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For power system expertise

TECHNICAL SESSION

"Distribution Network & Transformer Monitoring"

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& D2.53 WG - IoT for Power Industry

SHAPING OF THE POWER SECTOR BEYOND 2020

Agenda

Smart Grid Solutions

Introduction – DER & Network Issues

Distribution Network Management – Where data is King!

Distribution Transformer Monitoring

Advancing towards a Smart Grid

Smart Grid Solutions

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Distributed Energy Resources (DER)

- The increasing penetration of distributed energy resources (DERs) to electricity networks is changing power grids from a centralized system, served by large-scale generators, transmission and distribution networks, to ones with embedded small-scale DERs.
- In the evolving electricity system, customers benefit from using their DERs, such as energy storage systems (electric vehicles), rooftop solar photovoltaic (PV), to lower their electricity costs.
- Moreover, utilizing devices and energy management programs that enable load flexibility will help customers to act more as a grid resource to provide energy flexibility. The efficient integration of DER can also provide benefits to non-DER owners by lowering total system costs.

Smartening up the Grid

- Smartening up the electrical system has been one of the major goals towards modernizing the grid. Applying smart grid digital technology for the past decades has been the vehicle to do this. Initially the main emphasis through digital substations for a high-voltage transmission and smart meters on the distribution network.
- Improved pricing of sensors, as well as increased usage encouraged more applications. Their capabilities have improved, and their size became smaller, which resulted in more utilization. Today, advanced monitoring functions have been integrated into every segment of the grid, ranging from transmission components to reaching the behind-the-meter (BTM).
- The smaller size and lower prices have had a major impact by opening up the low-voltage levels of the distribution networks to the technology. Smart distribution equipment such as Smart Transformers, as well as switches, interrupters, and reclosers that can monitor and control feeders right up to the customer's meter.

Issue

Increased DER = Network Management

- Customer-connected DERs present an increasing operational challenge for a utility, as they currently sit outside of their direct control.
- DER operational data is usually unavailable to utility operators via SCADA and traditional distribution management systems (DMS).
- Traditional distribution systems were not however designed to take granular customer DER into account.
- The ability to manage, and ultimately optimize a much-more complex grid, is dependent upon having the visibility that comes with modelling all grid resources.
- The individual sporadic resources of DERs, as well as energy consumption pattern variations, once insignificant, now create a data void for utility distribution operators, as near real-time

Network Challenges

- The challenge for networks is that some of the available fixes are hard to implement on old infrastructure.
- Imagine a long feeder serving many customers, meaning that to maintain voltage in-tolerance for the last customer, the voltage closest to the transformer will leave the inverter very little headroom.
- The network provider can only adjust the voltage by changing the tap on the transformer if the transformer is new enough and has lower voltage taps available. The majority, however, of low voltage transformers don’t have that capacity, and transformer upgrades are expensive.
- Substation transformers are much more capable, but don’t offer granular voltage management.

Solar Generation vs Demand

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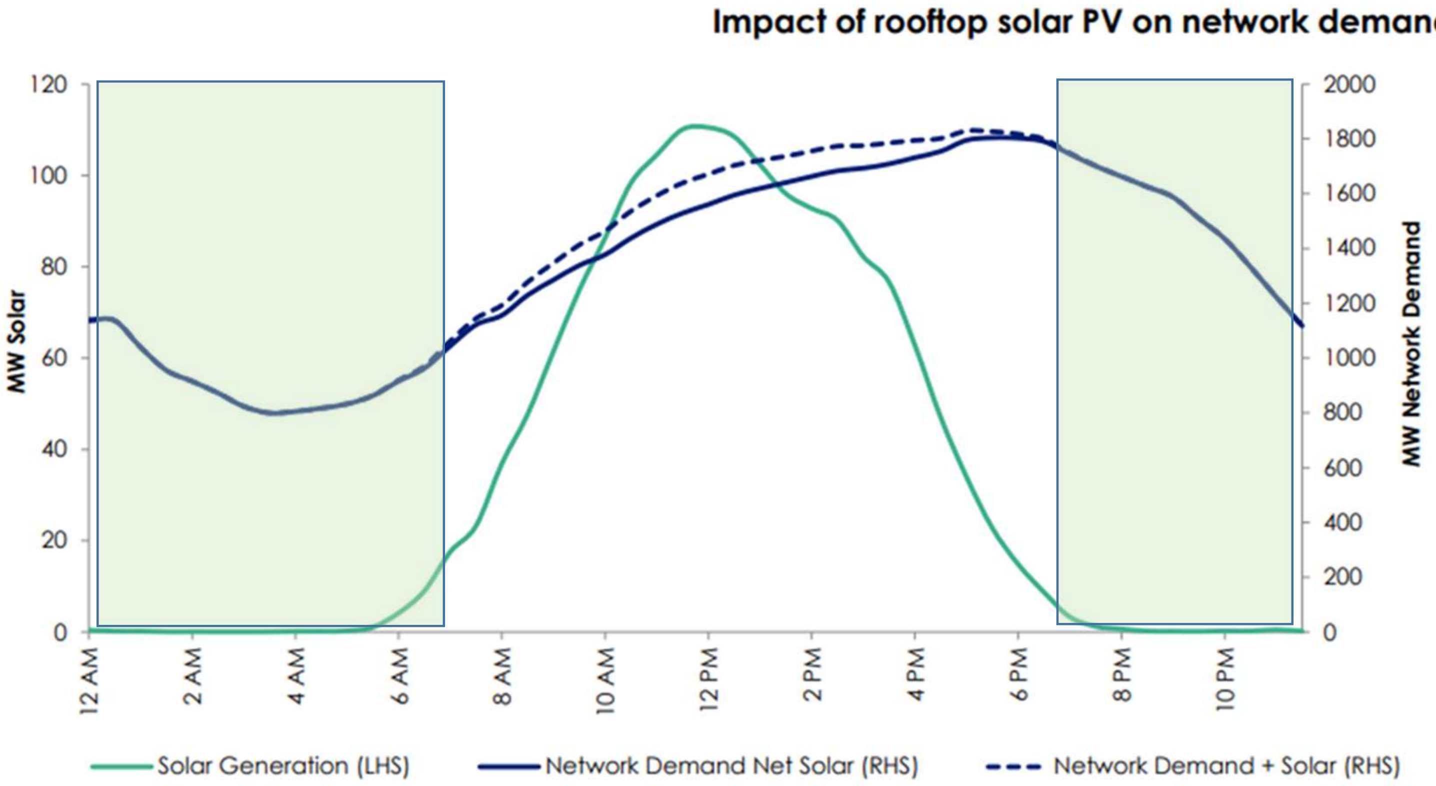

Problems Caused by Solar Inverters

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- The inverter has to be running at a higher voltage than the grid, so it can push power out (current flows from a point of higher voltage towards a point of lower voltage, never the other way around). The problem is every solar installation pushing power into the system lifts the network voltage just a little – and with tens of thousands of systems coming online each year, some systems are confronted with a grid with voltage outside inverter tolerance (the AS/NZS 4777.1 standard limits inverter voltage to 255V).
- The more granular the data-logging, the easier to see the impact on the customer..

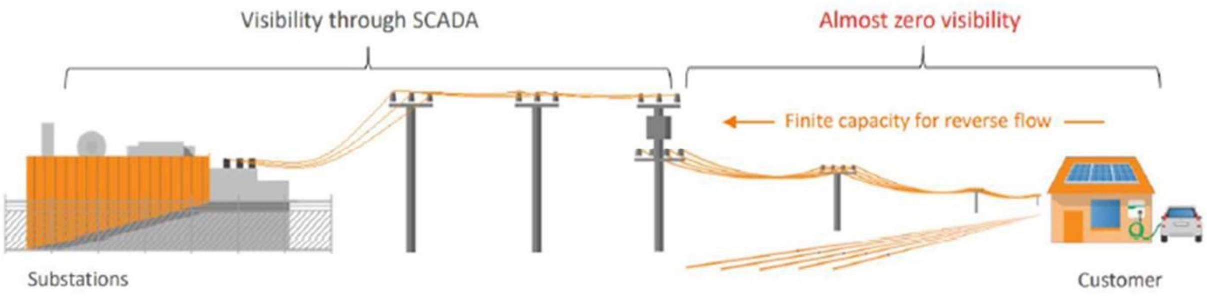

Figure 5: Limited LV Network Visibility for DNSPs (Source: AEMC, 2019)

Proposed Solutions

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Solutions for grid over voltage covered three main areas:

1. **Changes to solar inverters and their settings**
   - Australian Standards AS/NZS 4777 - Volt-var and volt-watt
   - Smart Invertors
2. **Upgrades to the grid**
   - New Transformers, tap changers, shorter distance, cabling and connections
   - Upgrading equipment for bi-directional flow – Voltage Regulating Relays (VRR)
3. **Changing electricity consumption patterns and generation ability**
   - Controlled loads, Export limits
   - Solar Sponges

Power Quality Issues

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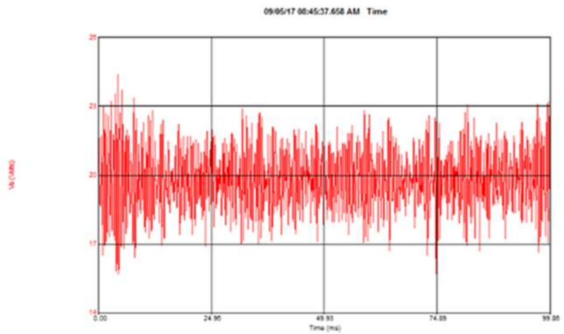
Power quality issues that arise with solar energy

The output of a solar panel is always fluctuating. This output goes through an inverter in order to convert the DC to AC. An unconditioned AC voltage can create various power quality issues.

- **Voltage fluctuation (dips & sags)**- core saturation, excessive heating and higher than normal inrush currents in motors.
- **Unbalance** - causes excessive heating and can burn out coils.
- **High speed transients -** can have adverse impacts on electronics.
- **Harmonics** - generate heating effects in equipment that contains coils.



EV Penetration

EV Impact – Charger Types

	Level 1 (AC)	Level 2 (AC)	Fast Charging (DC)	Ultra-Fast Charging (DC)
	2.4 - 3.7 kW	7 - 22 kW	50 kW	150 - 350 kW
	5 - 16 hrs	1 - 5 hrs	20 - 60 mins	10 - 40 mins
	10-20 km range per hr	30-120 km range per hr	250-500 km range per hr	1000+ km range per hr
	Residential	Residential, Workplace, Carparks	Metro, Destination, Commercial	Highway, Commercial Logistics

Typology of EV Charging

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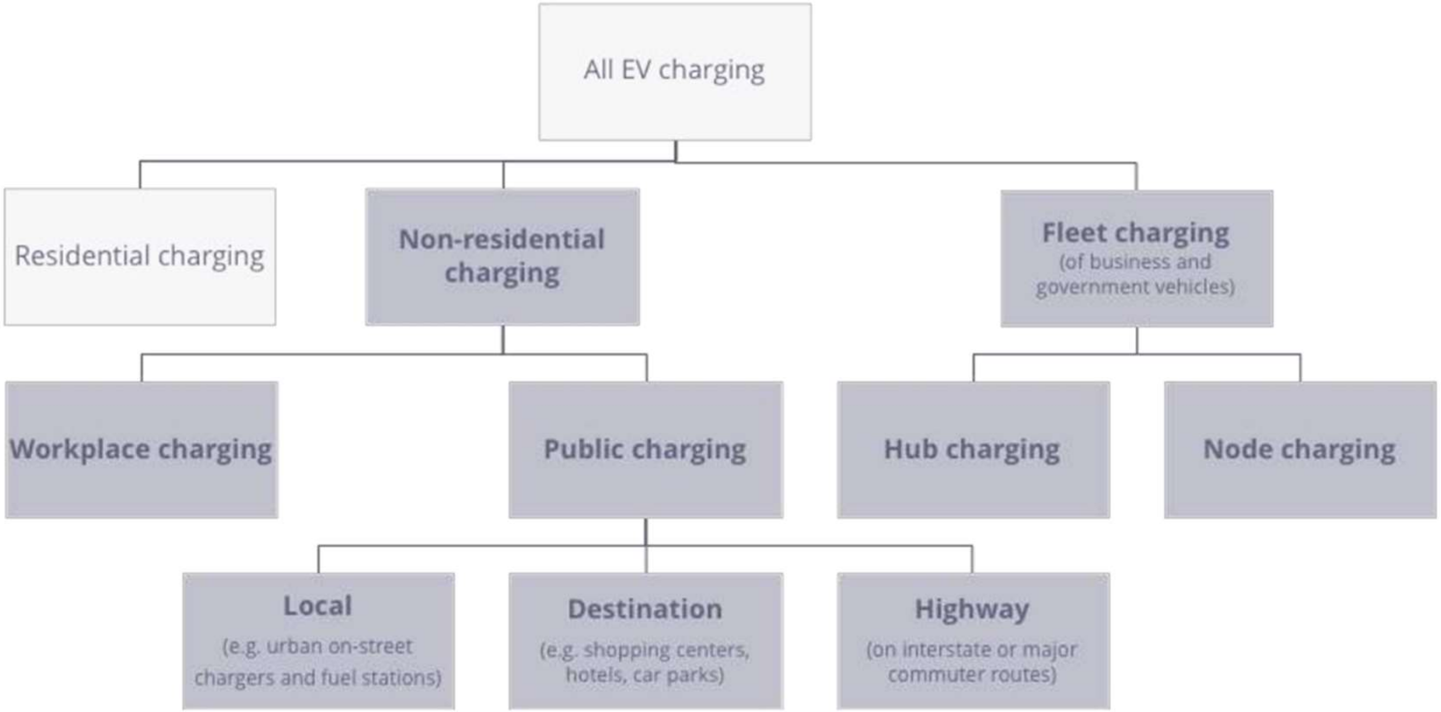

Figure 1: Typology of PEV charging

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EV charging hotspots

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- The factors that impact whether a hotspot will occur and its likely impact on the network include:
  - The available capacity of the upstream network assets
  - The number and type of chargers being used in a given area
  - The number and type of chargers connected to a given network asset
  - The utilization of those chargers
  - The start time and length of charging
  - The use of demand response
  - The presence of local generation and/or storage

EV Hotspot Management Options

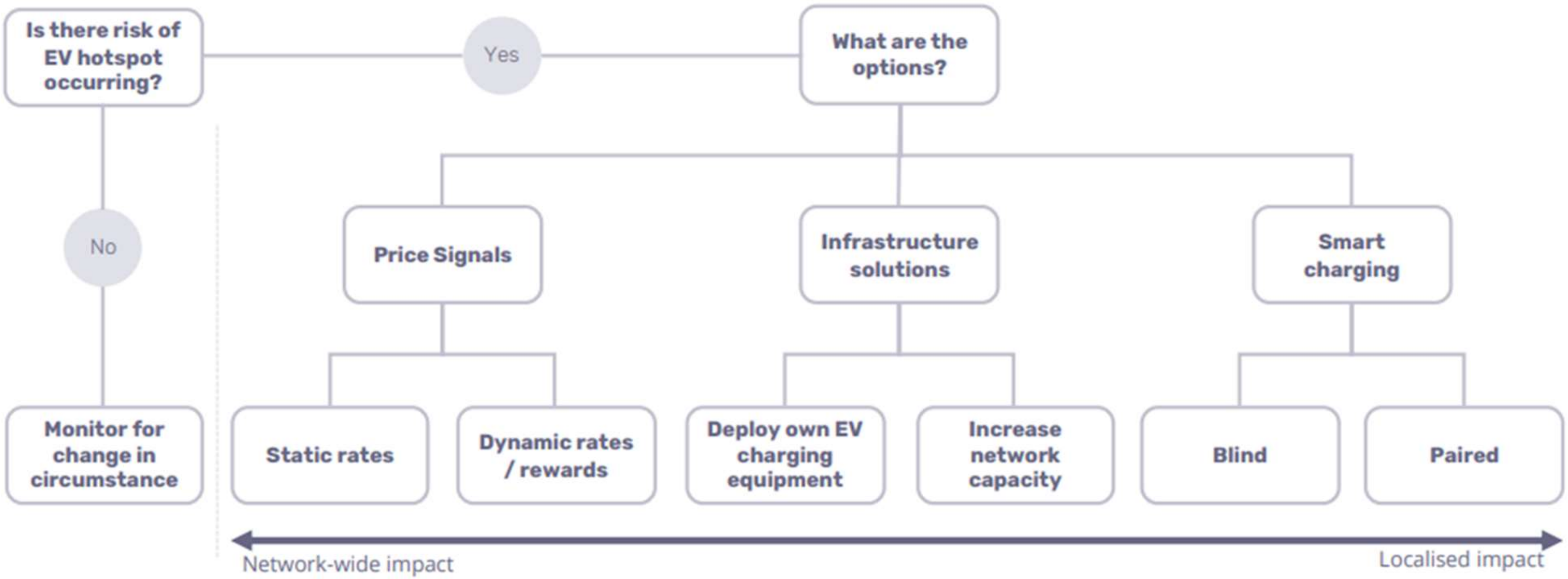

Figure 22: PEV hotspot management options

EV Smart Charging

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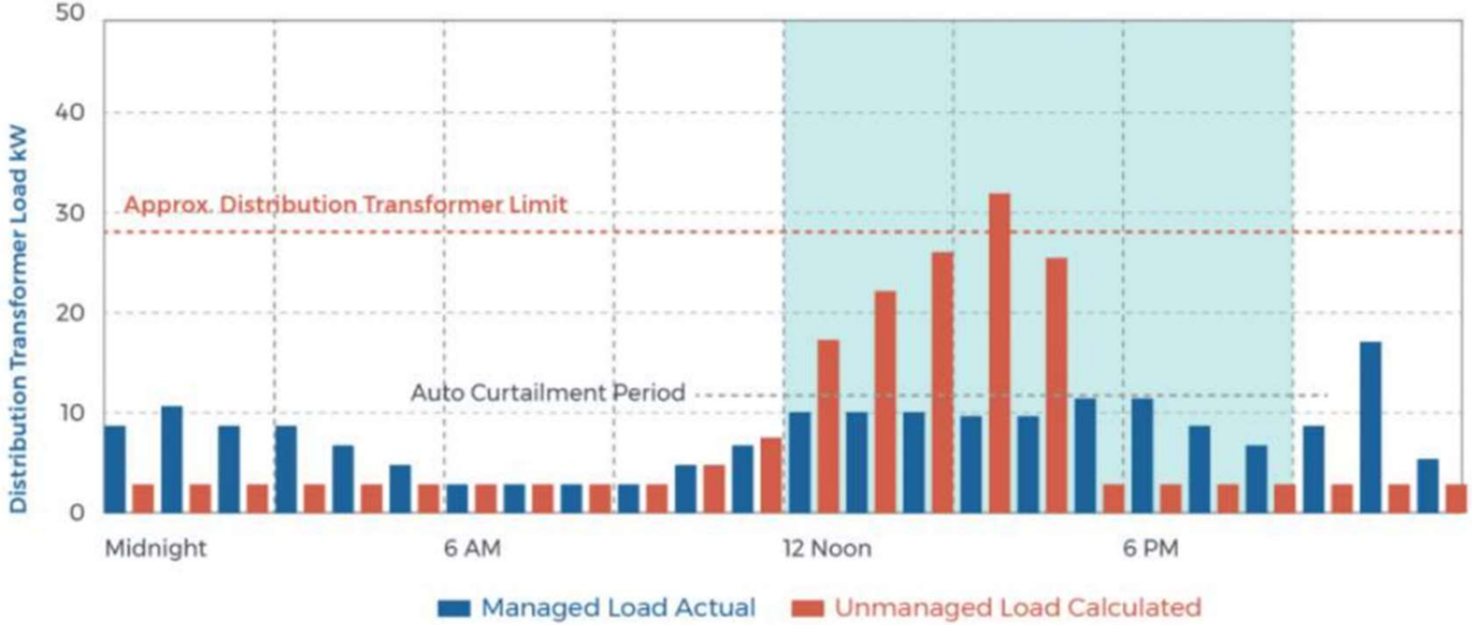

Figure 24: The results of the FleetCarma ChargeTO study - smart-charging program demonstrated the ability to reduce peak charging loads by half (55)

PV Penetration

Issues Associated with Rising DER Penetration

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Stakeholder	Category	Issue	Impacts
Customers with Solar PV	Investment	Connection Limits Export Limits	Connection standards can limit efficient investment choices in DER Connection standards can limit efficient operation of DER
		Inverter Curtailment	Inverter standards can reduce output and investment certainty
		Increased Energy Losses	Inverter standards can increase reactive power losses, reducing investment certainty
		Reduced Capacity	Inverter standards can increase reactive power, reducing inverter capacity and investment certainty
		Reduced Lifetime	Inverter standards can increase reactive power, reducing inverter lifetime, impacting investment certainty

Source: Energeia; Note: THD = Total Harmonic Distortion

Issues Associated with Rising DER Penetration

Stakeholder	Category	Issue	Impacts
Distribution Network	Power Quality	Over-Voltage	Excess generation can increase voltage above allowed thresholds
		Under-Voltage	Generation can increase voltage range, leading to under-voltage
		Flicker	Intermittent generation can lead to voltage flicker
		Harmonics (THD)	Inverters can inject additional harmonics
	Reliability	Thermal Overload	Generation levels can exceed thermal rating limit
	Safety	Protection Maloperation	Changes in generation and load patterns can break some schemes
		Islanding	Inverters can fail to disconnect, creating safety issue

Source: Energeia; Note: THD = Total Harmonic Distortion, Light Green indicates that issue is addressed by current inverter standards

Issues Associated with Rising DER Penetration

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Stakeholder	Category	Issue	Impacts
Distribution Network	System Security	Disturbance Ride-through	Inverters disconnect during disturbance, worsening the disturbance
		Under Frequency Shedding	Load shedding inverters can increase net load, worsening frequency
	Cost / Efficiency	Phase Imbalance	Inverters can be unevenly distributed, unbalancing the grid
		Forecasting Error	Stochastic inverter uptake and output can reduce forecast accuracy

Source: Energeia; Note: THD = Total Harmonic Distortion, Light Green indicates that issue is addressed by current inverter standards

Issues Associated with Rising DER Penetration

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Stakeholder	Category	Issue	Impacts
Generation, Transmission and Market Operations	Operability	Ramp Rate	Inverters can increase rate of change above system capabilities
	Reliability	Thermal Constraints	Large DER resources can overload thermal limits
	Safety	Fault Levels	Inverters can reduce fault current
	Cost / Efficiency	Forecasting Error	Uptake and operation can increase forecasting error
		Generation Curtailment	Curtailment of DER generation can increase wholesale market prices

Source: Energeia; Note: THD = Total Harmonic Distortion

Solution Costs by Invertor Penetration

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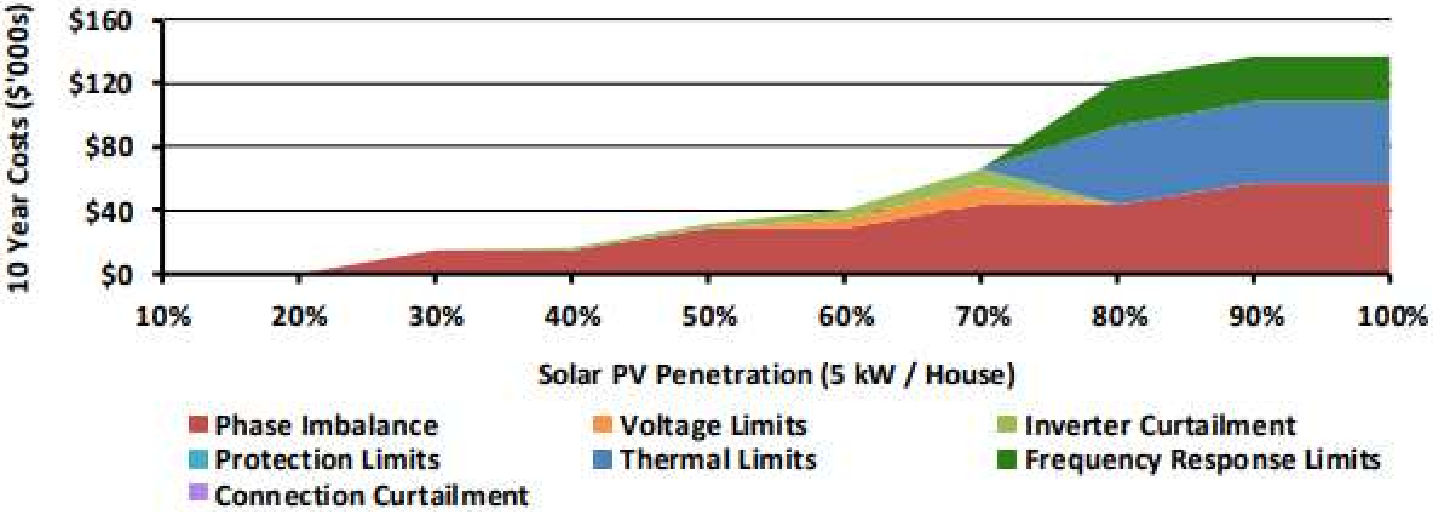
Illustration of Overhead, Urban LV Network Integration Solution Costs by Inverter Penetration Level



Source: Energeia,
Notes: 1. Transparent colours (i.e. Inverter Curtailment) indicates cost of solution is borne by consumers rather than by DNSPs

Network Management

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Network Modelling

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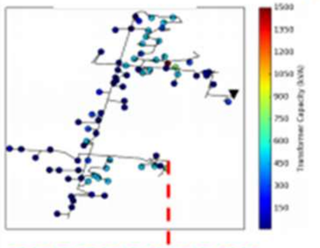
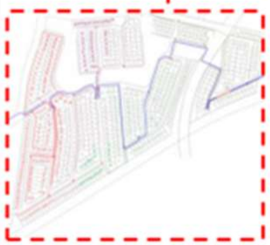
1. Introduction

The "HV-LV Analysis of Mini Grid Clusters" project was carried out to investigate the impacts of clusters of new PV-ready LV networks (100% PV) on an existing HV feeder.

2. HV – LV Network Modelling



- 22kV Feeder
- 79 Dist. Tx.
- 6.5MW Peak Demand



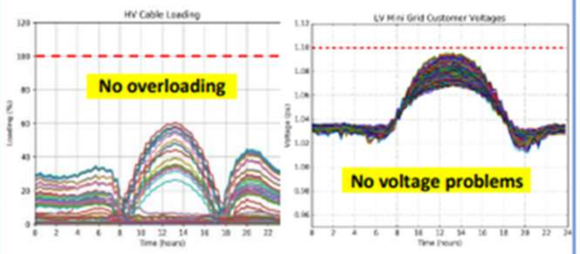
- 12 x 500kVA Tx. (22kV / 0.412kV)
- 4c / 240 sq.mm cables
- ~1400 Houses
- 100% PV – 4 kWp

Integrated HV-LV analysis, smart demand and generation data, time-series three-phase analysis.

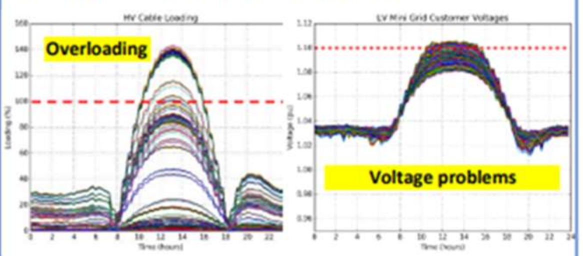
3. Impact Assessment

Impact assessment carried out for two cases, using data of a summer day with minimum midday demand.

Current (Minimal PV Penetration) HV Feeder State:



Future (50% PV Penetration) HV Feeder State:



4. Potential Solutions

Solutions Assessed	Line Utilization	Voltage Problems	Curtailment
No Solution	142%	9.3%	1.3%
Change OLTC Settings	147%	0%	0.2%
Change Volt-Watt Settings	98.4%	0%	55.9%
Enable Volt-Var Function	143%	1.15%	0.6%
PV Export Limit	99.5%	0%	57.3%
Grid-scale Storage	86.3%	0%	0%

4. Conclusions on Successful Solutions

- **Change Volt-Watt Settings**: High curtailment, requires extensive tuning, unfair curtailment depending on location in the network, uses existing assets.
- **PV export limit**: High curtailment, requires minimal tuning, uses existing assets.
- **Grid-scale Storage**: No curtailment, requires new assets (expensive).

Management Capabilities Required

Three key capabilities are identified as being required:

- **Advanced Distribution Management System (ADMS)** - the core platform for management of the High Voltage networks including substation protection and control across distribution networks.
- **Low Voltage (LV) network monitoring and visibility** - a portfolio of data streams from network monitoring devices at the LV network level. This will include data from network devices, smart meters, customer devices with the capability of secure integration of 3rd party information sources
- **Intelligent Grid Enablement** - a collection of enabling technologies to leverage and manage LV data, interact with the ADMS, the market/aggregators, customers to actively manage hosting capacity.

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Real-Time Analytics

- Currently data is generally collected from the network and then reviewed off-line for any analysis.
- Any insights are then manually transferred into action in the business.
- This is acceptable for longer term work like network planning but does not meet the needs of improving day to day operations, detecting unsafe conditions or maximizing real time utilization of the network, which is especially important with a growing range of DERs.
- It is expected that real time analytics and machine learning will form a key part of automated auditing of dynamic export connection agreements, ensuring that market participants are fulfilling their contractual obligations.
- The installation and maintenance cost of sensing is also reduced as modern analytical techniques are used to fill gaps and prioritize operational work.

ADMS & DERMS

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Big Data & Edge Computing

- Intelligent components is only part of the challenge because state-of-the-art devices need smarter control systems. Those cutting-edge control systems came in the form of standalone applications like distribution supervisory control and data acquisition systems (D-SCADA), distribution management systems (DMS), and outage management systems (OMS).
- Unfortunately as smarter equipment was deployed, a couple of hurdles had to be overcome. There was a lot of big data being produced, and it needed to be processed by each of the monitoring systems.
- Big data needs to be converted to actionable information. That is where big-data analytical software applications help along with cloud-based computing services.

ADMS

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- Applications such as D-SCADA, DMS, and OMS and their big data brought about features such as demand response systems, geographic information systems (GIS), and distribution network applications (DNA), but the level of complexity increased.
- It was apparent operators needed a common interface point to organize and intelligently manage the growing operational information and the number of elements. Some authorities described this as a convergence of information technology and operational technology. The blending produced several applications devoted to filling this need, but something was lacking. As the technology improved, real progress was made with the addition of the advanced distribution management system (ADMS).

DERMS

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- Think about ADMS as the integration of D-SCADA, OMS, DMS, GIS, DNA, and several other advanced software schemes into one common user platform designed to monitor, control, and optimize the distribution system. For the first time, the distribution operator was able estimate power flows, track outages, automated service restoration, control feeders, and predict outage on the distribution network, but changes were taking place everywhere.
- The commercial, industrial, and residential customers had embraced DER by installing record breaking amounts of DER technology. So much so, there were now two-way power flows. Because of this DER proliferation, utilities found they needed another type of management software to track what is taking place BTM; the distributed energy resource management systems (DERMS) filled the need.

Future Grid = Data Management

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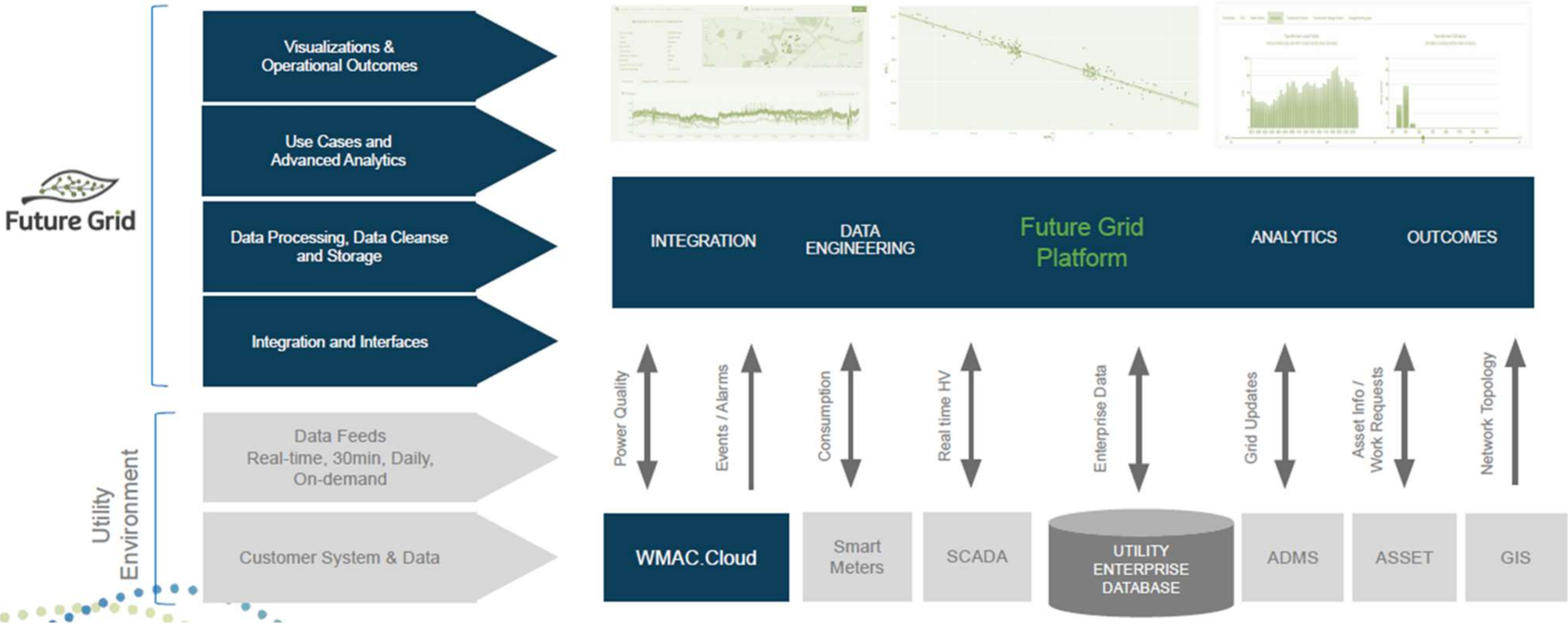

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AMI – Smart Meter

AMI - Dynamic Data Elements

- All data is collected at 5-minute intervals and made available in (near) real time.
- Site-level data is required to be captured using hardware that is accurate to class 1 (1% variance).
- DER level data is required to be captured using hardware that is accurate to class 4 (4% variance).

Table 3. Required Dynamic Data Elements

Required Data Point	Description	Units	Notes
Site Gross Load - Active/Reactive power	Total Active/Reactive power consumed by the customer (equals Imported + ∑DER generation – Exported - ∑DER consumed). Per phase is preferred with combined acceptable	kW/kVAr	Max, Min, Average
Site Active/Reactive exported power	Active/Reactive power exported from the site. Per phase is preferred with combined acceptable	kW/kVAr	Max, Min, Average
Site Active/Reactive imported power	Active/Reactive power imported from the grid to the site. Per phase is preferred with combined acceptable	kW/kVAr	Max, Min, Average
DER Generation - Active/Reactive power	Active/Reactive power generated by each DER. Per phase is preferred with combined acceptable	kW/kVAr	Max, Min, Average
DER Consumption - Active/Reactive power	Active/Reactive power consumed/stored by each DER. Per phase is preferred with combined acceptable	kW/kVAr	Max, Min, Average
Site Voltage	AC voltage over the period– measured at meter board. Recommended per phase with 10sec measurement interval	V	Max, Min, Average
Time	Accepted date format are yyyy-MM-ddThh:mm:ss or yyyy-MM-ddThh:mm:ss.sss	UTC	Date and time matched to AEMO VPP data (ISO 8601 format)

Phase Balancing & Tap Positions

Transformer tap to adjust local voltage level

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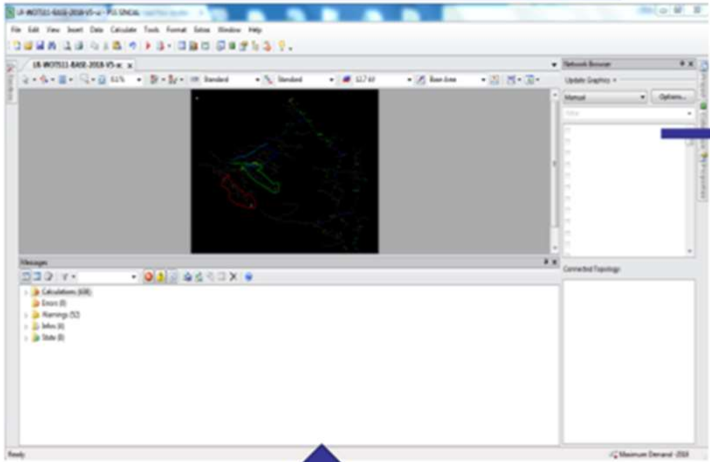
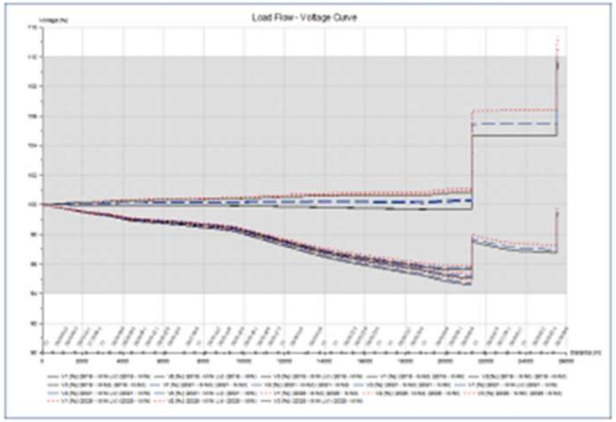
Power Flow Modeling and Simulation

Power flow model



Improved simulation results



AMI meter data

Distribution Monitoring

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Distribution Transformer Monitor (DTM)

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cloud
WMAC

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80% of benefits @ 20% of the cost

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Historically we have delivered benefits through smart meter data

Our assessment is that 70-80% of the Utility benefits can be delivered via WMAC.CLOUD

Fault Management

- Outage Detection (OVS) **
- Fault Location Identification **
- Loss of Neutral
- Transformer Loss of Neutral **
- Fire Prevention (Fuse Candling) **
- Blown HV Fuse **
- Phase outages for 3ph meters

Network Recommendations

- Planning User Interface **
- Transformer Utilization **
- Theft and Non-Technical Loss **
- Phase Identification
- Phase Balancing **
- Cross Reference and LV Mapping
- Network Recommendations **
- Profile Predictions (monthly data)

LV Voltage Management

- Power Quality Management **
- Dynamic Voltage Management **
- Transformer Constraint Management **
- High Voltage Management **

DER Enablement

- DER Hosting Capacity Management **
- DER Identification (solar, batt, EV)
- Air-conditioning Identification
- Electrical hot water Identification
- Solar installations that tripped

Finance and Billing

- Revenue Accruals for Network Billing
- Tariff Aggregations and Reporting

** Can be achieved with Transformer monitors

Communications

Networks & Communications

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- IoT applications have specific requirements such as long range, low data rate, low energy consumption, and cost effectiveness. The widely used short-range radio technologies (e.g., ZigBee, (Bluetooth) are not adapted for scenarios that require long range transmission.
- Solutions based on cellular communications (e.g., 2G, 3G, and 4G) can provide larger coverage, but they consume excessive device energy.
- Therefore, IoT applications' requirements have driven the emergence of a new wireless communication technology: low power wide area network (LPWAN).

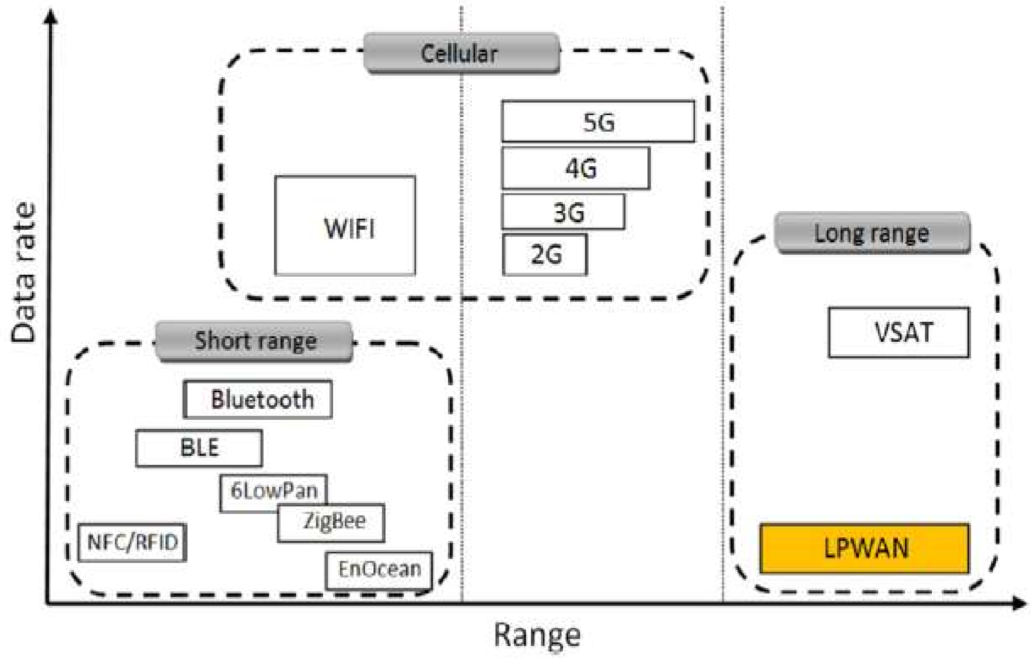

Fig. 1. Required data rate vs. range capacity of radio communication technologies: LPWAN positioning.

Transformer Monitoring

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Overloading of a Transformer

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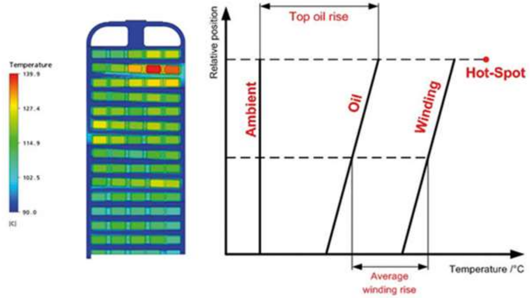
Overloading of transformers can cause different consequences:

- The temperatures of windings, insulation, oil etc. increase and can reach high levels.
- The leakage flux density increases, causing additional stray current heating in metallic parts linked by the flux.
- The moisture content in the paper insulation and in the oil increase with the temperature increase.
- Bushings, tap-changers, cable-end connections are exposed to higher stresses due to overloading



The factors affecting Transformer Ageing

Given a solid design and error-free manufacture, and an adequately protected network, then the factors that affect transformer ageing the most are:

- **Water, oxygen, oil aging products** (acids particularly) and particles of different origin are agents of degradation, that can shorten transformer life significantly under impact of **thermal, electric, electromagnetic and electrodynamics stresses**.
- There are three sources of excessive water in transformer insulation: Residual moisture in the "thick structural" components not removed during the factory dry out, ingress from the atmosphere, and aging (decomposition) of cellulose and oil.
- **Temperature**

Note - Loss of insulation life is irrecoverable.

Q_h	Relative Ageing Rate
92°C	0.5
98°C	**1.0**
104°C	2.0
110°C	4.0
134°C	64

Dissolved Gas Analysis (DGA)

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Gases : What gases, what fault?

FAULT INDICATION	FAULT GAS							
	CO	CO_2	CH_4	C_2H_2	C_2H_4	C_2H_6	O_2	H_2
Cellulose Aging	X	X						
Mineral oil decomposition			X	X	X	X		X
Leaks in oil expansion systems		X					X	
Thermal Faults – Cellulose	x	X	X				X	X
Thermal faults – Oil @150°C – 300°C			X			X		X
Thermal faults – Oil @300°C – 700°C			X		X	X		X
Thermal faults – Oil @ >700°C			X	X	X			X
Partial Discharge			X					X
Arching			X	X	X			X

Core, Coil & Tap Changer faults

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Windings

Core

OLTC

Image credit - Enging

Magnetizing Current Algorithm

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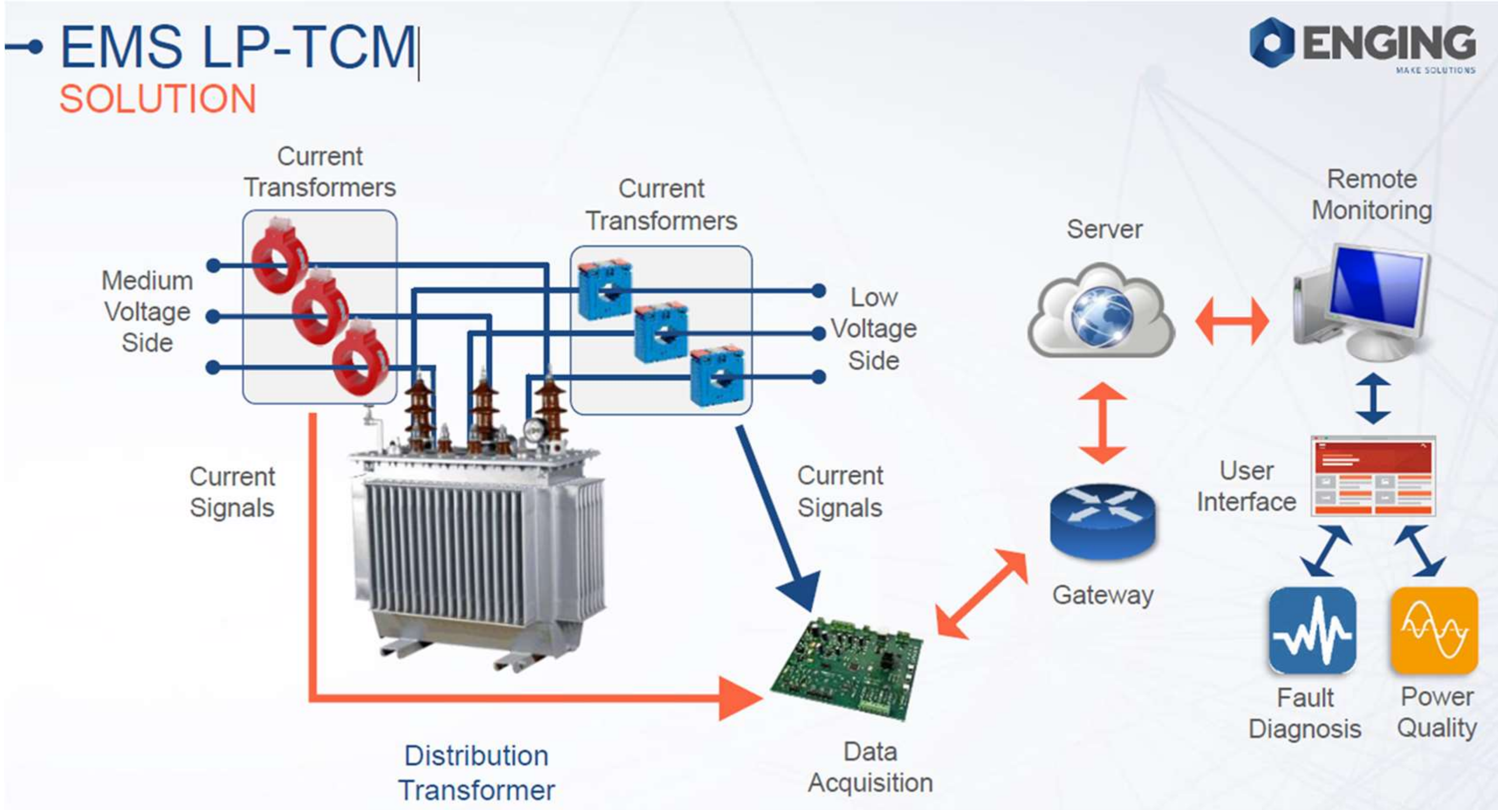

Artificial Intelligence (AI) & Machine Learning

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- AI possesses tremendous potential to transform the energy and utilities sector.
- In combination with other technologies like Big Data and IoT, it can aid the active management of electricity grids by balancing demand and supply.
- Some of the most promising are in asset management, demand response, outage management, customer services, energy storage, renewable resources, and many other areas in the power delivery system.
- Probably one of the most successful applications using AI technology is integrated asset management systems (AMS).
- This is an extremely important area for utilities, since sharing asset information throughout the organization has been identified as a method for improving enterprise efficiencies.

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