Connecting the Dots:
How inverters have, can, and should be used for ancillary services

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History of Inverter Participation

Sparse grid connected systems seen as negligible. Interconnection rules designed to enforce non-participation.

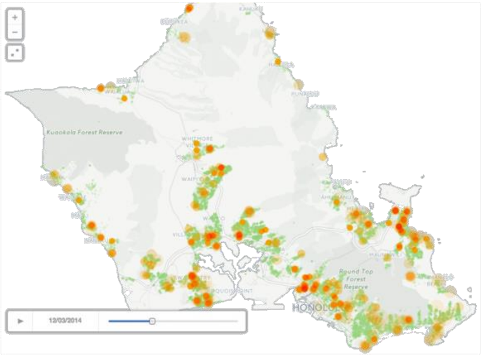
UL 1741
P1547 Initiated

1999 | 2001 | 2003 | 2005 | 2011 | 2012 | 2014 | 2015 | 2016 | 2017

UL 1741 Revised
Synchronized with
IEEE 929 and 519

History of Inverter Participation

Rapidly falling costs acceleration adoption. Issues begin to be observed on high penetration circuits.



UL 1741
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IEEE 1547 Approved
Underlying jurisdiction for Interconnections

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UL 1741 Revised
Synchronized with IEEE 929

IEEE 1547.1 Published
Testing of Interconnection Systems

UL 1741 Revised
Harmonized with 1547.1

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History of Inverter Participation

Industry responds by developing new interconnection behaviors. The “smart inverter” is born.

1999 | 2001 | 2003 | 2005 | 2011 | 2012 | 2014 | 2015 | 2016 | 2017

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Rule 21 Settlement

IEEE 1547A (.1A)
Amendment to allow Rule 21 and Rule 14H

UL 1741 Supplement A
Certification for Rule 21 and Rule 14H

HECO implements *mandatory* ride-through

History of Inverter Participation

Communication and interoperability standards to enable coordinated DER participation in grid regulation and control.

1999 2001 2003 2005 2011 2012 2014 2015 2016 2017

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Certification for Rule 21 and Rule 14H

HECO implements *mandatory* ride-through

IEEE P1547 Revision
Will supersede Rule 21 as the national standard.

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Smart Inverter Functions

Good Citizen Behaviors

- **Grid Entry Fee**
- **Outside ANSI limits**
- **Functions**
  - voltage ride through
  - frequency ride through
  - return-to-service ramp-rate
  - freq-watt with ANSI dead-band
  - volt-var with ANSI dead-band
  - volt-watt with ANSI dead-band

Ancillary Functions

- **Historically non-free service**
- **Within ANSI limits**
- **More dependence on communication**
- **Functions**
  - commanded var
  - commanded power limiting
  - freq-watt within ANSI limits
  - volt-var within ANSI limits
  - volt-watt within ANSI limits

Fixed power factor = grey area
Reduces inverter power rating

Hurdles to Adoption

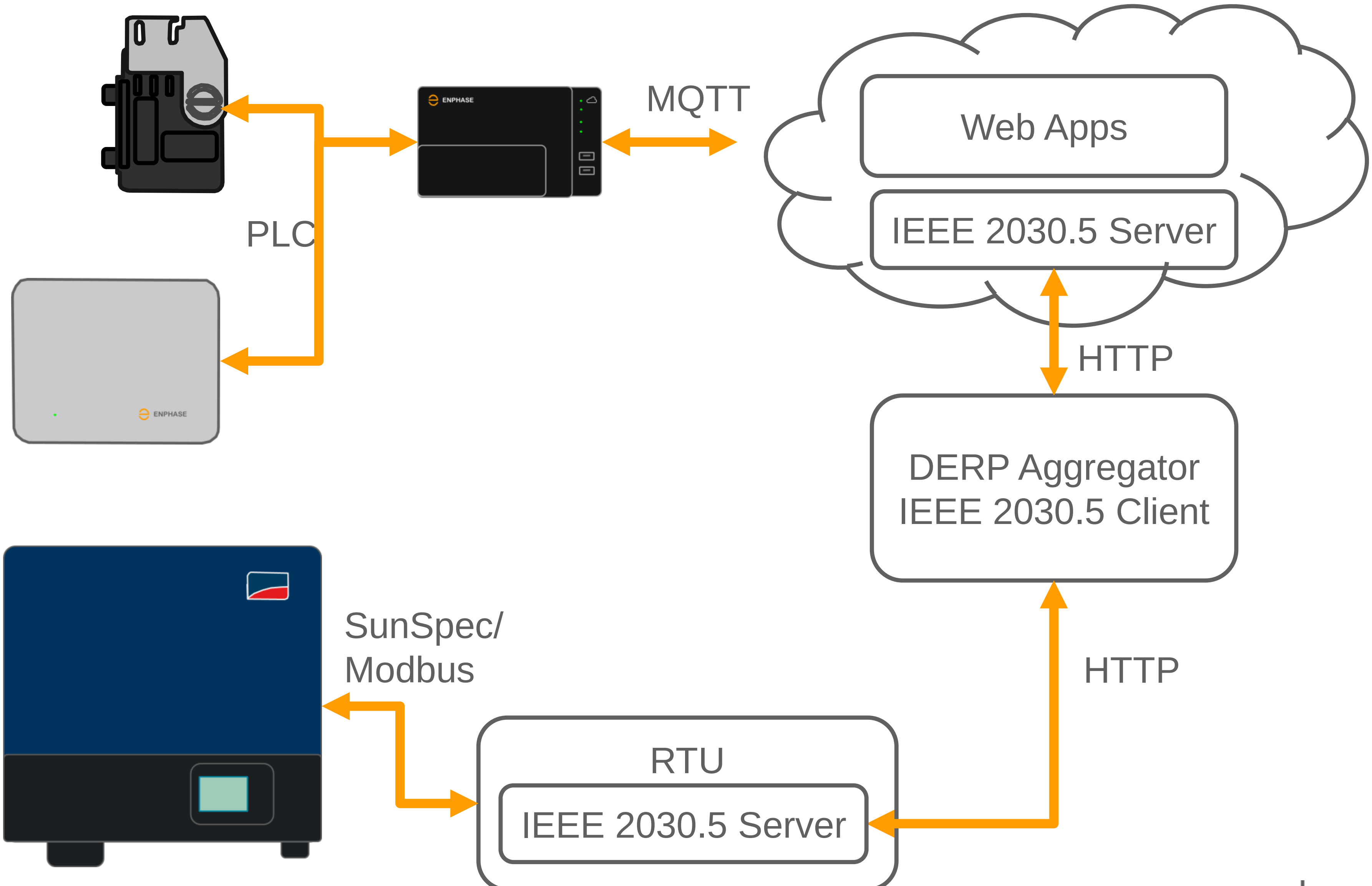
1. **Standardization**
   - Manufacturers can’t support everything and the kitchen sink
2. **Certification**
   - Interoperability and performance verification
3. **Communication (Security)**
   - New attack surfaces
4. **Scalability**
   - Exponential node increase
5. **Compensation**
   - How to implement appropriate incentives

Standardization

- **(currently) P1547 outlines 1 or 5 protocols be used**
  1. IEEE 2030.5 (SEP 2.0) – REST, HTTP, **IEC 61968/61850**, XML
  2. IEEE 1815 – DNP3
  3. Sunspec Modbus – **IEC 61850**, security?
  4. **IEC 61850**-8-1 over MMS
  5. **IEC 61850**-8-2 over XMPP

  ❖ Alternatives allowed under mutual agreement
- **Issues**
  1. No MQTT or CoAP - Emerging stars of the IoT space
     - Persistent, low latency, low bandwidth connections with millions of nodes
     - Flexibility vs. interoperability tradeoff
     - TLS not as well established as HTTP(S)
  2. Plugging security holes in option 3 may *create* interoperability issues
     - Sunspec more suited to site-level communications
     - 2030.5 designed to be run on-top of Sunspec

Idea: Cloud level compliance



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Certification and Compliance

- **UL1741 is just a product certification**
  - Product safety
  - Compliance with IEEE1547 allows grid connection
- **How are systems approved for ancillary services?**
  - 2030.5 (SEP 2.0) cert program for interoperability
  - P1547 does add interoperability (will be tested by 1741)
  - System level certification testing
  - Performance verification tests?
    - Self testing

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Communication

- **Network Media Options**
  - ECN
  - Public Internet
  - Cellular
  - Smart Meter Network
- **DER Media Options**
  - Ethernet
  - WiFi (IEEE 802.11)
  - Zigbee/Thread (IEEE 802.15.4)
  - Bluetooth (802.12)
  - Cellular
  - PLC
  - RS232
  - CANbus
- **DER Protocols**
  - Modbus/Sunspec
  - AllJoyn/IoTivity
  - REST API

Gateways as Area Controllers

1.5.3 Utility interactions directly with inverters or indirectly via a customer EMS

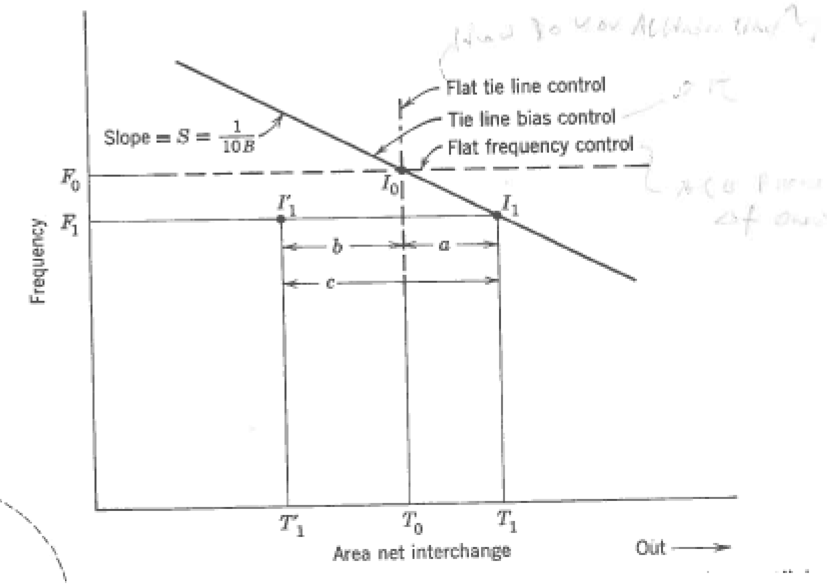
Utilities/ESPs can interact with inverter-based DER systems using different architectures. They may issue requests or commands directly to the DER systems either one-on-one or via broadcast/multicast communications.

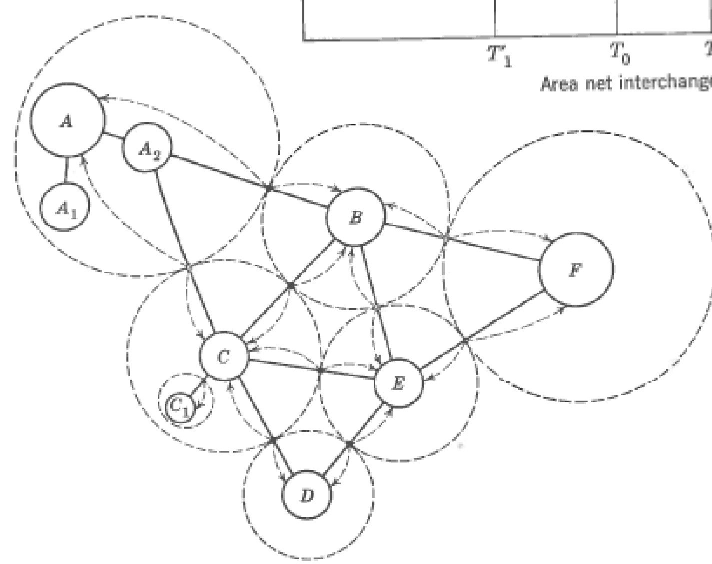
Alternatively, a customer EMS can help manage inverter-based DER system responses to the broadcast utility request, with the idea that this customer EMS will possibly be managing multiple inverter-based DER systems, customer appliances, other types of distributed generators and storage devices, and plug-in electric vehicles.

- **Local Energy Management Systems have some key advantages**
  - Access to local data, such as voltage, load, and resource constraints
  - Aggregation of data
  - Aggregation of commands
  - Better area economy through distribution
  - Communication Advantages
    - Secure internet connection with firewall
    - Bridging of communications protocols

Scalability– Tie Line Bias Control

- **The “United Pool” solved this problem in the 1940’s!**
- **Tie Line Bias Control**
  - Grid broken into “Areas”
  - Each Area has a “controller”
  - Meet “area requirement” by minimizing ACE
  - Matched bias setting
  - Optimize “area economy”
  - Manage resources
    - Generation
    - Sub-areas
      - Recursion!





Cohn, N. *Control of Generation and Power Flow on Interconnected Systems* New York: John Wiley & Sons, 1966. Print.

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Compensation

- **Utility driven pricing only techniques**
  - Time-Of-Use Pricing
  - Real-Time Pricing
  - Dynamic Pricing
- **Aggregator driven technologies**
  - Distribution System Operators
  - Virtual Power Plants
  - Transactive Energy and the Block-chain

var message = “Thank You!”

```
function _offer(uint energyUnits, int price, address seller)
private returns (bool success, bytes32 offerId) {
        if (energyUnits > 0) {
                offerId = sha3(energyUnits, price, seller, block.number);

                        Offer offer = offers[offerId];
                offer.energyUnits = energyUnits;
                offer.price = price;
                offer.seller = seller;
                success = true;
        } else {
                success = false;
                offerId = "";
        }
}

/*
 *@notice Only the offer seller is able to cancel the offer
 * @param offerId Id of the offer
 */    function cancel(bytes32 offerId) returns (bool success) {
```

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