WIS:dom®-P Distribution Co-optimization

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The present document provides an explanation of how the VCE® WIS:dom®-P distribution co-optimization module option within the model logic works. It describes key considerations in detail along with nuances that have been experienced in utilizing the module.

WIS:dom-P Estimates Distribution Spending Conservatively

It is important to understand what distribution values the model is trying to replicate and approximate. The EIA estimates (from FERC data[1]) that distribution spending for major utilities totaled $57.4 billion in 2019.[2] The approximate demand served by reporting utilities is 70% of the contiguous USA. Assuming that distribution spending is correlated with electricity consumed, then the total distribution spending across the US amounts to $82 billion in 2019. The FERC and EIA do not specify what voltage ranges they consider as distribution; however, it is extremely likely to be below 69-kV (important later).

By comparison, WIS:dom-P estimates that distribution spending across the contiguous US for 2020 is $80.4 billion. The spending includes all costs up to the 69-kV range, above which the model recognizes the values as transmission spending.

Therefore, it is likely that the WIS:dom-P is ***underestimating*** the total amount of spending within the distribution grid. As an extension, any savings formulated should be viewed as conservative under this paradigm.

Key Values and Assumptions in WIS:dom-P Model Structure

The values used in the WIS:dom-P distribution co-optimization are initialized by the "*Trends in Transmission, Distribution, and Administration Costs for U.S. Investor Owned Electric Utilities*" white paper published by UT Austin.[3] VCE re-computes the outputs using data from 1980 onwards. Prior to 1980 there are simply too many variables to account for to produce a reliable cost metric. These variables include suburbanization, rapid electricity growth due to industrial expansion, energy crisis, extreme summers expanding air-conditioning use, and others. Industrial growth as reflected in the share of industrial energy used that comes from electricity essentially stopped from 1980 onwards. This could explain why the correlations converge in the period after 1980 for data relating to customers, energy and power.[4]

VCE iterated the re-computed values for each region of the US to align with historical values in those regions. The main assumptions included in these computations are that capital spending is more aligned with estimated peak draw on circuits, while operations and maintenance are more aligned with electrical energy served over the year. These assumptions reflect a simplification of reality because customer type, density of customers, and other factors will impact the structure of total costs. However, the computed values align well with historical data. Because the WIS:dom-P model can currently only explicitly model down to the 69-KV level of the grid, VCE believes this approach is an appropriate first order approximation.

It is important to remember that at this time, the WIS:dom-P model is not a substitute for full integrated distribution planning that explicitly models each line, feeder, transformer, and distribution resource. Rather WIS:dom-P provides insights into possible tradeoffs of costs that arise when designing future electricity systems.

Embedded in the WIS:dom-P model is the additional major assumption that because the distribution grid is severely aging (in 2015 over 70% of transformers are over 25 years old and 60% of circuit breakers are over 30 years old[5]),

[1] https://www.ferc.gov/industries-data/electric/general-information/electric-industry-forms/form-1-electric-utility-annual
[2] https://www.eia.gov/todayinenergy/detail.php?id=48136
[3] https://energy.utexas.edu/sites/default/files/UTAustin_FCe_TDA_2016.pdf
[4] https://fas.org/sgp/crs/misc/R40187.pdf
[5] https://www.energy.gov/sites/prod/files/2015/09/f26/QTR2015-3F-Transmission-and-Distribution_1.pdf

replacements or upgrades will be required in the near future, regardless of the deployment of distributed resources. Therefore, planning the spending on the distribution grid simultaneously with demand growth, distributed resources, and a changing utility grid is the critical way to identify potential area of co-benefits and co-risks.

How Does the WIS:dom-P Model Perform Distribution Co-optimization?

1. In general, WIS:dom-P performs a co-optimized selection of where to site generation, transmission, distributed energy resources, and storage across the entire contiguous US. This selection reflects estimated costs for "*distribution*" infrastructure (below 69-kV) at an accumulation point (or event horizon) to minimize the system costs over each Balancing Area Authority ("BAA").
2. The WIS:dom-P co-optimization methodology can scale to coarser or finer granularity depending on data availability and computational limitations.
3. The estimated "*distribution*" costs (in the cost function) are designed to include:
    a. Sub-transmission (~34.5-kV through 69-kV) lines and transformers
    b. Primary distribution (~2.4-kV through ~34.5-kV) lines, transformers & feeders
    c. Secondary distribution (110-V through ~2.4-kV) distributors, lines, transformers & feeders
    d. Meters, monitoring, operations and maintenance.
4. Distributed resources are addressed at a 3-km granularity. The available space and technical potential for residential, commercial, and industrial solar PV, community solar, distributed storage, and residential storage are determined. The demand side management technical potential is determined from weather inputs along with the derived demand profiles, building stock, and categorization of demand types. Potential production profiles for distributed solar are generated for each 3-km grid cell. Distributed solar production profiles also reflect insolation, temperature and weather data.
5. Front-of-meter distributed solar PV and storage costs include an interconnector line to an associated 69-kV node. This connection cost element is based on the distance from the generator to the node and the cost of an associated transformer. Interconnector line costs also include a loss function for movement of power.
6. Behind-the-meter distributed solar PV and storage can only be constructed to the scale of the demand associated with the site location. The model limits generation from these resources so that it will not exceed the peak consumption within each 3-km grid cell.
7. Demand levels within each 3-km grid cell are accumulated at the associated (69-kV) nodes. As a result, the coincident demand for each demand category for the whole distribution grid and the flexibility of that demand is considered only at the node. Distributed resources sites are left explicit to enable site selection.
8. The transmission and utility portion of the grid is explicit for resource siting, transmission, and storage. These will co-optimize with the distribution approximation within the model.
9. The distribution co-optimization interface equation is formulated to enable the model to determine the tradeoff for distribution infrastructure and distribution resources versus utility grid resources.
10. When distribution co-optimization is deactivated, the model will ignore this interface, though all other assumptions and model elements remain the same. During post-processing of the model solution, costs from the interface are applied to ensure a consistent comparison with the model solution when the distribution co-optimization is activated.
11. There are two key cost components accounted for in the distribution co-optimization interface as shown in the equation below. The first is a capital expenditure cost associated with meeting peak power demands and managing possible back-flow onto the transmission grid. The second set of costs are the operational costs associated with serving and controlling total electricity demand. The λs in the cost function allow the user to alter the impact of the interface. Setting the λs to zero will have the impact of removing the interface. Setting the λs to infinite will disconnect the distribution systems below the 69-kV level from the transmission grid. Any values can be used for the $\mathcal{C}$s in the equation; standard values are derived as discussed above.

$$\Lambda \cdot \left\{ \mathcal{C}_{\mathcal{L}}^{d\mathscr{p}} \cdot \left[\mathcal{E}_{\mathcal{L}}^{\mathscr{p}} + \lambda_a \cdot \left(\mathcal{E}_{\mathcal{L}}^{\mathscr{b}} + \mathcal{E}_{\mathcal{L}}^{m} \right) \right] + \hbar \cdot \mathcal{C}_{\mathcal{L}}^{de} \cdot \sum_t \left(\mathcal{E}_{\mathcal{L}t} - \lambda_b \cdot \mathcal{J}_{\mathcal{L}t} \right) \right\}$$

12. Three constraints feed into the distribution co-optimization interface equation (as addressed in the WIS:dom-P technical documentation) and are reproduced below. The first constraint (1.19.1) determines the peak instance of flow into the distribution grid from the utility grid.

The second constraint (1.19.2) determines the peak instance of back-flow (from distribution to the utility grid). The peak instance back-flow requires a constant of the minimum instance of power consumption to complete the equation for the back-flow (which is added to the cost function above), because of the linearization of finding the minimum of a function. Thus, the cost function ***adds*** both the peak draw and peak back-flow together to determine the annual capital expenditure.

The final constraint (1.19.3) determines the total annual electricity consumption by the distributed grid from the utility-scale grid. The equation shows that any storage or demand-side management ***will increase the overall electricity consumption*** (to fully see this, one must recognize that storage and demand-side resources have inefficiencies that result in loss of electricity).

Distributed solar PV ***reduces*** total electricity consumption. These reductions are constrained by the limit on behind-the-meter solar PV (discussed in item 6, above) and additional costs applied to the front-of-meter solar PV for interconnection.

$$\mathcal{E}_{\mathcal{L}}^{p} - \mathcal{E}_{\mathcal{L}t} + \Lambda \cdot \sum_{\mathfrak{L} \in \mathcal{L}} \left[p_{\{DPV\}\mathfrak{L}t} + \sum_{\mathfrak{D}} \left(r_{\mathfrak{D}\mathfrak{L}t}^{-} - r_{\mathfrak{D}\mathfrak{L}t}^{+} \right) + \left(\mathfrak{D}_{\{dist\}\mathfrak{L}t} - \mathfrak{C}_{\{dist\}\mathfrak{L}t} \right) \right] \geq 0, \qquad \forall\, \mathcal{L}, t \tag{1.19.1}$$

$$\mathcal{E}_{\mathcal{L}}^{b} + \mathcal{E}_{\mathcal{L}t} + \Lambda \cdot \sum_{\mathfrak{L} \in \mathcal{L}} \left[\sum_{\mathfrak{D}} \left(r_{\mathfrak{D}\mathfrak{L}t}^{+} - r_{\mathfrak{D}\mathfrak{L}t}^{-} \right) + \left(\mathfrak{C}_{\{dist\}\mathfrak{L}t} - \mathfrak{D}_{\{dist\}\mathfrak{L}t} \right) - p_{\{DPV\}\mathfrak{L}t} \right] \geq 0, \qquad \forall\, \mathcal{L}, t \tag{1.19.2}$$

$$\sum_{\mathfrak{L} \in \mathcal{L}} \left\{ \mathcal{J}_{\mathfrak{L}t} - \Lambda \cdot \left[p_{\{DPV\}\mathfrak{L}t} + \sum_{\mathfrak{D}} \left(r_{\mathfrak{D}\mathfrak{L}t}^{-} - r_{\mathfrak{D}\mathfrak{L}t}^{+} \right) + \left(\mathfrak{D}_{\{dist\}\mathfrak{L}t} - \mathfrak{C}_{\{dist\}\mathfrak{L}t} \right) \right] \right\} = 0, \qquad \forall\, \mathcal{L}, t. \tag{1.19.3}$$

13. In simple terms, within the distribution co-optimization interface, distributed solar PV can increase back-flow (though it may not) via exceedance of the different aggregated subregion demands—this increases capital expenditures. If production is aligned correctly, distributed solar PV could reduce the peak draw from the utility grid. If distributed solar PV is front-of-meter, then an additional interconnection cost is added to the assets for distribution lines to the 69-kV node (discussed in item 5, above). All distributed solar PV generation will reduce the annual electricity consumption term in the overall solution. Distributed storage will increase the annual electricity consumption term. Distributed storage can discharge and lower the peak draw from the utility grid. Storage can also charge to lower the potential for high peak back-flow. Front-of-meter distributed storage, like front-of-meter distributed solar, will pay an additional interconnection charge. Demand-side management can also increase (but never decrease) annual electricity consumption. It can behave to reduce the peak draw or reduce the peak back-flow.
14. The biggest changes occur in the peak draw and back-flow. The change in operation costs due to annual electricity consumption are much smaller under distribution optimization because electricity is still being supplied and operations still exist. There are some savings seen because of additional distributed solar PV production, but it is limited by the added cost of front-of-meter interconnection and by the scaling of behind-the-meter being tied to peak draw. The alteration of the demand observed at the 69-kV nodes creates additional opportunities for the model relating to procurement of utility grid generation, transmission, and storage. The opportunities arise from the increase in available capital to deploy while reducing overall costs and from the added demand flexibility to better match supply.
15. Actual locational siting and savings will likely differ from the optimal solution that WIS:dom-P creates. Factors such as complexities in the distribution infrastructure, customer choice, and regulatory requirements (or inaction) will all determine whether reality tracks the optimized pathways that the model generates. The model primarily facilitate an alternative view of how the electricity system could evolve. This is particularly important as electrification of transportation and thermal loads advances because of the dramatic evolution of the distribution grid to address such demands.

16. Another model in the WIS:dom modeling suite—WIS:dom-DG—is currently being deployed to perform integrated distribution grid planning and interconnection of resources explicitly in a few geographies around the US. Experience gained from this work will help calibrate and improve the distribution co-optimization interface equation in WIS:dom-P.