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Transactive System Program Communication System Cost Model

September 2018

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U.S. DEPARTMENT OF ENERGY

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Prepared for
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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

Transactive energy is an economics and controls technique that aims to dynamically manage the generation and consumption of electricity within the power system. Much research has been done in the area of demonstrating the capability and performance of transactive systems, as well as valuing the benefits a transactive system can provide. Significantly less research has been done in the area of estimating the costs of a transactive system. This work aimed to build a model that would estimate the costs of the communications system that would be necessary to support a transactive system and be realized by a local utility. Dynamic pricing, and a customer's response to this pricing, is a key aspect of a transactive system; this would require a two-way communication system between utilities and customers. Since the system will vary based on many factors, the cost model was consequently designed for use in a wide variety of applications.

The cost model requires some basic user inputs regarding the system being analyzed, such as location and size. The user also identifies one or more generic circuit models that best represent the system. Additionally, a user can, but is not required to, change assumed equipment and installation costs and equipment lifetime within the model. These inputs will result in 20 year cost estimates for three different communication technologies that are capable of supporting the bandwidth needs of a transactive energy system.

The three communication systems included in the model are cellular, fiber optic and wireless mesh. Each vary significantly from one another and offer unique advantages and barriers. A cellular network avoids high upfront costs, but is limited to areas where there is coverage by the service provider and subject to the ongoing rate established with the service provider. A fiber optic system requires a large up-front cost, but it will provide a reliable system to areas where cellular and mesh may be unable to do so. Additionally, fiber provides more bandwidth than necessary for transactive systems and can offer additional business opportunities. A mesh system can be installed for less upfront costs than fiber and offers enough bandwidth to support a transactive system, but the ability to model this technology is done with less certainty than the other two options.

The estimated costs include the communication system that connects the customers to their nearest substation, in addition to the smart meter and radio that would be required for each customer. The communications from the substation to the utility are not included in estimates, as the need for upgrading that system would be assessed on a case-by-case basis. Although the cost of the smart meter and radio is included, no other appliance specific cost is included in the estimate provided by the model.

The communication system is a key aspect of the development of a transactive system. This work resulted in easily being able to estimate the costs of a communication system specific to the system being studied. This cost model will aid ongoing valuation and simulation work in the field of transactive energy.

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1.0 Introduction

Transactive energy is a controls philosophy that uses incentive signals to encourage or promote responses from participants that will meet the technical needs of the system. Much of the work in transactive systems research has focused on demonstrating the technical capability and performance of the systems to achieve these technical needs, as well as quantifying the financial benefits the various participants in the system receive.

Very little, if any, time has been spent quantifying the costs of implementing a transactive system, which are likely to be non-trivial. As compared to the non-transactive systems in use today, a transactive system has additional computation and communication requirements as a part of the operation of the system. For example, in non-transactive systems the cost of energy to residential customers is often updated no more frequently than once a year, whereas transactive signals may provide new values every minute.

The need for more frequent updates of certain signals will in many cases require the construction of a new communication system that would not exist otherwise. Though there are other cost components of transactive systems that would need to be taken into consideration (customer support, marketing, transactive system design and testing, etc.), the model developed in this work solely focuses on the costs of constructing and maintaining the communication system needed to support transactive systems.

2.0 Cost Model Details

2.1 Cost Model Overview

The communication system cost model is designed to be a screening model to estimate costs using a minimal number of inputs from the user. Inputs include the state in which the communication system will be built, the number of customers being served by the communication system, and built-in, generic circuit models that best represent the system. A cost estimate is calculated using this information and reasonable defaults for many of the model-specific parameters (reliability rates of equipment, cost of equipment, etc.).

2.1.1 Communication Technologies Considered

This model considers three different communications technologies with widely differing communication models:

- Cellular – Smart meters communicate with the utility control center through the existing cellular radio network, which was assumed to have sufficient coverage and bandwidth to support the transactive system.

- Fiber optics – The utility installs a new fiber optic network that provides a high-bandwidth fiber backbone from the substation with a short-range (10 – 30m) wireless connection to the smart meter.

- Wireless mesh – Smart meters are equipped with radios having a range of roughly two miles and are able to connect to strategically placed repeaters, or other smart meters, to dynamically route information to the substation.

In the latter two cases, it was assumed that once the information reached the substation the utilities' existing communication system could provide the back-haul transmission of the information to the utility control center. Some utilities may need to upgrade their equipment to support the high communications load but this upgrade was not modeled.

Similarly, all transactive systems require the communication of signals all the way to the controller of the appliance(s) in question, such as an HVAC thermostat. This communication was not included in the model as, depending on the specifics of the equipment involved, it may already be fully supported, and some of the costs of this equipment may be borne by the customer.

Additionally, transactive systems require bi-directional communication, and all three technologies support this. Some existing communication systems that were installed as a part of smart meter deployment by utilities do not necessarily support bi-directional communication, but others may. This model assumes the utility will replace any existing communication system with a new one that supports a transactive system. Similarly, not all smart meters support a connection to a communication system, so the model assumes all meters would need to be replaced.

2.1.2 Communication Bandwidth and Data Volume

The average bandwidth required by each smart meter to support transactive communications is very modest by contemporary communication standards. For the purposes of communicating the information required by a transactive system, both the cellular and fiber-optic networks would have sufficient bandwidth *prima facia*. The mesh networking technology, however, could have bandwidth limitations due to the need for some nodes to retransmit data from other nodes, ultimately limiting the bandwidth available for their own transmissions. An industry group called the Wi-SUN alliance has created a standard (adopted as IEEE 802.15.4) that specifies a minimum bandwidth of 50 kbps, which is sufficient for the purposes of transactive systems (Beecher 2015). This model assumes all mesh network components conform to this standard.

An analysis based on Xcel Energy's AMR system in Boulder, Colorado made meter reads every two minutes, conforming to the ANSI C12.22 and C12.19 smart meter communication standards. This resulted in a total data transfer of 2.3 MB/day (Adke, 2011). The raw data being sent per sample, as defined in the C12.22 standard, was only 64-600 bytes (McGrew 2015). When looking at the scenario where meter reads were made every two minutes, the total transmission size was 3,300 bytes, implying 2,700 to 3,263 bytes of protocol overhead per transmission.

The Pacific Northwest Smart Grid Demonstration executed a pilot project with a transactive system that included forecasted prices for 56 time periods and was formatted in XML (Kuchar 2015). This resulted in a payload size of roughly 6.5 kB sent by the transactive agent (smart meter) and assuming an approximately 3 kB protocol overhead for this data (based on the above analysis) results in a total one-way transmission of 9.5 kB for a total round-trip of 19 kB sent every five minutes, 228 kB/hour, 5.5 MB/day, 164 MB/month on a per-meter basis.

In the interest of preserving data, the payload could be adjusted by removing the XML headers information and formatting the data as an ASCII comma-separated value (.CSV) file. (Doing so would require documentation of the format to be known by the sending and receiving agents rather than simply parsing the self-documenting XML format). Adjusting to this newer format reduces the payload file size to roughly 1.9 kB, for a total one-way transmission of 4.5 kB and a total round-trip of 9 kB sent every five minutes, 108 kB/hour, 2.6 MB/day, 78 MB/month on a per-meter basis.

All of this is based on the particular transactive system defined for the Pacific Northwest Smart Grid Demonstration, which could have significantly smaller or greater data requirements compared to the system under consideration. It is reasonable to expect that as transactive systems continue to grow and expand that the data requirements would grow as well.

2.2 Technology Models

As discussed in section **Error! Reference source not found.**, the three main technologies supported by this model are cellular, fiber optics, and wireless mesh. Choice of communication system technology determines the up-front capital costs for equipment, the labor associated with the initial installation of the equipment, and in the case of the cellular technology, the recurring fees associated with operating the equipment. A detailed examination of how the three different models were constructed follows.

2.2.1 Cellular

The model for the cellular communication system is virtually non-existent: deploying a cellular-based transactive communication system out-sources the communication system costs to the cellular service provider and exchanges up-front equipment costs for on-going service fees. No additional equipment costs outside of the purchase of the smart meter and the modem/radio were assumed.

A cellular based network offers several advantages:

- Avoids significant up-front capital costs by utilizing existing infrastructure.
- Provides a predictable and easily managed monthly fee instead of facing more unpredictable system maintenance, as in the other two technologies.
- Depending on the service provider, the use of older cellular technologies (3G, for example) may be possible at a lower cost, as the equipment is fully depreciated and any fee the service provider collects is essentially free money.

The most significant technical limitation for a cellular-based communication system is the issue of coverage. This model assumes that all smart meters would be well-covered by the cellular service provider; however, this may or may not actually be the case, particularly for rural areas.

The cost of the cellular network was taken from an advertised plan for a major network provider. Based on the data volume calculations described in section 2.1.2, it was assumed the plan providing 150 MB per month would be sufficient. Though the listed rate is used in the cost model, it is reasonable to assume that a lower rate could be negotiated for very large installations.

Share Group	A*		1					2			
Allowance	200 KB	500 KB	1 MB	5 MB	25 MB	50 MB	150 MB	250 MB	1 GB	5 GB	10 GB
Monthly Access	$2.00	$3.00	$5.00	$7.00	$10.00	$15.00	$18.00	$20.00	$25.00	$50.00	$80.00
Overage Rate/MB	$1.00		$1.00					$0.015			

Figure 2.1. Cellular Network Costs[1]

2.2.2 Fiber Optic

Fiber optic communication systems are not typical for deployment in smart grid systems. They have very large up-front capital costs and have significantly more bandwidth than is required for typical transactive systems. Fiber optics as a technology option was included in this model for a few reasons:

- Fiber is the wired technology of choice. Wireless technologies are not a good match for rural areas where cellular coverage can be poor and the distance between meters is more likely to exceed the range of the mesh network radios.
- A high-bandwidth technology provides additional business opportunities like home internet service; such business cases are being built in rural areas.
- In dense urban areas, the high bandwidth may be needed for communicating with a large number of devices participating in the transactive system.

The calculated costs of a fiber optic network are very dependent on the geography of the customers being served by the network and the topology of the existing electrical grid because the model assumes the fiber would be routed along the same right of way. Rather than requiring the user of the model to define these datasets, the model makes use of existing distribution system feeder models that are available as a part of the GridLAB-D distribution[2]. These models have been built to reflect typical circuit characteristics based on the region of the country and the type of circuit (urban, rural, suburban) of interest (Schneider 2008). The models provide distance between nodes and an associated script[3] populates the feeders with houses, providing an estimate of the location and number of houses served in a given circuit.

Using these models, a script was written that parsed the GridLAB-D model and calculated the lengths of fiber as well as the number of fiber optic switches that would be required to construct the network. It was possible to estimate the total equipment costs and labor time to build such a network by using costs provided by PNNL IT staff who have experience with constructing these networks.

One of the interesting characteristics of the fiber network is that the marginal costs of extra bandwidth are relatively small at construction time. That is, a fiber cable with eight pairs of fiber costs little more than one with two pairs. Similarly, the marginal costs of fiber switches as the number of ports increases is also very small. Given this, the choice of including additional fibers and ports for redundancy and future

[1] https://www.verizonwireless.com/biz/plans/m2m-business-plans/ Accessed September 27 2018
[2] https://github.com/gridlab-d/Taxonomy_Feeders Accessed September 27 2018
[3] https://github.com/gridlab-d/Taxonomy_Feeders/tree/master/PopulationScript Accessed September 27 2018

applications doesn't play a large role in total cost, and the size of equipment was based on reducing the network costs. For this reason, the installation of 8-pair fiber and 12-port switches was assumed.

To determine the topological location for the fiber switches, a small sensitivity study was done to determine if it was less expensive to merge fibers at a switch as often as possible (merge early) or if it made more sense to allow parallel fibers to run until all ports on the switch could be filled (merge late). The results of that analysis showed that merging early to reduce the total length of fiber installed was generally less expensive. Thus, it was assumed only four of the twelve ports would be used at the time of installation, leaving a large number of spares for redundancy and potential future expansion.

As part of this study it became apparent that the very end of the communication system, the customer connection, was going to be a very expensive part of the network. Rather than assuming fiber would be directly run to the home it was assumed that a wireless connection point would be installed that allowed one or more smart meters to connect. The distance involved was assumed to be on the order of 10 – 30 meters and would be co-located with the final distribution transformer. Doing so ensured that the number of customers connected to a given wireless access point would be minimized as the size of the distribution transformers is limited and serves a limited number of customers. For scenarios where the number of customers at each fiber termination point is one, the cost of providing direct connection for that customer can be safely assumed to roughly equal the equipment cost of the wireless connection point.

Lastly, rather than assuming the equipment purchased had been ruggedized for outdoor operation, traditional equipment rated for indoor-use would be used and located in a weather-proofing enclosure.

2.2.3 Wireless Mesh

Wireless mesh communication technology is something of a "Goldilocks" technology for smart grid communications. The up-front capital costs are relatively modest as installed infrastructure outside of the smart meter itself consists of wireless repeaters and a substation collector. Though the supported bandwidth is relatively small by modern standards, it is more than sufficient for transactive system applications. If in-range, the smart meters are able to talk directly to the collector at the substation, and if they're not, they can route the signal through nearby repeaters and other smart meters, hopping through devices as necessary to reach the collector.

From a modeling stand-point, though, the appropriate estimation of the system components is more challenging due to increased data requirements of full x,y or latitude, longitude location information. The GridLAB-D models used for the fiber optic network only supply distances between nodes, which is sufficient for fiber but not for wireless modeling. Additionally, the only general values were provided by the vendor consulted to understand the technical specifications and costs of equipment.

Given all of this, the following assumptions were made to determine how many repeaters and collectors would be necessary for each of the typical circuits

- The smart meter radios had a range of roughly 2 miles (vendor provided values of 1-5 miles).
- The collector (the device located in the substation that connected the wireless signals to the existing wired communication infrastructure) could support data from 1,500 meters. If more meters than that were present in a circuit, additional collectors were added as needed.

- Repeaters did not require a wired connection back to the substation. Instead, they were assumed to have superior antennas and transmitters with higher bandwidth so that they could directly reach the collector in the substation.

The same script used to estimate the fiber network was also used to estimate the topological location of the necessary repeaters in the network, such that the distance along the electrical network was less than the range of the smart meter radio. This results in a conservative estimate, as the straight-line distance from a smart meter to a repeater is generally less than the distance along the electrical wiring path.

2.3 Economics Model

In order to achieve a lifetime system cost, the component costs modeled in section 0 were used as inputs in a cost model built in Microsoft Excel. The cost model calculates a location and size specific estimate in 2017$ for installing and maintaining a fiber, mesh and cellular network over a 20-year time period. This cost model is dependent on relevant data inputs and assumptions that are built into the model and user-selected inputs, which provides specific cost estimates.

2.3.1 User Inputs

The cost model is able to provide estimates specific to certain user inputs, to estimate the costs of a system the user must provide some information regarding the system that the costs are being estimated for. These user inputs are:

1. The US state in which the transactive system costs will be estimated.
2. The number of customers or meters that the transactive energy system would serve.
3. The typical distribution system feeder model(s) that most closely represent the system costs being estimated.
4. The retail price of equipment installation.
5. The failure or replacement schedule of the equipment.

It should be noted that the model includes default values for user inputs 4 and 5 listed above, so the user does not need to have knowledge of that information. However, user inputs 1, 2 and 3 are necessary for the user to estimate costs. In order to fulfill input 3, the user will need to know fundamental information regarding the system being evaluated. This will include general information about the load being served and geographic make up. In the model, the user identifies which distribution system feeder models, as described in section 2.2.2, are most representative of the system for which costs are being estimated.

2.3.2 Cost Calculations

Once the user inputs have been provided, the model automatically generates system cost estimates for each fiber optic, mesh and cellular network that meet the user's specifications. The selected distribution system feeder model(s) are used to determine the necessary quantity of equipment for the system being modeled. The model generates the costs of the communication system for the typical distribution system feeder model(s) and then divides that value by the number of customers in the typical distribution system feeder model(s). That per-customer value is then multiplied by the number of customers the user provided to determine the cost of the system being modeled.

The cost of the communication system is composed of equipment costs and installation costs. Equipment costs can be specified by the user or default values can be used, then a state specific sales tax rate is applied. State sales tax data was obtained from The Sales Tax Clearinghouse[1] and are a weighted average combined city and county rate specific to each state.

Labor costs are generated based off of the assumed hours required for installation per unit of equipment and an hourly labor rate that varies by state. The hourly labor value is the state's mean hourly wage for telecommunications line installers and repairers with an industry multiplier applied. Then it is scaled to include total compensation costs. The average wage for this type of labor in the electric generation industry is 1.3784 times more than the mean hourly wage according to the BLS[2]. The BLS also stated that in 2017 wages only accounted for 68.4% of total compensation for private industry installation, maintenance and repair occupations.

For example, to determine the total national average total compensation cost, the 2017 national average mean hourly wage of $25.88 an hour is scaled by the industry multiplier average of 1.3784, which results in an hourly rate of $35.67. Since this value is only 68.4% of total compensation, it is then divided by the hourly rate to arrive at a national average for hourly compensation cost of $52.15 an hour.

The labor and installation costs for the initial system installment show up in year 1 of the analysis (2017). Depending on the user input for the equipment replacement schedule, costs are also incurred within the 20-year analysis in the year that equipment fails. The exception to this is for the cellular network option, where there is an ongoing annual fee based on a contract. The replacement of equipment and the ongoing cellular costs are the only O&M costs included in the 20 year analysis.

All of the costs in this model are represented in 2017$ and are not escalated to account for inflation in future years. Therefore, one of the cost model results is a total cost per customer for the entire 20-year analysis in 2017$.

2.3.3 Future Potential Modifications

While the cost model in its current state provides an estimation of system costs, there are additional options that would make it more robust. This section of text aims to start a discussion about what additional work can and should be done in this space.

From the standpoint of the communication systems model, the mesh network model has the most uncertainty. Designing these networks well takes considerable effort as the effects of the specific geography and topology are considerable. The typical distribution system feeder models used in this analysis only specify distance between the nodes and not the actual latitude/longitude locations. Worst case assumptions were made when estimating the coverage distance of the repeaters and radios but even these may not be conservative enough in some situations (and are likely to often be too conservative). A greater effort could be made to engage industry and improve the process of determining the required system components for these feeder models.

One relatively simple improvement that could be made to the current model is a variable analysis base year. This option would allow a user to start a 20-year analysis in years either before or after 2017.

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[1] http://thestc.com/STrates.stm

[2] https://www.bls.gov/oes/current/oes499052.htm#3

Inflation data and projections would be used so that the results would be reported in the analysis base year's dollars. This option would allow the cost model to be used as a more diverse planning tool, and if previous system installation cost data exists, the model could be set to an earlier year to validate the accurateness of the cost estimates.

Financing is another major component of a transactive system that is not currently accounted for in the cost model. If the system is financed, there are additional factors and costs that should be considered. Since financing a transactive system is a likely scenario, including financing costs would make the model more applicable to a broader range of users.

Introducing an experience curve and applying it to the price of transactive technology is also a model component that should be considered. The experience curve applies to the production of a good or service, and the concept is that as production volume increases, value added costs fall. This effect can be attributed to multiple reasons, including but not limited to labor efficiency improvements, standardizations, improved production methods, improved product design, and even the effect of shared experiences within the industry. It is useful to consider this effect when discussing the cost of emerging technologies and considering an analysis period of 20 years. Research would need to be done regarding how this effect has been seen in the industries relevant to transactive systems if it were implemented in the model.

The scope of the model could also be expanded to include other direct and indirect costs of installing and operating a transactive system: servers and software, customer support, upgrades of existing equipment, etc. Some of these values are likely to be readily available (customer support, server costs) but others would be speculative as commercial products are not presently available (transactive system management software).

Adding a way for users to more closely define the area for which they are calculating costs, beyond the current base models, is another way to increase the model's utility. Possible inputs could be values such as population density, type of building and zoning of the area, which could lead to certain infrastructure assumptions. This may likely require the user to have a more thorough understanding of the area of analysis than the current state, but the cost calculations would be specific to the analysis area rather than the 23 base model options.

3.0 Cost Model User Guidance

This section of this document is intended to explain to a user how to obtain cost estimates using the cost model. The model was developed in Microsoft Excel and is only designed to be used within Excel. No additional software is required for use.

The first sheet is named "Home" and is where the user will find directions and where the cost estimates will be displayed once user inputs have been updated. A screen shot of the Home sheet is shown in Figure 3.1. The only additional information not shown in this figure is of the Home sheet is a 20 year network cost table for the mesh and cellular networks below the visible table for fiber.

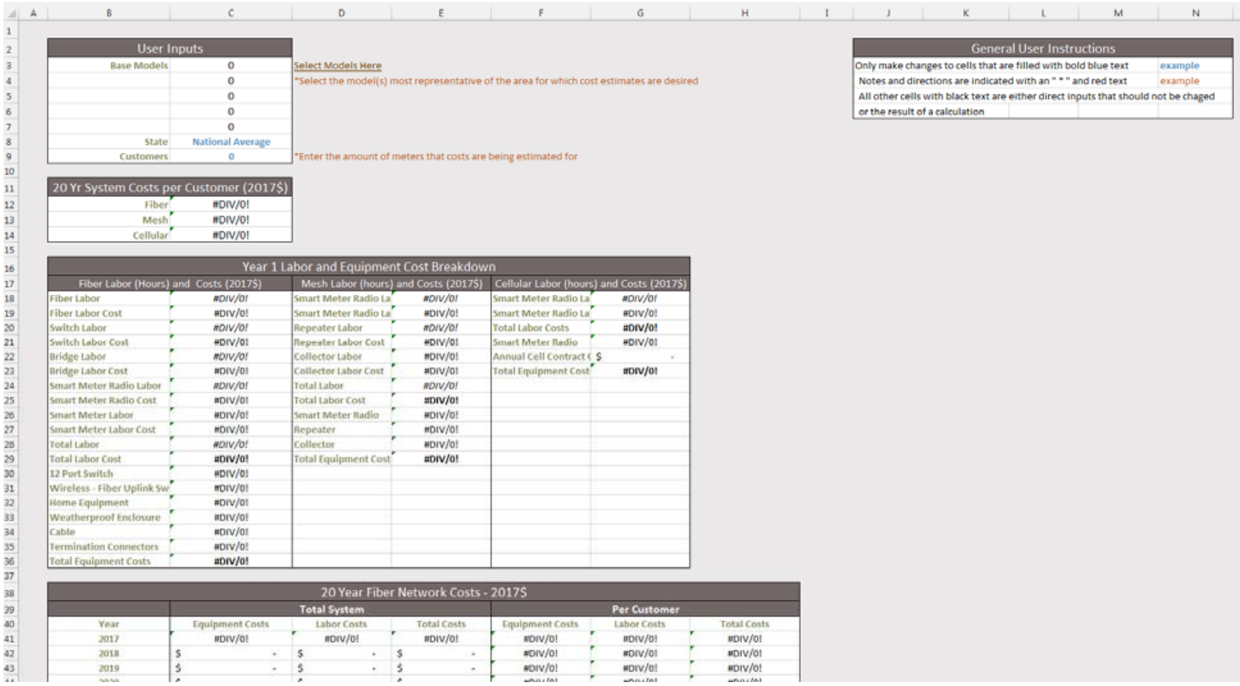


Figure 3.1. Cost model "Home" sheet

At this time the user should read the "General User Instructions," so they clearly understand what cells should and should not be edited within the model.

Next, a user should input the values relevant to their analysis in the cells C8 and C9 on the "Home" sheet. The value for customers should be the number of meters included in the system for which costs are being estimated, regardless of household size. If the user does not specify a non-zero value for the customers user input, the model will not estimate any costs. If the state for which the analysis is being is unknown, the user can select the national average option. It should be noted, however, that this is not a population weighted national average, but rather the average of the values for each state. These user input fields are shown in Figure 3.2.

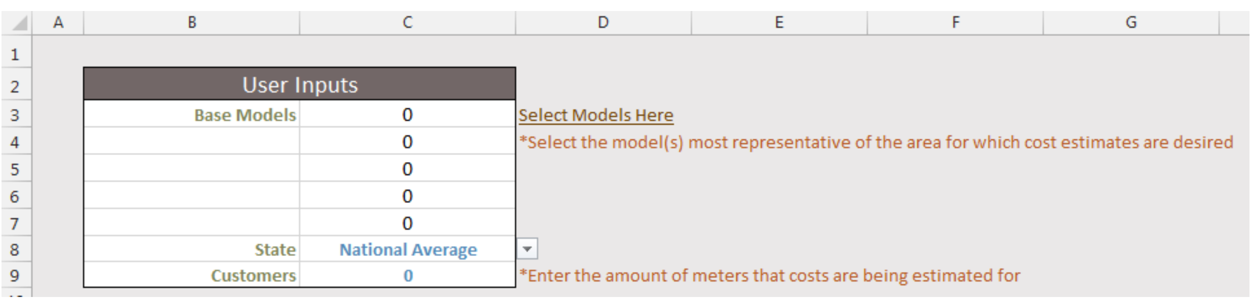
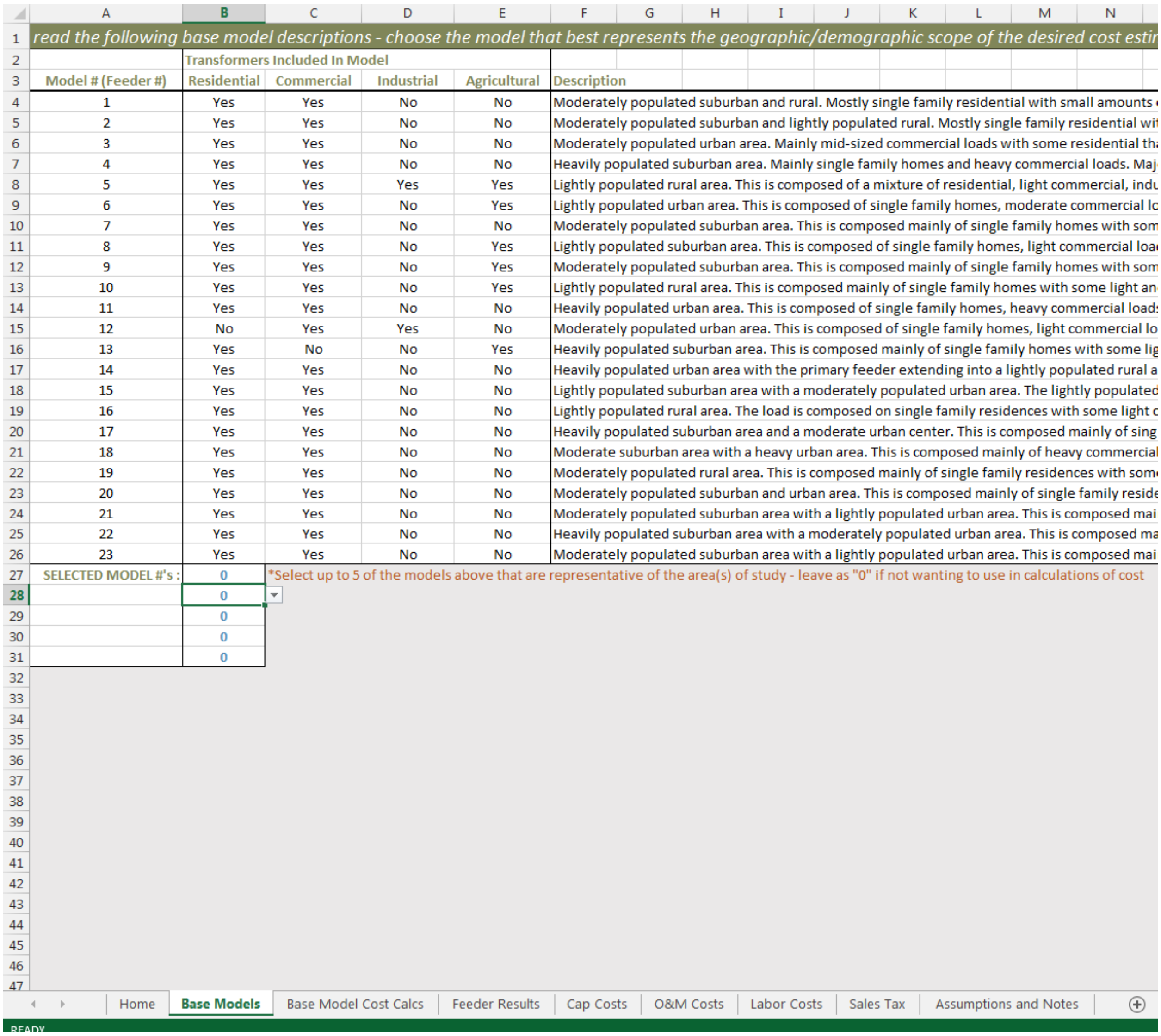


Figure 3.2. Cost model distribution system model selection fields

After this, the user should follow the hyperlink in cell D3 on the Home sheet, which should automatically direct them to the "Base Models" sheet. The user should read the descriptions of the 23 typical distribution system feeder model options. In cells B27-31 the user should select up to five base models (typical distribution system feeder models) that are representative of the area and system for which costs are being. If the user does not wish to use five models, the extra cells in this area should be left as "0". If the user does not select at least one typical distribution system feeder model, the model will not be able to estimate any costs. The only options to enter into these cells are the values 0 through 23. The home page will automatically update with the typical distribution system feeder model that the user selects. This user input field is shown in Figure 3.3.

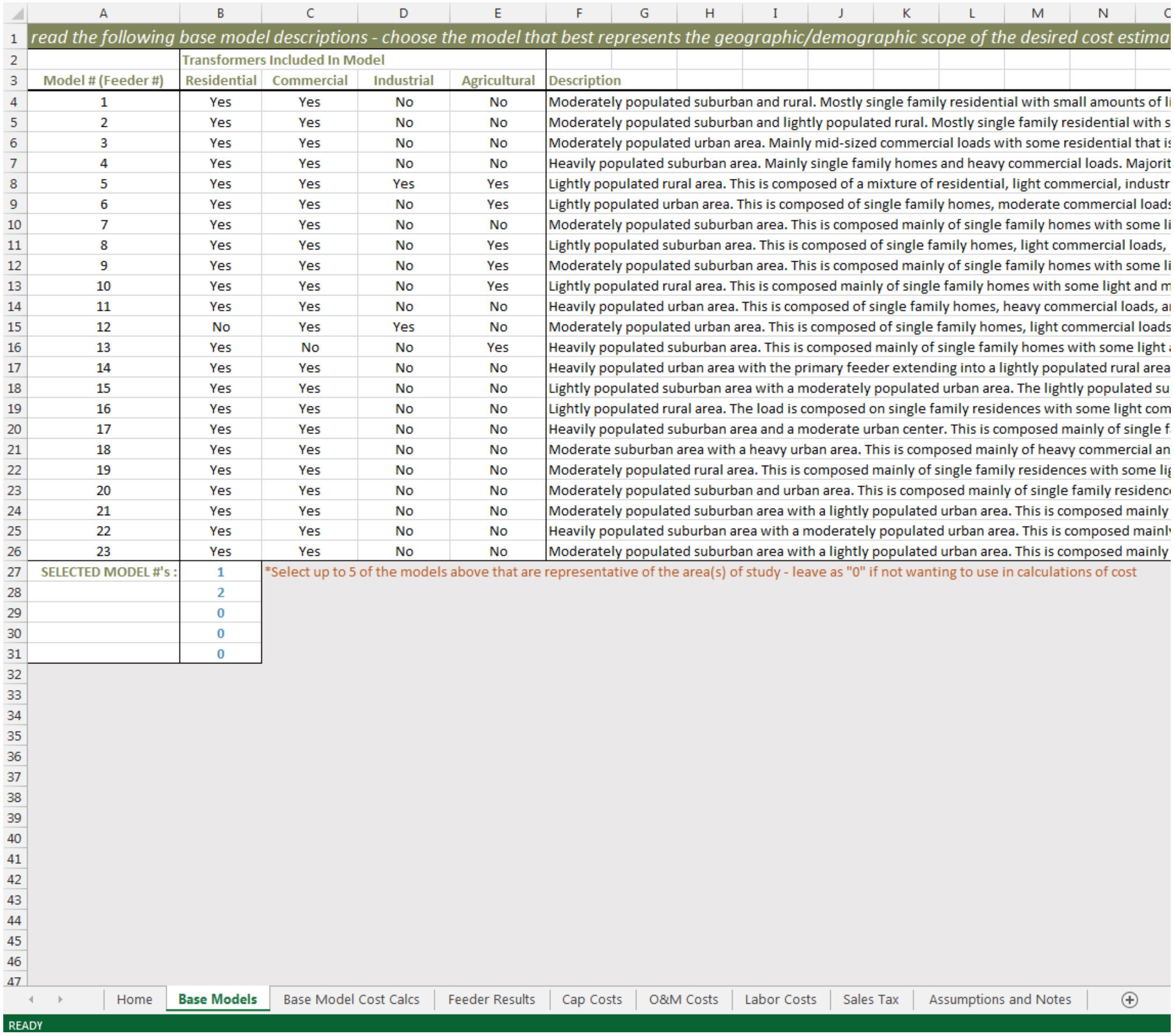


read the following base model descriptions - choose the model that best represents the geographic/demographic scope of the desired cost estir

	Transformers Included In Model				
Model # (Feeder #)	Residential	Commercial	Industrial	Agricultural	Description
1	Yes	Yes	No	No	Moderately populated suburban and rural. Mostly single family residential with small amounts
2	Yes	Yes	No	No	Moderately populated suburban and lightly populated rural. Mostly single family residential wi
3	Yes	Yes	No	No	Moderately populated urban area. Mainly mid-sized commercial loads with some residential th
4	Yes	Yes	No	No	Heavily populated suburban area. Mainly single family homes and heavy commercial loads. Maj
5	Yes	Yes	Yes	Yes	Lightly populated rural area. This is composed of a mixture of residential, light commercial, indu
6	Yes	Yes	No	Yes	Lightly populated urban area. This is composed of single family homes, moderate commercial lo
7	Yes	Yes	No	No	Moderately populated suburban area. This is composed mainly of single family homes with som
8	Yes	Yes	No	Yes	Lightly populated suburban area. This is composed of single family homes, light commercial loa
9	Yes	Yes	No	Yes	Moderately populated suburban area. This is composed mainly of single family homes with som
10	Yes	Yes	No	Yes	Lightly populated rural area. This is composed mainly of single family homes with some light an
11	Yes	Yes	No	No	Heavily populated urban area. This is composed of single family homes, heavy commercial load
12	No	Yes	Yes	No	Moderately populated urban area. This is composed of single family homes, light commercial lo
13	Yes	No	No	Yes	Heavily populated suburban area. This is composed mainly of single family homes with some lig
14	Yes	Yes	No	No	Heavily populated urban area with the primary feeder extending into a lightly populated rural a
15	Yes	Yes	No	No	Lightly populated suburban area with a moderately populated urban area. The lightly populated
16	Yes	Yes	No	No	Lightly populated rural area. The load is composed on single family residences with some light c
17	Yes	Yes	No	No	Heavily populated suburban area and a moderate urban center. This is composed mainly of sing
18	Yes	Yes	No	No	Moderate suburban area with a heavy urban area. This is composed mainly of heavy commercial
19	Yes	Yes	No	No	Moderately populated rural area. This is composed mainly of single family residences with som
20	Yes	Yes	No	No	Moderately populated suburban and urban area. This is composed mainly of single family reside
21	Yes	Yes	No	No	Moderately populated suburban area with a lightly populated urban area. This is composed mai
22	Yes	Yes	No	No	Heavily populated suburban area with a moderately populated urban area. This is composed ma
23	Yes	Yes	No	No	Moderately populated suburban area with a lightly populated urban area. This is composed mai
SELECTED MODEL #'s :	0	*Select up to 5 of the models above that are representative of the area(s) of study - leave as "0" if not wanting to use in calculations of cost			
	0				
	0				
	0				
	0				

Figure 3.3. Cost model "Base Model" sheet with no models selected

Figure 3.4 and Figure 3.5 are screen shots of what both the "Home" and "Base Model" sheets look like if a user were to have input base models (typical distribution system feeder models) 1 and 2 for an analysis of 1000 customers in the state of California.



read the following base model descriptions - choose the model that best represents the geographic/demographic scope of the desired cost estima					
	Transformers Included In Model				
Model # (Feeder #)	Residential	Commercial	Industrial	Agricultural	Description
1	Yes	Yes	No	No	Moderately populated suburban and rural. Mostly single family residential with small amounts of li
2	Yes	Yes	No	No	Moderately populated suburban and lightly populated rural. Mostly single family residential with s
3	Yes	Yes	No	No	Moderately populated urban area. Mainly mid-sized commercial loads with some residential that is
4	Yes	Yes	No	No	Heavily populated suburban area. Mainly single family homes and heavy commercial loads. Majorit
5	Yes	Yes	Yes	Yes	Lightly populated rural area. This is composed of a mixture of residential, light commercial, industr
6	Yes	Yes	No	Yes	Lightly populated urban area. This is composed of single family homes, moderate commercial loads
7	Yes	Yes	No	No	Moderately populated suburban area. This is composed mainly of single family homes with some li
8	Yes	Yes	No	Yes	Lightly populated suburban area. This is composed of single family homes, light commercial loads,
9	Yes	Yes	No	Yes	Moderately populated suburban area. This is composed mainly of single family homes with some li
10	Yes	Yes	No	Yes	Lightly populated rural area. This is composed mainly of single family homes with some light and m
11	Yes	Yes	No	No	Heavily populated urban area. This is composed of single family homes, heavy commercial loads, a
12	No	Yes	Yes	No	Moderately populated urban area. This is composed of single family homes, light commercial loads
13	Yes	No	No	Yes	Heavily populated suburban area. This is composed mainly of single family homes with some light a
14	Yes	Yes	No	No	Heavily populated urban area with the primary feeder extending into a lightly populated rural area
15	Yes	Yes	No	No	Lightly populated suburban area with a moderately populated urban area. The lightly populated su
16	Yes	Yes	No	No	Lightly populated rural area. The load is composed on single family residences with some light com
17	Yes	Yes	No	No	Heavily populated suburban area and a moderate urban center. This is composed mainly of single f
18	Yes	Yes	No	No	Moderate suburban area with a heavy urban area. This is composed mainly of heavy commercial an
19	Yes	Yes	No	No	Moderately populated rural area. This is composed mainly of single family residences with some lig
20	Yes	Yes	No	No	Moderately populated suburban and urban area. This is composed mainly of single family residenc
21	Yes	Yes	No	No	Moderately populated suburban area with a lightly populated urban area. This is composed mainly
22	Yes	Yes	No	No	Heavily populated suburban area with a moderately populated urban area. This is composed mainl
23	Yes	Yes	No	No	Moderately populated suburban area with a lightly populated urban area. This is composed mainly
SELECTED MODEL #'s :	1	*Select up to 5 of the models above that are representative of the area(s) of study - leave as "0" if not wanting to use in calculations of cost			
	2				
	0				
	0				
	0				

Figure 3.4. Cost model "Base Model" tab with electrical distribution system models "1" and "2" selected

User Inputs		
Base Models	1	Select Models Here
	2	*Select the model(s) most representative of the area for which cost estimates are desired
	0	
	0	
	0	
State	California	
Customers	1000	*Enter the amount of meters that costs are being estimated for

20 Yr System Costs per Customer (2017$)	
Fiber	$ 3,659.79
Mesh	$ 582.68
Cellular	$ 2,844.95

Year 1 Labor and Equipment Cost Breakdown					
Fiber Labor (Hours) and Costs (2017$)		Mesh Labor (hours) and Costs (2017$)		Cellular Labor (hours) and Costs (2017$)	
Fiber Labor	5588	Smart Meter Radio La	2000	Smart Meter Radio La	2000
Fiber Labor Cost	$ 333,332	Smart Meter Radio La	$ 119,297	Smart Meter Radio La	$ 119,297.38
Switch Labor	269	Repeater Labor	14	Total Labor Costs	$ 119,297.38
Switch Labor Cost	$ 16,046	Repeater Labor Cost	$ 824	Smart Meter Radio	$ 325,650
Bridge Labor	706	Collector Labor	2	Annual Cell Contract (	$ 120,000
Bridge Labor Cost	$ 42,092	Collector Labor Cost	$ 110	Total Equipment Cost	$ 445,650
Smart Meter Radio Labor	2000	Total Labor	2016		
Smart Meter Radio Cost	$ 119,297	Total Labor Cost	$ 120,232		
Smart Meter Labor	0	Smart Meter Radio	$ 325,650		
Smart Meter Labor Cost	$ -	Repeater	$ 37,500		
Total Labor	8563	Collector	$ 5,000		
Total Labor Cost	$ 510,767	Total Equipment Cost	$ 368,150		
12 Port Switch	$ 146,000				
Wireless - Fiber Uplink Sw	$ 383,000				
Home Equipment	$ 325,650				
Weatherproof Enclosure	$ 43,800				
Cable	$ 649,294				
Termination Connectors	$ 146,000				
Total Equipment Costs	$ 1,693,744				

20 Year Fiber Network Costs - 2017$						
	Total System			Per Customer		
Year	Equipment Costs	Labor Costs	Total Costs	Equipment Costs	Labor Costs	Total Costs
2017	$ 1,693,744	$ 510,767	$ 2,204,510	$ 1,694	$ 511	$ 2,205
2018	$ -	$ -	$ -	$ -	$ -	$ -
2019	$ -	$ -	$ -	$ -	$ -	$ -
2020	$ -	$ -	$ -	$ -	$ -	$ -
2021	$ -	$ -	$ -	$ -	$ -	$ -

Home | Base Models | Base Model Cost Calcs | Feeder Results | Cap Costs | O&M Costs | Labor Costs | Sales Tax | Assumptions and Notes

READY

Figure 3.5. Cost model "Home" sheet with models selected

It should be noted that at this point the "Home" sheet displays cost estimates. The additional user inputs are optional for users with more detailed information and are not required to be changed in order for the model to generate results.

If the user is aware of specific equipment costs they can enter them at this time. This value should be a pretax price since taxes are applied within the model. These prices should not include any aspect of installation costs. Figure 3.6 is a screen shot of this user input on the "Cap Costs" sheet.

Capitol Expenses			
	Item	Pre Tax Cost (2017$)	Unit
ALL	Smart Meter and Radio	$ 300	each
Fiber	Wireless to fiber uplink switch	$ 1,000	each
	Weatherproof Enclosure	$ 300	each
	Cable	$ 2.61	ft
	Termination Connectors	$ 50	each
	12 Port Switch	$ 1,000	each
Mesh	Collector	$ 5,000	each
	Repeator	$ 5,000	each
Cellular	Contract	$ 120	Meter/Year

*Preset with reasonably assumed prices - can be changed if prices are known to be different

Figure 3.6. Cost model capital cost "Cap Costs" sheet

The values shown above are the default prices that were estimated by the research team and subject matter experts. If for some reason the model has been cleared of these values, the values above can be entered into the model to obtain cost estimates.

If the user is aware of specific equipment replacement schedules they can enter them at this time. Figure 3.**7** is a screen shot of this user input on the "O&M Costs" sheet.

Equipment Replacement Schedule																						
Replacement Schedule			% of Failures - Year																			
	Item	Initial Install Quantity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Home Equipment (Smart Meter and Radio)	0	5%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	4%	25%	50%
Fiber	Wireless to fiber uplink bridge	0	5%	1%	1%	1%	1%	1%	1%	1%	25%	45%	30%	1%	1%	1%	1%	1%	1%	1%	25%	45%
	Weatherproof Enclosure	0	5%	1%	1%	1%	1%	1%	1%	1%	25%	45%	30%	1%	1%	1%	1%	1%	1%	1%	25%	45%
	Cable	0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Termination Connectors	0	5%	1%	1%	1%	1%	1%	1%	1%	25%	45%	30%	1%	1%	1%	1%	1%	1%	1%	25%	45%
	12 Port Switch	0	5%	1%	1%	1%	1%	1%	1%	1%	25%	45%	30%	1%	1%	1%	1%	1%	1%	1%	25%	45%
Mesh	Collector	0	5%	1%	1%	1%	1%	1%	1%	1%	25%	45%	30%	1%	1%	1%	1%	1%	1%	1%	25%	45%
	Repeator	0	5%	1%	1%	1%	1%	1%	1%	1%	25%	45%	30%	1%	1%	1%	1%	1%	1%	1%	25%	45%

Figure 3.7. Cost model "O&M Costs" sheet

The values shown above are the default replacement schedules that were estimated by the research team and subject matter experts. It is assumed that a small amount of equipment will fail each year, slightly more in year 1 (the so-called "infant mortalities"). The smart meter and related equipment is assumed to have an average lifetime of 20 years. The fiber is assumed to not need replacement in the 20-year analysis. The remainder of the equipment included in the cost calculations is assumed to have a 10 year lifetime, meaning two replacements would be needed within the 20 year analysis for most of the installed equipment. If for some reason the model has been cleared of these values, the values in Figure 3.7 can be entered into the model to obtain cost estimates. It should be noted that if equipment is expected to need replacement multiple times within the 20 year analysis, the row totals would equal over 100%.

The above instructions include all of the current user inputs to the model. Any changes made beyond what is described above is not recommended and could lead to an inaccurate cost estimate.

4.0 Conclusion

This cost model is designed to assist ongoing research in the area of transactive energy by quantifying the costs of one of the most critical aspects of transactive systems, the possible communication systems. Beyond that, the estimates can be tailored to a specific location and size with multiple communication system options. As the potential implementation and benefits of transactive energy become better understood, it will be important to better understand the associated costs.

5.0 References

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