the second mile. For radial distribution circuits (as in most distribution systems except for urban underground networks) DER must be downstream of the location of a loading issue to help mitigate the problem.

Similarly, voltage problems on circuits are typically local in nature. Low voltage at the end of the circuit does not imply low voltage near or at the station. Indeed, attempting to cure the low voltage at one location by raising overall circuit voltages may cause too high a voltage in another location. Traditional mitigations to voltage issues are to deploy local apparatus that affects voltage locally, such as capacitors or voltage regulators. Controlling flicker is more difficult as capacitors and voltage regulators are not designed for rapid or frequent operation, so static VAR compensators or local DER capable of varying real and reactive quickly are required ; or alternatively, the circuit must be (expensively) re-engineered to decrease its impedance and thus the sensitivity of circuit voltages to changing DER output.

The second principle relates to how the effectiveness of a DER in relieving circuit violation(s). If we examine the hypothetical case where the first mile of a circuit needs to be reinforced and the argument that DER only affects loadings on the upstream portions of the circuit, then this introduces the concept of how to place a locational value on the DER. If the DER midway on the overloaded portion of the circuit deferred the need to upgrade capacity on the first half of the circuit, conceivably it could at maximum avoid half of the cost. The DER located at the downstream end of the affected portion of the circuit could, by contrast, avoid all the cost. So, conceptually, the second DER offers twice as much Value to the Grid as the first DER. This concept can be generalized. For any DER, its locational value is affected by the sensitivity of the circuit condition requiring capacity or voltage investments to the real and reactive power from that DER.

The third principle of time is important because circuit capacity and voltage problems typically do not happen to the same extent across every hour of the year, and in fact may only occur for a limited number of hours a year. The DER technology must be able to provide real and reactive power when they are needed as well as where they are needed. Therefore, there are three elements to valuing DER: First is the avoided cost of required circuit upgrades and how that cost is apportioned among affected parts of the circuit; and second is how effective real and reactive power input from the DER is at a given location of reducing or avoiding that cost. Third is how different DER technologies align with the temporal value of DER and how much of the generic DER value a given technology can realize.

This paper describes a framework for establishing the Value of DER to the grid that addresses these questions. The framework is grounded in engineering and economics, draws on parallels from the wholesale concepts of locational marginal pricing adapted for valuing infrastructure investment, and establishes two new economic concepts that are key parts of the framework. One is the Marginal Cost of Capacity (MCC) which is the methodology for allocating the capital and other costs of traditional wires upgrades to locations on a distribution system across the hours of the year. The other is the « Locational Marginal Value » (LMV) of DER which establishes its value of an increment of generic DER to the grid at each location at each hour.

3. DESIRED FEATURES OF A DER VALUE TO THE GRID METHODOLOGY

The methodology proposed for determining the DER Value to the grid should be efficient, accurate, and fair. Efficiency denotes maximizing the flexibility of the system and further deferring large investments to accommodate for changes in load. As for accuracy, DER should be compensated for services they provide to the distribution grid by addressing different characteristics/capabilities of different DER technologies, as well as, addressing differences in the locational and temporal value of DER. An equitable and fair methodology limits impact to non-participating customers and avoids under and over-compensation. It further should avoid double counting when some sources of DER value are compensated elsewhere, and supports the penetration of DER that can provide value.

The case for full AC analysis

A simple connectivity analysis (using a « transport » model) could be developed to assess the DER valuation for avoiding ampere capacity upgrades, if losses and other factors were ignored. Depending upon the DER location, it may produce additional capacity relief by reducing losses and thus reducing demand upon upstream conductors and station transformers. Behind-the-meter DER connected on the secondary would also relieve secondary transformer losses.

Additionally, circuit power factors vary widely by time of day and location. Typical circuit power factors might be in the range of 95%. If DER reactive power withdrawal and injection can be used to obtain near-unity power factor on a dynamic basis, then an additional 4%-5% of amp capacity can be freed up to deliver power. Finally, managing circuit voltage levels is also important and a source of capacity upgrades. Some, such as adding capacitor banks, are fairly inexpensive, but if high voltages due to high DER penetration or high flicker levels are the issue, mitigation can be more expensive. DER with smart inverters can possibly offer a lower cost approach. So the DER valuation needs to consider controlled reactive power injection and withdrawal.

It would be possible to develop approximations to each of these three issues; average loss factors and average power factor improvements can be assumed, and a cost of traditional reactive power management can be used as a local proxy for DER valuation. But the three issues interact, and voltage/power factor issues are very locational. A framework rooted in full AC analysis that reflects the interaction of the multiple effects is ultimately a better approach.

4. NUMERICAL EXAMPLES

Example calculations are presented below using variations on the IEEE 33-bus network to illustrate the methodology. It should be noted that the assumed costs are hypothetical and illustrative, the calculated LMV-P and LMV-Q are not intended to represent real world distribution capacity deferral cases.

First, we look at a simple case where thermal overloads are projected to exist on branches 1-5 in future, as shown in Figure 1**Error! Reference source not found.**.

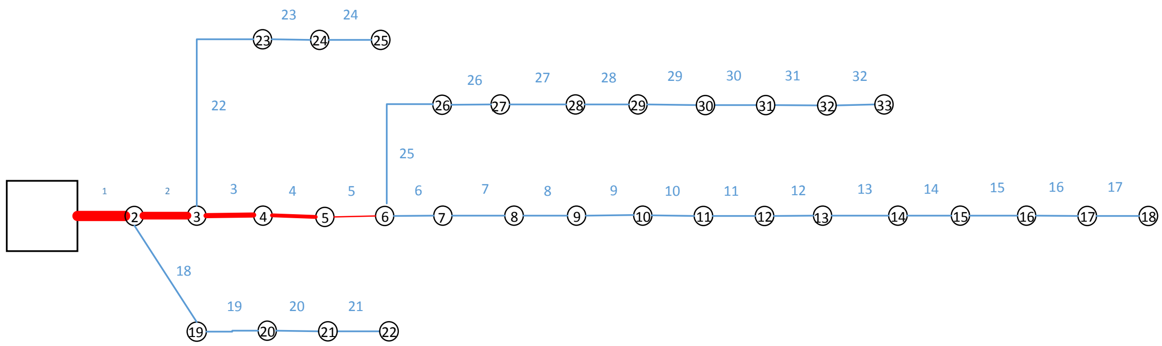

Figure 1 IEEE 33-Bus Circuit with Overloaded Sections

For this hypothetical case, we set the MCC to be $12,000 annually to represent the annualized cost of upgrades. The resulting LMV-P and LMV-Q for DER are as shown in Figure 2**Error! Reference source not found.** for a peak hour. We see that the LMV-P and LMV-Q increase as we move down the circuit such that DER at the nodes will affect more and more overloaded branches. Once all the nodes are downstream of the overloads, the LMV increase very slightly and only due to losses. Lower LMVs in nodes 19-25 are due to limited contribution of these nodes to relieving congestion in upstream branches 1 or 2.

LMV-Q shows the value of reactive injections at each node. This is important in relieving thermal overloads as improving the power factor to unity at each branch decreases the current required to deliver load. Depending upon the circuit conditions, initial power factors may be 90-95% and constantly correcting this can add significant capacity to the circuit.

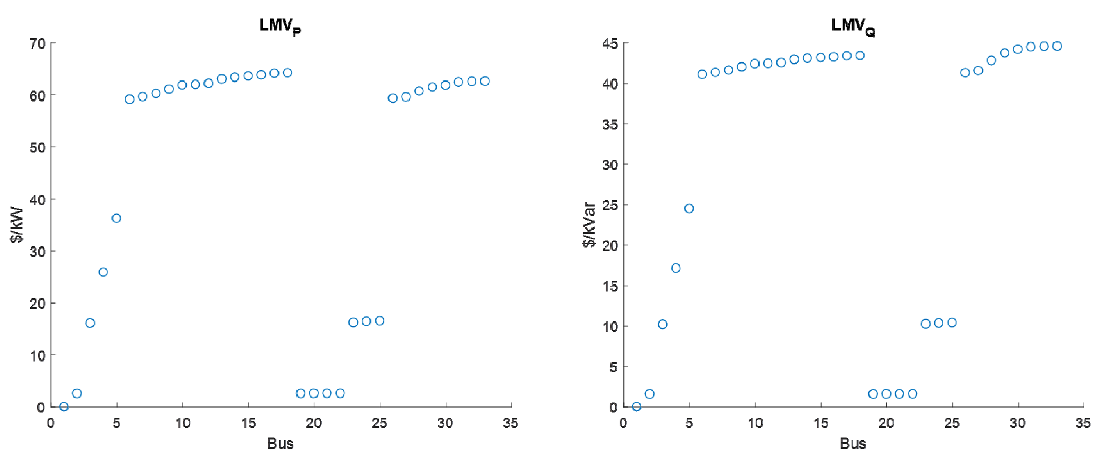

Figure 2 Overload Only, LMV-P and LMV-Q

Second, we look at another simple example where nodes near the end of a branch (nodes 16-18) of the circuit experience undervoltage at peak, in Figure 3**Error! Reference source not found.**. For this hypothetical case, we set the MCC to be $600 annually to represent the annualized cost of upgrades to fix voltage violations. Nodal LMV-P and LMV-Q are shown in Figure 4**Error! Reference source not found.**. Here, the LMV-P is a result of decreasing current along the branch thus decreasing impedance related voltage drop. The LMV-Q is a result of this effect as well as the voltage support provided by reactive injection. LMV in nodes 19-25 are much lower since injections at these nodes has little effect on the voltages at nodes 16-18.

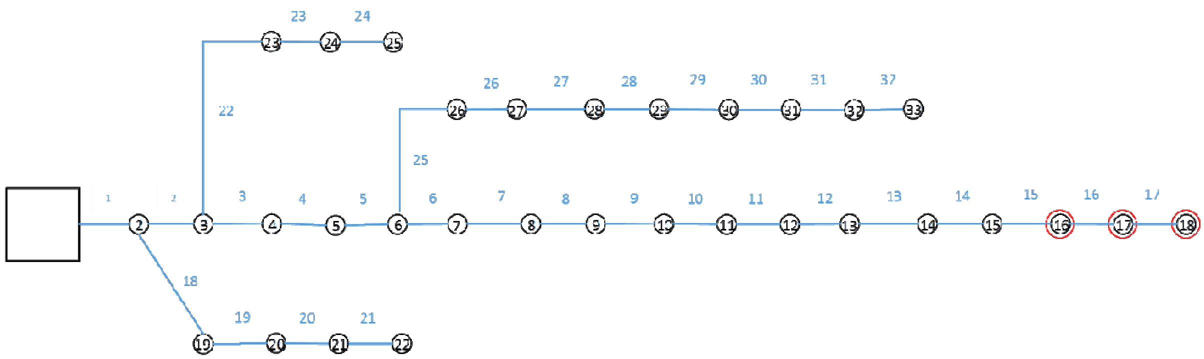

Figure 3 IEEE 33-Bus Circuit with Undervoltage Nodes

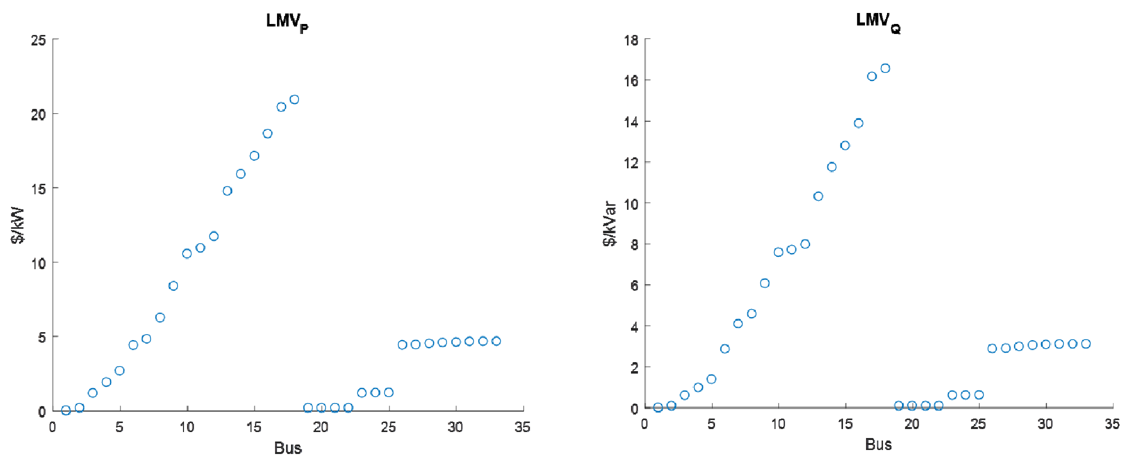

Figure 4 Undervoltage Only; LMV-P and LMV-Q

A more complex example is shown in Figure 5**Error! Reference source not found.**, where thermal overloads and nodal undervoltages exist. It is assumed that separate projects as described above are planned to fix both thermal and voltage violations. In this case, the LMV-P and LMV-Q reflect the value of DER real and reactive powers in correcting both of these issues. This is shown in Figure 6**Error! Reference source not found.**. It should be noted that similar trends in LMVs are observed as in the overload case only. This is because in this case, the cost of overload mitigation is much higher than the cost of fixing voltage and primary driver is thermal overload. LMVs in nodes 2-19 are slightly higher than the overload only case due to undervoltage violation.

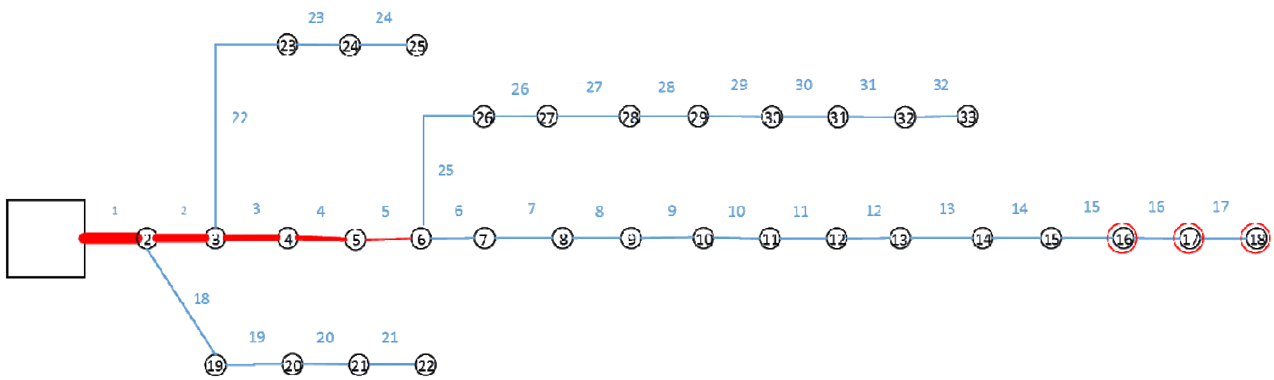

Figure 5 IEEE 33-Bus Circuit with Overloaded Sections and Undervoltage Nodes

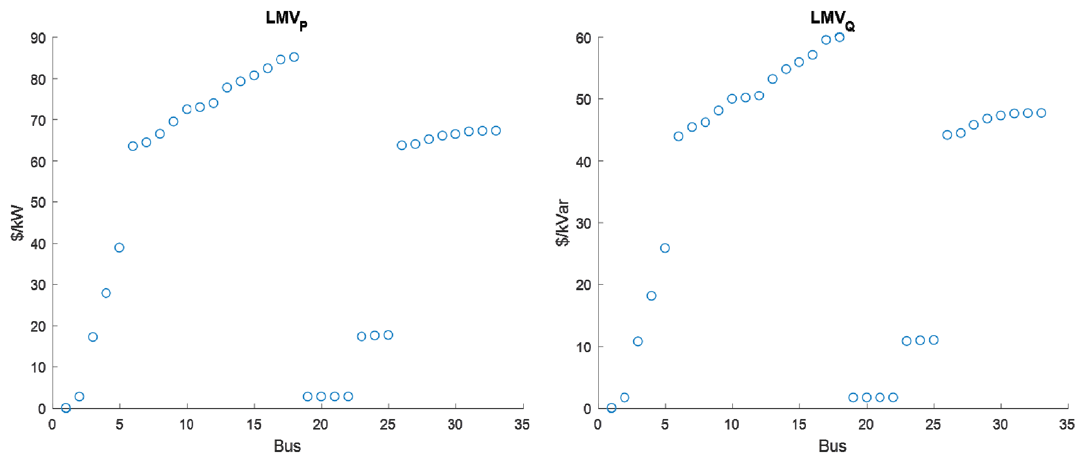

Figure 6 Overload and Undervoltage; LMV-P and LMV-Q

High PV penetration can cause overvoltages on the circuit, especially at lower loads as is now a well-known phenomenon on weekends in shoulder months. In extreme cases, this can also cause backfeed or reverse power flow on the circuit back to the transmission system. Figure 7**Error! Reference source not found.** illustrates this where branch 18 is overloaded in the reverse direction and nodes 2 and 19-22 are overvoltaged.

Capacitors cannot correct this problem. Reconductoring to decrease circuit impedance and increase thermal ratings is the (expensive) traditional solution. DER capable of withdrawing real power and/or withdrawing reactive power are a solution (such as storage). Figure 8**Error! Reference source not found.** illustrates this where the LMV-P and LMV-Q are negative in most nodes, indicating the value of withdrawal, not injection (and coincidentally, putting a negative value on additional PV on the circuit). Positive LMV-Q at node 19 is to help with reverse flow issue. Finally, although same cost is assumed as for undervoltage upgrade, the LMV in this case is much lower than undervoltage. This is because lower impedance in upstream sections requiring more withdrawal and therefore resulting in lower LMV.

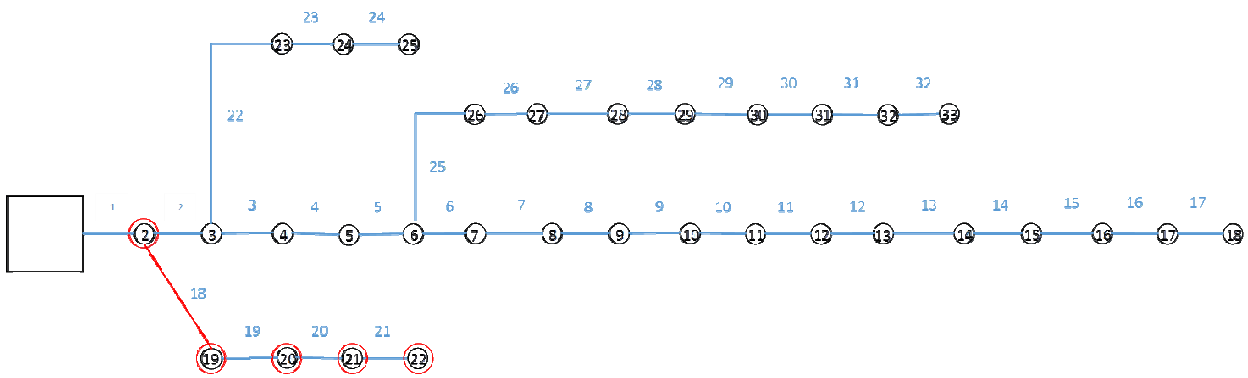

Figure 7 IEEE 33-Bus Circuit with reverse flow and overloaded nodes

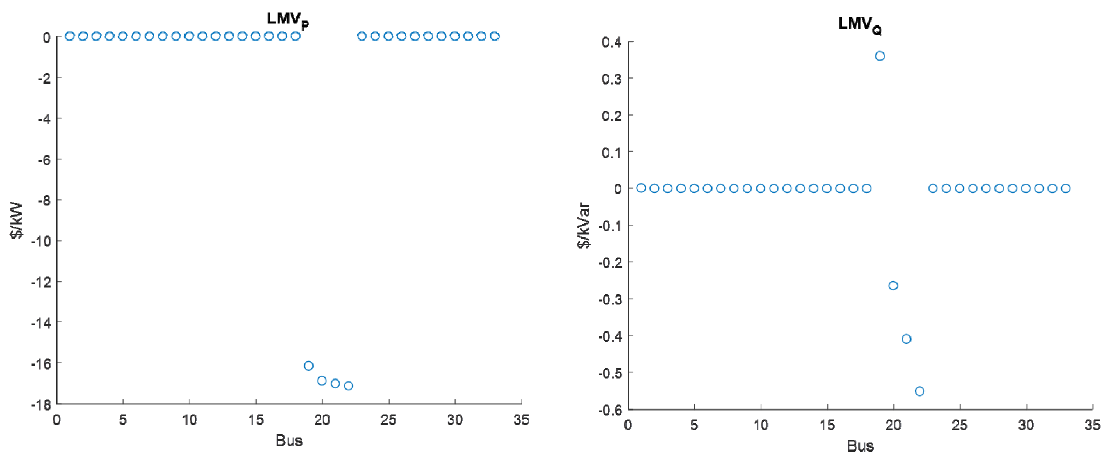

Figure 8 Backfeed and Overvoltage; LMV-P and LMV-Q

5. CONCLUDING REMARKS

Deciding how much of the traditional capacity cost to allocate in each year is a critical decision. There are several possibilities, each with advantages and disadvantages:

- Allocate all of the cost in the first year and use the resulting locational marginal value (LMV) as an upfront incentive for DER. The appeal of this approach is the simplicity and the higher magnitude of incentives. The challenge, however, is that in the event that conditions change in future years necessitating a traditional investment, then the incentives were overstated. This also creates a first-in or grandfathering effect – once the loading is mitigated, presumably DER incentives would cease for additional DER.
- Evaluate the LMV annually and accordingly vary annual incentive payments using the annual revenue requirement of traditional investments as the cost basis. The advantage of this is complete accuracy, which, minimizes customer impact. The disadvantage is complexity, which may pose a disincentive to DER and produce future uncertainty.
- Establishing a time frame for the calculation of customer impact of the traditional investment and then use the net present value of this as input to the LMV calculation. The time frame could be tied to a known or expected deferral period after which a traditional upgrade would be re-evaluated or could be tied to the life expectancy of typical DER assets (less than T&D assets in general). This is a compromise between the first two alternatives with the pros and cons of each to different degrees.

« Real » distribution networks and circuit models have characteristics not present in a simulated example. These include much higher branch node counts (as high as 2000), three-phase unbalances, single and two phase portions of the circuits, and the inclusion of zero-impedance links in the circuit model. Also, many distribution analysis programs embed the load in the branch models as well as having provisions for nodal spot loads.

Conceptually, the framework and its implementation extend easily to handle larger node counts and three-phase imbalance. However, a branch-node representation with all load and DER represented as being at a node, not along a branch, is a mathematical requirement as is the elimination of zero-impedance links. From a practical viewpoint, whether a utility or regulator will want to publish and utilize LMV values that vary only in the third or fourth decimal place along a section of a circuit is a valid question. One solution is to use the LMV as calculated from an exact circuit representation and then to derive « smoothed » values that are constant in regions of the circuit. Another alternative is to employ network reduction before calculating the LMV which results in the same effect.

Many problems associated with high PV penetration are found on « thin » single phase lateral branches, and this argues for a three-phase unbalanced representation. While some DER technologies can be used to dynamically balance phases, this is of relatively little value today. The cost of shifting load to achieve better balance on a three-phase circuit is so low that there is no non-wires alternative value. When re-engineering single-phase laterals is required, there may be real value to be realized. An interesting question is whether higher DER penetration, especially PV and EV, will lead to greater dynamic imbalance and make the value of DER for dynamic balancing greater.

6. FUTURE WORK

Theoretical extensions of the framework could include uncertainty in load forecasts and DER production and adoption. In addition, applications of the Value of DER to portfolio optimization and to utilizing DER to enhance reliability are possible areas of investigation.

BIBLIOGRAPHY

[1] https://rev.ny.gov/about/
[2] https://drpwg.org/archive-ica-and-lnba-working-group
[3] Future Energy Jobs Act http://www.ilga.gov/legislation/publicacts/99/PDF/099-0906.pdf