Some Simple Economics of TAC Allocation to Distributed Front-of-Meter Generation[1]

MEMO (DRAFT)

Benjamin F. Hobbs

Chair, CAISO Market Surveillance Committee and Schad Professor of Environmental Management, The Johns Hopkins University

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1. Purpose and Basic Assumptions

The purpose of this memo is to analyze the possible implications for power supply of implementation of a proposal for exempting load served by front-of-meter (or "wholesale") distributed generation (FOMDG) from the transmission access charges (TAC) presently borne by load in the California ISO.[2] These implications include changes in the amount of power provided by three basic sources: bulk power resources; FOMDG; and behind-the-meter DG (BTMDG); and changes in consumer prices and overall supply and network costs. Very simple assumptions are made so that the fundamental economic issues can be highlighted. Some of these assumptions include:

- simulation of long-run supply response using a single representative hour;
- supply curves that describe how bulk supply and FOMDG react to the locational marginal prices they face;
- a supply curve for BTMDG that represents the response of consumers to changed retail prices;
- retail competition such (i) that all retail consumers pay the same price of supply plus bulk network costs (the TAC) and distribution network costs, and (ii) the entire financial benefit of exempting load served by FOMDG from TAC is realized by the FOMDG. This is modelled by assuming there are two types of load serving entities (LSEs):
    - one that has no FOMDG, and passes through its TAC plus the cost of bulk supply to consumers, just as now, tacking on the average (per kWh) cost of the distribution network to consumer net demand ("customer energy downflow"); and
    - the other type of has contracts for FOMDG equal to customer energy downflow, and so would pay no TAC under the proposal. Assuming a competitive retail market, this type of LSE pays FOMDG the bulk power price plus the avoided TAC, and passes those costs through to the consumer.[3]

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[1] Thanks to Jim Bushnell, Scott Harvey, and Chris Devon for their comments, but the responsibility for any errors or opinions is the author's.

[2] See C. Lewis., Clean Coalition, "Briefing on transmission access charge wholesale billing determinant initiative," Presented at the Market Surveillance Committee Meeting, June 17, 2016, Folsom, CA, available at caiso.com.

[3] Because this assumption about LSEs affects who pays and doesn't pay the TAC in the end, I address it further here. Of course other more complex assumptions about the structure of LSE competition could be made. Yet in a competitive retail environment, it would be expected that consumers would pay the marginal cost of supplying their load. Given a fixed amount of FOMDG, that marginal cost would be the bulk power price plus TAC. Similarly, given retail competition and the level of load a LSE is serving, FOMDG would expect to be paid its marginal benefit

In the next section, I summarize the basic conclusions of the analysis. Section 3 discusses some aspects of the problem that haven't been modeled, and discusses some of their implications. Section 4 presents the detailed mathematical model, whose numerical results for a range of cases are shown in Section 5. Two sets of cases are discussed: the situation in which network costs (both EHV and distribution costs) are largely fixed and relatively unaffected by the location of generation; and the situation in which shifting generation among bulk power resources, FOMDG, and BTMDG will change the amount of network investment needed and the resulting costs.

2. Summary of Conclusions

The economic net benefits of basing TAC charges on net flow from the EHV system (i.e., consumer net demand minus front-of-meter distributed generation = FOMDG), rather than on consumer net demand depends on how the resulting increase in FOMDG (1) affects bulk power generation and behind-the-meter DG (BTMDG) and their costs, and (2) what the resulting change is in EHV and distribution network costs.

Whether it is bulk generation or BTMDG that decreases more as a result of the additional FOMDG depends on their relative elasticities of supply. The economic efficiency impacts of those shifts depend on the size of the TAC and the divergence of retail rates from marginal cost of serving load. In addition, whether there are avoidable EHV and/or distribution network costs arising from changes in bulk and FOMDG generation also affects the overall net benefits of changing the TAC charging system.

If EHV and distribution network costs are fixed, under the above basic assumptions concerning the TAC charging system, $/kWh retail rates will increase. That is because the TAC will be determined by dividing the fixed EHV cost by a smaller number of MWh (load net of FOMDG, rather than load), and retail competition will ensure that LSEs will charge load the marginal cost of service, and will pay FOMDG the marginal value of their supply, including TAC savings. The increase in rates will incent additional BTMDG; the increased BTMDG and FOMDG means that bulk generation and bulk prices will decrease. If retail rates reflect average distribution costs and are well above marginal costs of bulk supply, *this change will mean that the total cost of supply will increase. That is, allocation of TAC costs to load net of FOMDG would in that case likely decrease market efficiency if total network costs are relative fixed.* This conclusion is robust to the changes in assumptions concerning supply elasticities and fixed network costs.

On the other hand, if marginal avoided EHV and/or distribution network costs are similar to average EHV costs, then the increases in DG could result in lower total generation and network costs of supply, or at least partially mitigate the cost increases described in the previous paragraph. *Thus, the key tradeoff is between increased inefficiency of supply (if increased FOMDG is at the expense of cheaper bulk supply, and either has no effect on BTMDG or increases it) and saved network costs.*

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to the LSE purchasing its power, which would be the avoided payment for bulk power plus the TAC cost savings to the LSE, because the LSE is buying one more MWh of FORMDG and one less MWh of bulk power.

I now contrast my conclusions to those of the Clean Coalition.[4] They conclude that (i) the proposed TAC reallocation would provide value to DG through avoided TAC, making them more competitive in procurement decisions; (ii) Increased deployment of distributed energy resources (DER) would occur; (iii) this deployment slow the growth of (or even decrease) TAC rates over time; and (iv) savings of billions in delayed or avoided transmission investments would result. My model is structured so that (i) occurs—FOMDG receives a higher net price, and would expand the amount of FOMDG over time, consistent with (ii). However, whether TAC rates increase or decrease depend on how much transmission investment changes as a result of increases in FOMDG production, which occurs at the expense of cheaper bulk supply and may be accompanied by increases in costly BTMDG.

- If only minor network cost savings result, the TAC expenses borne by consumers will increase on a $/MWh basis. What consumers pay for TAC will also increase on a total $ basis, because FOMDG, in effect, will receive an extra payment from consumers equal to the TAC times its generation.
- But if the cost of the network is roughly proportional to transmission energy downflow, then transmission revenue requirements and total TAC payments would decrease, as Clean Coalition argues. However, some of the network cost savings might be offset by increased supply inefficiencies, by diverting supply from inexpensive bulk sources to more expensive DG both in front of and behind the meter. If the network cost savings are minor, then those supply inefficiencies result in a net increase in the cost of meeting load (the sum of resource and network costs).

These results indicate that in order to assess the magnitude and even the sign of net market benefits of the proposal to reallocate TAC costs so that FOMDG benefits, it is important to understand:

- The elasticities of supply for bulk generation, FOMDG, and BTMDG;
- The effect of load changes on distribution costs, and changes in load minus FOMDG upon EHV network costs and revenue requirements; and
- The structure of retail rates, especially the recovery of distribution network costs.

3. Some Model Limitations and Possible Extensions

It is desirable to consider how the following complications could affect these conclusions:

- Resistance losses. These would increase the benefits of distributed generation, and would lessen the inefficiency resulting from purchasing fewer kWh from cheaper bulk generation and more kWh from more costly DG. FOMDG's impacts on losses might be quite different from BTMDG's impact, depending on DG siting and output profiles.
- A switch from volumetric (per kWh) TAC and distribution network charges to either per peak kW charges or customer charges. Such a switch might conceivably be encouraged by implementation of the proposed TAC reallocation. That kind of switch could dampen the response of BTMDG to changes in customer rates, and lower the inefficiency that results from shifting generation from bulk sources to BTMDG. However, a shift to a demand charge might

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[4] Op. cit.

incent inefficient investments in BTM storage instead, unless the demand charges reflect the marginal avoided cost of distribution and EHV network expansion.

- Shifts in generation among bulk sources, FOMDG, and BTMDG could have other system cost impacts that are not considered here, including congestion, local reliability, and interconnection upgrades. These changes might enhance or decrease the efficiency impacts of those shifts.

4. The Model

Consider the below schematic of a power system with:

- ***A bulk (EHV) system*** that has two cost components: (1) network cost ("transmission revenue requirement") as a function of bulk generation ($F_{EHV}(S_B)$, in \$/hr), and (2) bulk supply cost. Bulk supply's response to the bulk price of power P_B (\$/MWh) is described by the constant-elasticity supply function $S_B = \alpha_B P_B^{\varepsilon_B}$. The cost of bulk supply is the integral of the inverse supply function (price/marginal cost as function of quantity supplied). This energy flows from the EHV system through the EHV-distribution interface ("transmission energy downflow").
- ***A distribution system*** that also has two cost components: (1) network cost ($F_D(S_B + S_D)$ in \$/hr as a function of bulk and FOMDG supply $S_B + S_D$ (MW) that is flowing through to the customer, and (2) front-of-meter DG supply cost. DG supply's response to the price it receives for power is P_D (\$/MWh) is described by the constant-elasticity supply function $S_D = \alpha_D P_D^{\varepsilon_D}$. The cost of that DG supply is the integral of the inverse supply function (price/marginal cost as function of quantity supplied).
- ***A retail customer*** who consumes fixed amount D (MW) and who also has behind-the-meter DG (BTMDG) (S_R, in MW). That DG supply's response to the retail price P_R (\$/MWh) is described by the constant-elasticity supply function $S_R = \alpha_R P_R^{\varepsilon_R}$. The cost of that DG supply is the integral of the inverse supply function (price/marginal cost as function of quantity supplied).[5]

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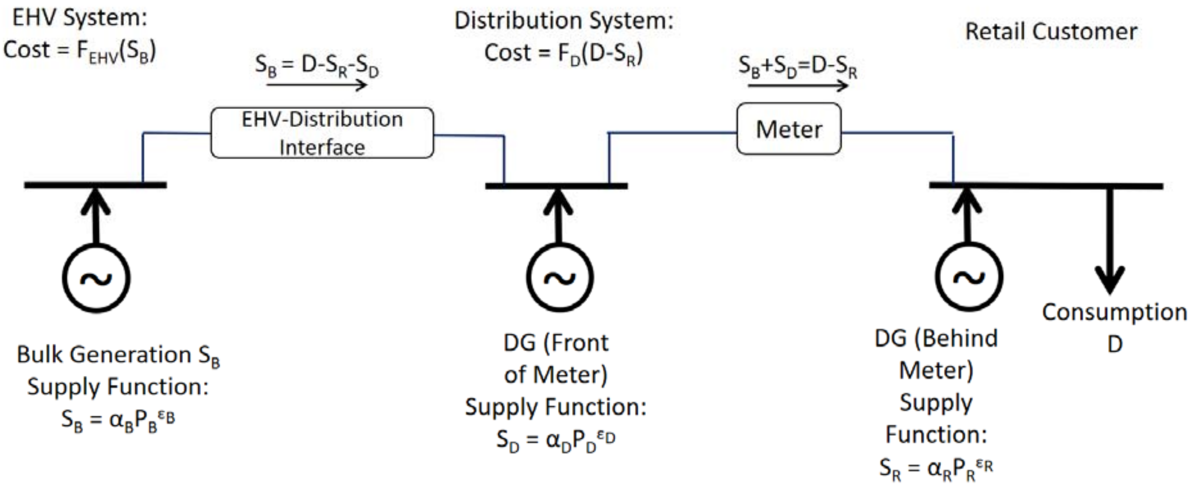
[5] "BTMDG" could be generalized to include consumer energy efficiency and demand response, but for simplicity are omitted.



Assuming competitive conditions and average cost-based retail ratemaking, and disregarding technical details such as losses, congestion, and time-varying load and variable renewables allows a simple market equilibrium model to be defined by the following conditions:

- *Supply curves:* Each type of supply responds to the relevant price by following its supply curve (conditions (1)-(3) below);
- *FOMDG price-TAC relationship:* The price received by FOMDG is the same as that receive by bulk generation under the present TAC allocation system (condition (4)), or equals the bulk power price plus the TAC if instead TAC is allocated to load net of FOMDG (condition (4')));
- *Retail price definition:* Retail price equals the bulk power price plus TAC plus the average distribution network cost (conditions (5) and (5')); and
- *Market clearing:* Consumption equals the sum of the amounts provided by the three supply sources (condition (6)).

Solving those conditions simultaneously for a given set of supply, network, and demand parameters yields the prices and quantities supplied for each of the three sources, as well as total social cost (supply plus network costs). By comparing the solutions for the two TAC allocations systems (represented by conditions (1)(2)(3)(4)(5)(6) and (1)(2)(3)(4')(5')(6)) for various parameterizations, we can draw some conclusions about the general nature of the market efficiency effects of reallocating TAC to load net of FOMDG.

In mathematical terms, those conditions are:

$S_B = \alpha_B P_B^{\varepsilon_B}$ (1)

$S_D = \alpha_D P_D^{\varepsilon D}$ (2)

$S_R = \alpha_R P_R^{\varepsilon R}$ (3)

$P_B = P_D$ (4) (present TAC system);
$P_B = P_D + TAC = P_D + F_{EHV}(S_B)/(D-S_R-S_D)$ (4') (alternative TAC system)

$P_R = TAC + F_D(D-S_R)/(D-S_R) + P_B = F_{EHV}(S_B)/(D-S_R) + F_D(D-S_R)/(D-S_R) + P_B$

(5) (present TAC system);

$P_R = TAC + F_D(D\text{-}S_R)/(D\text{-}S_R) + P_B = F_{EHV}(S_B)/(D\text{-}S_R\text{-}S_D) + F_D(D\text{-}S_R)/(D\text{-}S_R) + P_B$

(5’) (alternative TAC system)[6]

$D = S_B+S_D+S_R$ (6)

5. Parameters and Simulation Results

5.1 Fixed EHV and Distribution Costs

In the base case, the following parameters are assumed:

$D = 10$ MW

$F_D = \$500/\text{hr}$; $F_{EHV} = \$150/\text{hr}$

$S_B = P_B^{0.5}$; $S_D = 0.2P_D^{0.5}$; $S_R = 0.2P_R^{0.5}$

For each supply, an elasticity of 0.5 is assumed. For any given price, there would be five times as much bulk power supplied as either FOMDG or BTMDG.

The following table compares the prices, supply sources, and costs of the present and alternative TAC systems, where the present system assigns all EHV grid costs to net consumer load $D\text{-}S_R$, while the alternative assigns those costs to net load minus FOMDG (i.e., $D\text{-}S_R\text{-}S_D$).

Fixed Network Costs/Base Case	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.47	1.29	2.24	41.80	41.80	125.58	650.00	201.94	851.94
Alternative TAC	6.17	1.58	2.25	38.04	62.36	126.90	650.00	206.34	856.34
								Increase in Cost	4.40

Under these assumptions, changing the allocation of TAC increases FOMDG generation, as would be expected (from 1.29 to 1.58 MW) because the price received by that generation goes up from \$41.80/MWh to \$62.36/MWh. (I.e., the market value of such generation increases by the avoided TAC charge, which is about \$20/MWh.) The total supply from other sources (bulk and BTMDG) has to decrease by an equal amount in order to meet the fixed demand D of 10 MW. That overall decrease is obtained by the net effect of a still larger decrease in bulk supply and a slight increase in BTMDG (the latter increase incented by the approximately 1% increase in retail prices due to the reallocation of TAC). Basically, the growth in DG on the distribution grid mainly displaces bulk generation; this increases overall supply costs because the displaced bulk generation is less expensive (about \$40/MWh) than the incremental supply of FOMDG (about \$50/MWh, on average).

This shift, and the magnitude of the resulting cost changes, depends on the supply elasticity assumptions. The following four tables look at four different elasticity assumptions. (These

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[6] (5) and (5’) can be shown to be expressable by the same condition: retail price = (total network cost plus total bulk + FOMDR supply payments)/net consumer load:

$P_R = (F_D(D\text{-}S_R) + F_{EHV}(S_B) + P_BS_B + P_DS_D)/(D\text{-}S_R)$ (5”) assumptions included halved elasticity for all three sources; and halved elasticity for one source at a time. Supply function parameters α are adjusted so that the present TAC proposal results in the same equilibrium as the base case). Decreasing all the elasticities by half results in a roughly proportional decrease in the cost impacts of changing TAC allocation. The other assumptions also show reduced cost impacts to varying degrees. The qualitative results are the same, however as the base case; the increase in FOMDG mainly acts to displace bulk generation, accompanied by a slight increase in BTMDG due to a retail rate increase.

Fixed Network Costs/Halved Elasticities for all Supply	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.47	1.29	2.24	41.80	41.80	125.58	650.00	121.16	771.16
Alternative TAC	6.33	1.43	2.25	38.34	62.05	126.52	650.00	123.05	773.05
								Increase in Cost	1.89

Fixed Network Costs/Halved Bulk Supply Elasticity	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.47	1.29	2.24	41.80	41.80	125.58	650.00	165.90	815.90
Alternative TAC	6.22	1.55	2.23	35.84	59.95	124.30	650.00	167.93	817.93
								Increase in Cost	2.03

Fixed Network Costs/ Halved FOMDG Supply Elasticity	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.47	1.29	2.24	41.80	41.80	125.58	650.00	201.94	844.73
Alternative TAC	6.30	1.44	2.26	39.70	63.50	128.14	650.00	198.30	848.30
								Increase in Cost	3.57

Fixed Network Costs/Halved BTMDG Supply Elasticity	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.47	1.29	2.24	41.80	41.80	125.58	650.00	201.94	814.41
Alternative TAC	6.17	1.58	2.25	38.11	62.40	126.90	650.00	168.30	818.30
								Increase in Cost	3.89

The shift in supply and the resulting efficiency impacts also depends on the magnitude of the EHV and distribution system fixed costs, which are \$500/hr and \$150/hr respectively. The next three tables show the impact of halving the fixed costs of the EHV network; the distribution system fixed costs; and both systems' fixed costs, respectively. Generally, when both fixed costs are halved, the efficiency impacts fall by about 75%, which is consistent with the general result that the impact of price distortions upon welfare is proportional to the square of the deviation between price and true social marginal cost.

Fixed Network Costs/Halved Network Fixed Costs	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.79	1.36	1.85	46.08	46.08	85.98	325.00	178.25	503.25
Alternative TAC	6.65	1.49	1.86	44.25	55.53	86.23	325.00	179.10	504.10
								Increase in Cost	0.85

Fixed Network Costs/Halved Bulk Network Fixed Cost	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.54	1.31	2.15	42.75	42.75	116.03	575.00	195.12	770.12
Alternative TAC	6.39	1.45	2.16	40.86	52.59	116.35	575.00	196.16	771.16
								Increase in Cost	1.04

Fixed Network Costs/ Halved Distribution Fixed Cost	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.71	1.34	1.95	45.04	45.04	94.71	400.00	182.36	582.36
Alternative TAC	6.43	1.61	1.96	41.39	64.71	95.79	400.00	185.97	585.97
								Increase in Cost	3.61

5.2 EHV and Distribution Costs That Depend on Flows

The above conclusions result from assuming that EHV and distribution network costs do not depend on the amount of bulk or FOMDG supply accommodated by the network. Here, I consider alternative assumptions on the opposite extreme, in which network costs are proportional to the flows accommodated. The first case considers EHV costs to be proportional to S_B, but distribution network costs are fixed; while the second case instead considers distribution costs to be proportional to S_B+S_D, but EHV network costs are fixed. The last case assumes that both EHV and distribution system network costs are proportional to flows. Cost parameters are selected so that the present TAC system results in the same equilibrium supply and prices as the base case in the first table above.

The results in the first and third tables below show that because FOMDG would primarily displace bulk generation, then if the EHV grid costs are variable (proportion to bulk supply), the result would be enough savings in network costs to yield a net cost savings from the proposed TAC system. Under our assumptions, the proposal would provide a premium to FOMDG that is the same as the EHV network cost savings, and this would be more efficient. On the other hand, if only distribution network costs are variable (and not EHV network costs), then the alternative TAC proposal would increase costs for the same reasons as in the cases in the previous subsection.

Therefore, a key question is the extent to which reduction in bulk generation (or reduction in the growth rate of bulk power generation) would decrease EHV network costs. If those costs are largely fixed (with few or no transmission additions being avoided as a result of lower bulk generation), then the efficiency benefits of the alternative TAC proposal are small or negative.

Variable EHV Network Costs ($F_{EHV} = 23.2S_B$)	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.47	1.29	2.24	41.80	41.80	125.58	650.00	201.94	851.94
Alternative TAC	6.19	1.57	2.24	38.28	61.48	125.95	643.54	205.33	848.87
								Increase in Cost	-3.07

Variable Distribution Network Costs ($F_D = 64.443(S_D+S_B)$)	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.47	1.29	2.24	41.80	41.80	125.58	650.00	201.94	851.94
Alternative TAC	6.17	1.58	2.25	38.05	62.37	126.81	649.29	206.27	855.56
								Increase in Cost	3.62

Variable EHV and Distribution Network Costs	S_B	S_D	S_R	P_B	P_D	P_R	Network Cost	Supply Cost	Total Cost
Present TAC	6.47	1.29	2.24	41.80	41.80	125.58	650.00	201.94	851.94
Alternative TAC	6.19	1.57	2.24	38.28	61.48	125.93	643.35	205.31	848.66
								Increase in Cost	-3.28