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A Classification of Revenue Metering Arrangements for Renewable Generation at Transmission Interconnection Points

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Abstract

Renewable generation at transmission voltages arrives as clusters of assets, in which photovoltaic capacity and battery storage owned by several parties share a single point of interconnection, and the resulting metering data is distributed to several recipients. Engineering literature treats revenue metering as a measurement-accuracy problem and pays limited attention to the configuration of the arrangement itself. This review classifies revenue metering arrangements at transmission interconnection points into four types, described here as interconnection, intra-connection, interchange, and integration, which are distinguished by the number of parties receiving revenue-grade data, the location of the settlement boundary, the direction of data flow, and the number of generation owners above that boundary. The channel budget of the revenue log is then developed as a design constraint governing how much physical infrastructure a project must build. A worked budget shows a demand of 22 channels against a device capacity of 16, resolved by distributing data across a main meter and a sub-meter while replicating status channels in both. Generalization yields a lower bound on the device count such that the effective capacity of a device equals its nominal capacity, reduced by the shared status channels. An 800 MW co-located facility at 345 kV illustrates the framework.

Keywords: *Revenue Metering, Transmission Interconnection, Renewable Generation, Battery Energy Storage, Point of Interconnection, Metering Channel Capacity, Settlement Boundary.*

INTRODUCTION

A single point of interconnection can accommodate photovoltaic capacity and battery storage owned by more than one party, and the metering data generated there is sent to more than one recipient. Interconnection queues in the United States show the scale of this shift, since more than half of the storage capacity proposed in them is in hybrid configurations co-located with solar or wind (Manocha et al., 2025).

Engineering literature on revenue metering has concentrated on measurement accuracy. Work in this area examines how harmonic content in the load current changes meter readings, since those readings form the basis of financial settlement (Kampik et al., 2024). Related work addresses the accuracy limits of instrument transformers in high-voltage substations and their migration toward digital outputs under IEC 61850-9-2 (Kim et al., 2024), and traces measurement error to the direction of harmonic power, to load properties, and to manufacturing differences among devices (Yang et al., 2024).

A second body of work examines co-located hybrid plants, covering sizing methodology, optimization technique, energy management, and control strategy (Bade et al., 2024). Economic analysis shows that hybridization improves utilization of existing grid infrastructure (Chinaris et al., 2025), and capacity expansion modeling shows that co-location at a single interconnection point reduces the grid connection capacity a system requires (Manocha et al., 2025).

Neither body of work treats the configuration of the metering arrangement as a design object. The first asks how well a device measures, and the second asks how much capacity to build and where. A question sits between them, covering how many parties receive settlement-quality data from a single point, where the settlement boundary falls, and what those answers require of the equipment. A search of journal databases from 2021 to 2026 returned no framework that separates metering arrangements by these criteria.

METHODS

This work is a conceptual review. No original empirical study

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was conducted, and no primary datasets were generated or analyzed. The classification rests on regulatory and market documents governing generator interconnection and settlement data, manufacturer documentation for settlement meters and controllers, and the author's professional practice across interconnection projects at 69 through 765 kV.

The four types describe the space of arrangements encountered across transmission and distribution metering practice, while the focus here falls on their appearance at transmission voltages. Intra-connection occurs at the distribution and community scale more often, and it enters the discussion because it fixes the settlement boundary by contrast with the other three types.

Separation among the types rests on four attributes: the number of parties receiving revenue-grade data from one point, the location of the settlement boundary with respect to the physical point of interconnection, the direction of data flow across one-way aggregation, division among recipients and bilateral exchange, and the number of generation owners above the boundary. The classification derives from practice within the regulatory context of the United States; therefore, transfer to other jurisdictions requires verification against local standards, and all cost figures are estimates provided by the author without independent audit.

RESULTS

A Four-Type Classification of Metering Arrangements

The first type is interconnection, where one or more generation owners connect their resources to a single utility, and that utility purchases and distributes the revenue-billing data produced at the boundary. The settlement boundary coincides with the physical point of interconnection, and data flow runs one way toward a single counterparty. This arrangement covers most transmission interconnections between 69 and 345 kV, and its channel demand follows from the count of feeder points terminating there.

The second type is intra-connection, where revenue billing data from one metering point is shared among two or more utilities. The settlement boundary remains at the point of interconnection while the data is divided downstream by recipient, an arrangement adopted by distribution and community solar projects. Channel demand exceeds that of the interconnection case because each recipient requires its own view of the measured quantities, and data belonging to one utility remains protected through access control and module-level segregation.

The third type is interchange, where multiple streams of metering data move between multiple owners and multiple utilities. The settlement boundary is distributed across several points, and data flow is bilateral, so channel demand is highest here, since each pair of counterparties requires segregated quantities. The same word carries a different meaning in the reliability standards of the North American Electric Reliability Corporation, where interchange denotes the transfer of energy between balancing authorities under a formal coordination procedure. Usage in this review is confined to the exchange of metering data.

The fourth type is integration, in which a generating facility delivers revenue-billing data to two or more utilities along the transmission path, with metering points between the facility and the final delivery point. The settlement boundary sits at an intermediate location, where metering equipment serves as a pass-through for data belonging to parties further along the path, and channel demand recurs at each such point.

The four types are not mutually exclusive. A project can present the attributes of integration and interchange at once, with data passing through an intermediate metering point and moving bilaterally among counterparties beyond it. Classification then proceeds attribute by attribute, and the resulting profile identifies which channel demands apply. Table 1 summarizes the attributes that separate the four types.

Table 1. Attributes separating the four metering arrangement types

Attribute	Interconnection	Intra-connection	Interchange	Integration
Parties receiving revenue-grade data	One utility	Two or more utilities	Several utilities and several owners	Two or more utilities along the path
Settlement boundary	At the physical point of interconnection	At the point, data divided downstream	Distributed across several boundaries	Intermediate point on the path
Direction of data flow	One-way aggregation	One-way, divided by recipient	Bilateral exchange	Cascaded through intermediate metering
Generation owners above the boundary	One or several	One as a rule	Several	One or several
Voltage level of common occurrence	69 to 345 kV	Distribution and community scale	Transmission, multi-utility corridors	115 to 345 kV
Implication for the channel budget	Demand set by feeder count at one point	Duplication across recipients	Highest demand, segregation per counterparty	Demand recurs at each intermediate point

Selecting an Arrangement

Assignment of a project to one of the four types follows from four questions asked in order. The first asks whether more than one party receives revenue-grade data from the point, and a negative answer identifies interconnection and ends the procedure. The second asks whether data flows in both directions between counterparties, thereby identifying interchange. The third asks whether a metering point lies between the facility and the final delivery point, thereby identifying integration. A project reaching the fourth question, on whether billing data divides among utilities at the boundary, falls under intra-connection.

Budget dominates the decision from the perspective of the owner of the generating resource, with capital cost, operating cost, return on investment, and the speed of reaching commercial operation governing the choice. Decision authority rests with those owners, and the utility accepts the resulting configuration. On the utility side, channel and memory limits of the metering devices constrain what can be accepted, alongside aggregation capability, the method of loss compensation, and the engineering effort required for controller programming and field testing.

Compliance with the reliability standards of the North American Electric Reliability Corporation and with the orders of the Federal Energy Regulatory Commission is a condition of admission, since a violation of the interconnection agreements blocks onboarding approval. Requirements for settlement data also differ among market operators, with reported quantities, reporting intervals, and the treatment of co-located facilities varying across the California, New York, and Midcontinent Independent System Operators, so an arrangement designed for one set of requirements does not transfer without review. Participation rules in ancillary service markets have been opened to a wider set of distributed resources, thereby expanding the quantities that a metering arrangement must report (Gulotta et al., 2023).

The Channel Budget as a Governing Constraint

The revenue log of a settlement meter holds a fixed number of channels. Each channel records one measured quantity at the interval required for settlement, and the depth of storage follows from the retention period the utility must maintain. Device memory sets the ceiling, and a quantity without an allocated channel does not reach settlement, whatever its magnitude.

Channel demand follows from the composition of flows crossing the point, where each metered flow requires two channels, one for real power and one for reactive power. Demand N is given by Equation 1.

$$N = 2(F + A + R) + S \qquad (1)$$

Here F counts resource feeder points, A auxiliary load points, R retail load points, and S status signal channels.

A facility with two photovoltaic feeder points and two storage feeder points per owner, across two owners, presents eight channels of photovoltaic resource flow and eight of storage resource flow. Auxiliary load adds two channels, and station service, which the utility settles as retail load, adds two more. Status signaling adds two channels, one carrying a heartbeat indicator that confirms the communication path and one carrying the idle flag. Total demand reaches 22 channels, while the revenue log of the settlement meters applied here holds 16. Figure 1 shows the shortfall and its resolution.

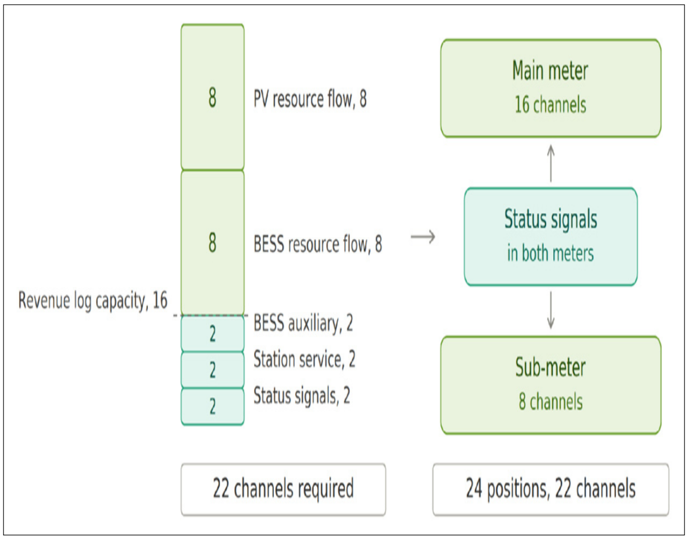

Fig. 1. Channel demand at the point of interconnection against revenue log capacity

Distribution of the 22 channels across two devices resolves the shortfall. A main meter carries 16 channels and a sub-meter carries eight, yielding 24 positions for 22 distinct quantities. The two additional positions arise because the heartbeat channel and the idle flag channel appear in both devices, since each reports the status of its own communication path and cannot validate the data it holds without them.

The arrangement generalizes. For M devices of capacity C, with N distinct channels of which S are status channels replicated in every device, the requirement takes the form of Equation 2.

$$MC \geq N + S(M - 1) \qquad (2)$$

Equation 2 rearranges to Equation 3, the minimum device count.

$$M \geq \frac{N - S}{C - S} \qquad (3)$$

The effective capacity of a device equals C − S, so shared status channels introduce overhead that scales with the device count and limits the benefit of consolidation. Table 2 applies Equation 3 at a capacity of 16 channels and two shared status channels.

Table 2. Minimum settlement device count as the facility size grows

Resource feeder points	Resource channels	Total unique channels	Minimum devices at C = 16, S = 2
2	4	10	1
4	8	14	1
6	12	18	2
8	16	22	2
10	20	26	2
14	28	34	3

The measurement chain proceeds from resource meters through summation meters of the SEL-735 type, which aggregate and calculate, to a compact metering controller of the SEL-3530-4 type holding the Modbus register map, and from there to settlement meters of the ION8650A type at the boundary. Collection uses MV-90, and loss compensation is computed for each path element and combined into a dynamic loss scheme. Legacy protocols in the Modbus family carry bulk data across multiple nodes over long distances, making the identification of the location and type of a malfunction a demanding task (Kumar et al., 2023).

Storage installations introduce metering categories that generation alone does not produce. Power crosses the boundary in both directions at the same point, so the arrangement records wholesale export and back-feed with equal fidelity. Auxiliary load forms a separate measured category, and station service within a wholesale facility is treated as retail load, so one location serves two regulatory regimes and two recipients. The idle flag serves as a settlement-relevant signal and consumes a channel accordingly. Measurement accuracy here depends on the behavior of instrument transformers with distorted currents, since inverter-based resources produce harmonic content that degrades transformation accuracy (Kaczmarek et al., 2022). Shared settlement also places data from different parties within a single device, where segregation is achieved through modules within the revenue log and through access control.

Functional Layers of the Metering Architecture

The metering architecture at a co-located facility is divided into functional layers. Resource meters record flows at photovoltaic and storage feeder points, production tax credit meters record generation from photovoltaic and wind installations, and auxiliary meters record storage auxiliary load and station service. Summation meters aggregate and calculate; settlement meters produce revenue-billing quantities; and indication meters carry supervisory control and data acquisition quantities over Modbus. Figure 2 shows how these layers relate across the boundary.

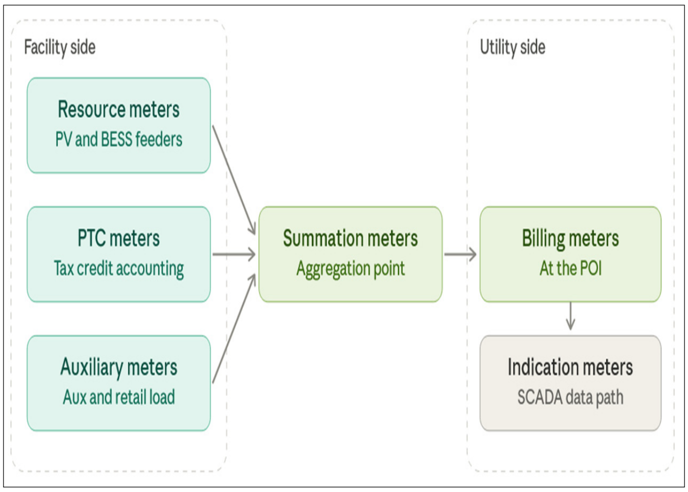

Fig. 2. Functional layers of the metering architecture

Production tax credit meters record energy from photovoltaic and wind installations, store it, and forward it to the summation meters, the utility revenue billing meters, and onward to the market operator. The record determines tax benefits and supports after-the-fact settlement quantities. Storage installations do not qualify as renewable generation in this accounting, so the layer covers only a portion of a co-located facility while excluding the rest.

A metering schematic carries what the revenue log reads. Production tax credit meters and indication meters carry quantities outside revenue billing, so they are omitted from the drawing while forming part of the installed equipment, and a schematic that reads as an inventory of devices misrepresents the arrangement.

Illustrative Case: A 345 kV Co-located Facility

The framework applies to a co-located photovoltaic and storage facility in New Mexico, interconnected at 345 kV, comprising 400 MW of photovoltaic capacity and 400 MW of storage. Atrisco Solar and Atrisco BESS, owned by Clenera, account for 600 MW, and Quail Ranch Solar and Quail Ranch BESS account for the remaining 200 MW. Public Service Company of New Mexico operates the utility side. The project began with the Atrisco installations and expanded when a second owner joined, which carries a lesson: the channel budget is verified at every expansion, since each added feeder point consumes two channels.

Applying the selection procedure of Section 3.2, the facility presents the attributes of integration and of interchange at once. Revenue billing data spans more than one utility; metering points sit between the generating facility and the final delivery point; and data moves in both directions among counterparties. The channel budget in Section 3.3 resulted in a shortfall of 22 channels against a capacity of 16. Consolidation at a single boundary avoided the need for a separate substation, control house, transmission line, and a set of power and instrumentation equipment for each owner.

DISCUSSION

The framework supplies a shared vocabulary for interconnection agreements. Naming an arrangement by type fixes the counterparties, the settlement boundary, and the direction of data flow before procurement begins, and it moves verification of the channel budget to early design, where a shortfall requires a revision of the metering plan and a late discovery incurs equipment and schedule penalties.

Consolidation at one boundary avoids the construction that separate arrangements would require. The author estimates the avoided cost at the facility of Section 3.5 at 32 million dollars, resting on the cost of new 345 kV overhead line construction, which the author places at 5 million dollars per mile for a single-circuit design over easy terrain and 7 million dollars per mile for a double-circuit design, under New Mexico conditions from 2023 to 2025. The figure has not undergone an independent audit and depends on the length of the avoided line, so it serves as an order-of-magnitude estimate. Independent modeling by Manocha et al. (2025) and by Chinaris et al. (2025) supports the direction of the effect.

Consolidation carries costs that offset part of the savings. Programming within the compact metering controller is complex, and translating protocols from summation meters through the controller to settlement meters compounds that complexity, so a fault in the register mapping can require effort comparable to programming the project from the start. Verification resists automation, since each register and each module setting requires manual confirmation before certification. Field commissioning tests each resource individually, even though the data arrives as a combined dataset. The capital gain is paid for in part through commissioning effort, so a project with a short avoided route and few owners may find that the balance does not favor consolidation.

Several limitations bound the conclusions. No primary data support the quantitative claims beyond the author's professional practice; the regulatory context is the United States, and one project provides the illustration. The ceiling of 16 channels describes the configuration used in that project and is not a property of an equipment class, since capacity varies by device model and retention period. Further work can formalize the model for an arbitrary number of resources and compare settlement data requirements across market operators.

CONCLUSION

Revenue metering arrangements at transmission interconnection points are divided into four types separated by the number of parties receiving settlement-quality data, the location of the settlement boundary, the direction of data flow, and the number of generation owners above that boundary. The types are interconnection, intra-connection, interchange, and integration; they are not mutually exclusive, so a project profile can combine attributes of more than one.

The channel budget of the revenue log governs how much physical infrastructure a project must build. A demand of 22 channels against a capacity of 16 forced the distribution of data across a main meter and a sub-meter at an 800 MW facility at 345 kV. Generalization yields a lower bound on the device count such that the effective capacity of a device equals its nominal capacity minus the number of shared status channels, so consolidation delivers diminishing returns as facilities grow.

The metering arrangement and the device population at a facility remain distinct objects, since production tax credit meters and indication meters exist at a facility yet are absent from the schematic, which reflects what the revenue log reads. Consolidation avoids substations, control houses, transmission lines, and duplicated equipment, and transfers part of those savings into controller programming, protocol translation, manual verification, and separate field commissioning. Projects with short avoided routes and few owners should weigh that transfer before adopting a consolidated arrangement.

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