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Coordinated Industry Development of DERMS Control Functions

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SUMMARY

This paper highlights the challenges for utility integration of DER as they proliferate utility distribution systems. Distributed Energy Resource Management Systems or DERMS are the software control systems that can intelligently manage and enable integration of large number of DER cohesively with distribution management systems in a way that is practical, sustainable, interoperable and extensible. A DERMS operates with two levels of interface – group-level and device-level. A typical application of DERMS to offer grid support in a thermally overloaded feeder is used to illustrate the basic concepts and architecture of a DERMS.

The second section of the paper describes results of industry efforts led by the Electric Power Research Institute (EPRI) through a public working group to develop a reference set of control methods for DERMS functions. Control methods in DERMS maps the group-level command to device-level command and vice-versa to meet the desired control objective. Different control methods that are possible for the DERMS function, DER real power group dispatch are explained. An algorithm to execute one of the control methods is also provided.

KEYWORDS

Distribution Management System (DMS), Distributed Energy Resources Management System (DERMS), Distributed Energy Resources (DER), Grid Services, Interoperability, DER Interconnection Standards, Grid Codes, DER Aggregators, Smart Inverters, DER Group Management, Common Functions for DER

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Introduction

For several years, stakeholders in the power industry have been working toward a future in which large quantities of widely distributed solar generation provides a large portion of our energy needs. With the recent release of the IEEE1547, the US will soon have vast quantities of smart and flexible distributed energy resources (DER) connected to the grid, but with no clear vision or consensus methods for how to integrate and manage these devices with utility operations. Development of tools and methods for integrating these resources will require strong industry coordination to assure interoperability. This paper describes results of industry efforts to develop a reference set of control methods to manage these DER using distributed energy resources management systems (DERMS). The paper summarizes some of the DER management methods developed and documented by an industry working group to address this critical next step for DER integration.

Need for DERMS

Recent updates to DER interconnection standards like IEEE 1547 [1] and grid codes like Rule-21 [2] specify DER to provide grid supportive functions and the communication interfaces to manage them. Some of the mandated grid supportive functions [3] include constant power factor mode, voltage – reactive power or Volt-Var mode, frequency – active power or Frequency – Watt mode etc. This was a first step. A necessary step, but not sufficient to achieve end-to-end integration of DER with the grid. A substantial gap was recognized between the granular controls of individual DER and the type of organized services needed for grid support, integration with distribution management systems (DMS) and grid operations. In 2012, stakeholders began working to define a common set of grid-supportive services [4] and means to integrate large quantities of DERs into utility systems in a way that is practical, sustainable and extensible. Because multiple parties could be involved; utilities, DMS providers, DER aggregators and facility/microgrid controller providers are working together.

Technical Challenges for grid integration of DER

Quantity of DER providing grid services: It becomes challenging for grid operators to manage each DER in alignment with the power system as the number of DER increases. This drives the need for operating groups of DER in aggregate to provide grid services as organized groups.

Complexity in services: DER have complex modes of operation (e.g., curve settings, volt-var, volt-watt, real power curtailment) with an infinite number of potential settings and multiple ways to provide a service. Grid operators are concerned with the net effect and not the granular functional settings and services of each DER.

Languages in which services are provided: With the diversity in DER scales and technologies like PV, energy storage, flexible loads etc., the communication protocols supported by these makes integration challenging and requires new technology to address.

Utility business goals: DER integration without optimizing the needs of the utility can increase system losses, increase asset utilization and reduce power quality.

The logical component that will address all these challenges has become known as a DER Management System, or DERMS. In short, a DERMS bridges the gap between utility operations and DER by taking the complex capabilities of many and presenting them as a simpler more manageable set of services.

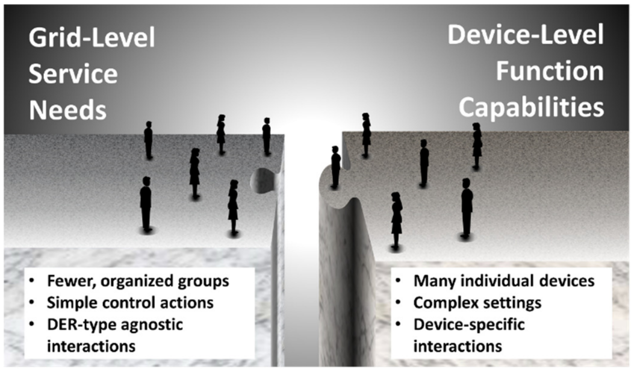

Figure 1. The gap addressed by DERMS

How DERMS addresses these challenges?

***Aggregation* –** DERMS take the services of multiple (potentially millions) individual DER and present them as a smaller, more manageable, number of aggregated virtual resources that are aligned with the grid configuration. How DER are organized into groups is in itself a research question and must be flexible.

Simplification – DERMS provide simplified aggregate services that are useful to distribution operations. The services are power-system centric rather than DER-type centric. Complex device-level settings, such as volt-var curve points and fast iterative settings updates are abstracted away as services are achieved and sustained. The simplified services provided by DERMS are standardized supporting the ability of multiple upstream calling entities.

Translation – Individual DER may speak different languages, depending on their type and scale. DERMS handle these diverse languages, and present to the upstream calling entity (e.g., a DMS) in a cohesive way.

Optimization – A given service to be provided by a DER group may be achieved in many ways. Different smart inverter functions may be best at different locations or times. Different types of DER (e.g., storage, advanced loads, or solar) may make more sense in one circumstance than in another. DERMS provide requested grid services in the optimal way – saving cost, reducing wear, and optimizing asset value.

A DERMS Use Case – Managing Equipment Capacity Constraint

There are several evolving applications of DERMS to provide effective grid supportive services. This section explains one such example of relieving a distribution feeder from a thermal overload. The example considers a distribution system operator using DERMS to orchestrate the fleet of DER under his control. The following sequence of steps are followed by the system operator to mitigate this issue.

1. Measurement from the field using AMI and SCADA provide the necessary information for the system operator to forecast a thermal overload or a distribution system constraint in the feeder. These real time measurements along with modern forecasting tools using weather data has the capability to predict the overload in a forward looking horizon as shown in Figure 2.
2. To prevent the system from this thermal event, the system operator comes up with the (a) correct formation of DER groups (b) and the DER group command to mitigate this thermal issue. In this example, there are two specific groups – a PV group and a mixed DER group – created by the system operator.
3. The system operator then calculates the appropriate DER group setpoint (e.g. real power setpoint) to be issued to the DERMS which then disaggregates the setpoint to individual device commands.

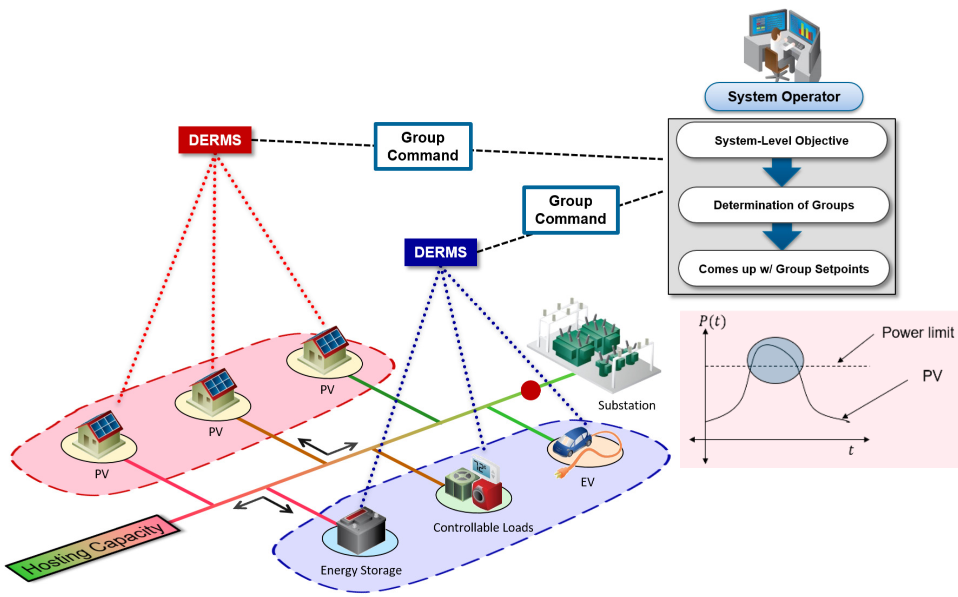

Figure 2. An example application of DERMS – Managing Equipment Capacity Constraint

Group-level and Device-level Functions

In the previous section, the two interfaces of a DERMS – group-level and device-level interfaces was introduced. It is important to note the key differences between the two interfaces to understand the architectural significance of DERMS.

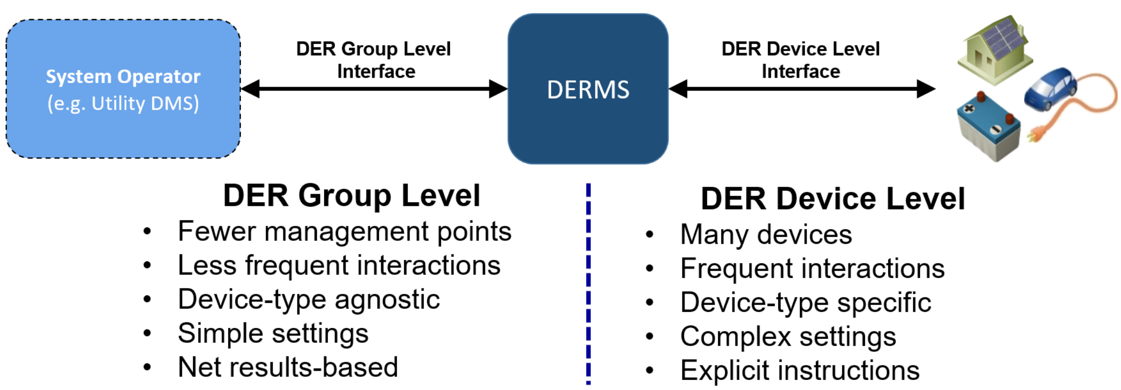

Figure 3: Reference Architecture Illustrating DER Group-Level Commands Mapped to Device-Level Commands through DERMS

Device-Level Functions (DERMS-DER Interface) vs. Group-level Functions (DMS-DERMS Interface): With the accelerated deployment and increased customer adoption of smart DER technologies, DER are proliferating throughout utility distribution systems. A key difference between the group-level and device-level interface of a DERMS is the frequency of interactions required to maintain grid reliability. At the device level, these interactions should be very frequent to maintain DER output. In particular, variable energy resource like solar requires very frequent monitoring and control to be reliably managed.

Moreover, these devices have device-type-specific settings which differ based on their mode of operation. For example, reactive power support can be provided only by inverter-based DER and not conventional demand response technologies like flexible loads which are non-inverter based. At the group-level, the settings are device-type agnostic. The DMS will send the same type of group commands to a PV aggregator (DERMS) and a load aggregator (DERMS).

Also, the grid supportive functions and the associated settings at the device-level are very granular and contains a range of information unlike the group-level functions. Reactive power request at the group level can be requested by a simple reactive power group setpoint whereas the device-level functions like volt-var or volt-watt require much more granular information. Finally, the instructions at the group level sent from the DMS are net-result oriented and not the specific function or settings used to achieve the result.

DERMS Control Methods

This section of the paper describes results of industry efforts led by the Electric Power Research Institute (EPRI) through a public working group to develop a reference set of control methods for DERMS functions to provide grid support. A real or a reactive power group command sent by the DMS (the left column in the table) to the DERMS can be achieved in a number of ways using the device-level functions (the right column in the table). Control methods in DERMS maps the group-level command to device-level command and vice-versa to meet the desired control objective. There are different ways to execute the control methods to achieve the desired objective. The next section will discuss the different control methods that are possible for the DERMS function, DER real power group dispatch identified by the working group.

Table 1: Group level and device level functions for real and reactive power dispatch functions

DER Group-Level Functions	Supportive DER Device-Level Functions
DER Group Real Power Dispatch	1. Limit DER Power Output Function 2. Storage Charge/Discharge Commands 3. Volt-Watt Function 4. Frequency-Watt Function
DER Group Reactive Power Dispatch	1. Constant var Function 2. Volt-var Function 3. Constant PF Function 4. Watt-PF Function

DER Group Real Power Dispatch

The purpose of this function is to request/dispatch a specified level of real power from a DER group. The real power group dispatch command is an absolute value that gets set as a specified level, as illustrated in Figure 4.

The entity requesting the real power group dispatch command can be a distribution system operator, a transmission system operator, an aggregator, microgrid controller etc. The entity managing the DER group and responding to the request has the necessary logic that maps the group-level real power dispatch function to individual device-level functions. This logic can be implemented on a group of similar or mixed type of DER technologies.

1. **Uniform Distribution in Watts**

This method sets/limits the active power level, till maximum power limit is reached, of each device in the DER group to the same power level to achieve the specified level.

2. **Uniform Distribution as a percentage of Nameplate**

This method sets/limits the active power of each device in the DER group to the same % of its present capacity in order to achieve the specified level for the group.

3. **Weighted Distribution in Watts**

This method sets/limits the active power level of each device in the DER group based on weighting factors defined for each device, in order to achieve the specified level for the DER group.

4. **Weighted Distribution by Percentage of Present Capability (WDP):**

This method sets/limits the active power of each device in the DER group to a percentage of its present capacity based on weighting factors defined for each device, in order to achieve the specified level for the group.

5. **Priority-based Dispatch:**

This method sets/limits the active power level of each device in the DER group based on a priority list defined by the entity managing the group, in order to achieve the specified level assigned to the DER group. In PBD, each DER is completely dispatched/curtailed before proceeding to the next one in the priority list.

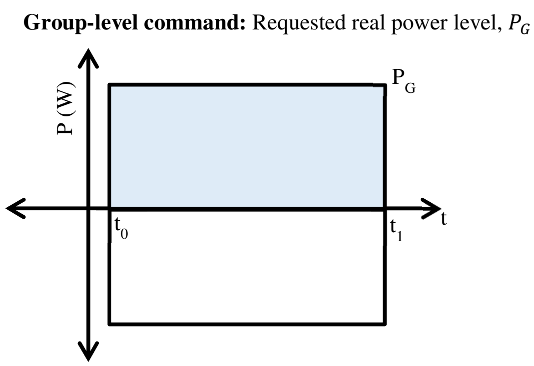

Figure 4 Real power group dispatch command

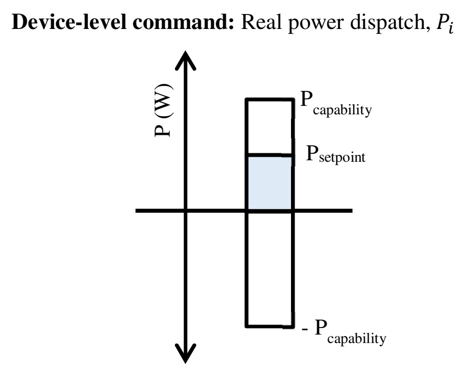

Figure 5 Real power dispatch function in a DER

Parameter	Description
P_G	Requested real power level
t_1-t_0	Effectivity schedule: the time/date window for which this request is active

Parameter	Description
P_i	Device-level real power setpoint in Watts
P_i^{max}	Capability of the DER

An Example DER Group Real Power Dispatch Method – Weighted Distribution by Percentage of Present Capability (WDP)

This method sets/limits the active power of each group member in the DER group to a percentage of its present capability based on weighting factors defined for each device, in order to achieve the specified level for the DER group. The weighting factors assigned to each group member are defined by the operator. The weighting factors may be defined on a member-by-member basis.

There exist multiple variations of the general WDP approach, as illustrated in the following Table

Table 2: Different factors that determine the weights in the method Weighted Distribution by Percentage (WDP)

Name of WDP variation	Description
WDP – DER type	Weighing factors are assigned based on type of DER
WDP – Grid services provided by the DER	Weighing factors are assigned based on the type of grid services supported by the DER e.g., assigning higher weighting factors for devices that can provide only real power-based services over devices that can provide both real and reactive power services.
WDP – DER capability	Weighing factors are assigned based on present and forecasted capability e.g., a fleet of ES can be assigned weighing factors in the descending order based on the time remaining before fully discharged when discharging at a specific rate (kW) e.g., number of DR calls
WDP – DER forecasted confidence	Weighing factors are assigned based on the forecasted confidence level of the DER's capability to dispatch (max/min) e.g., confidence level around the maximum capability to dispatch PV could be less than storage, etc.
WDP – DER ownership	Weighing factors are based on the type of ownership of DER e.g., higher weightage for utility-owned versus non-utility owned DER, etc.
WDP – Utilization of assets	Weighing factors are based on the amount of usage in the past to improve asset health e.g., for ES, this could be based on the number of charge/discharge cycles over the past e.g., for DR devices, this could be based on the number of previous DR calls
WDP – Level of commitment (i.e. Binding vs Non-binding dispatch)	Weighting factors are based on the level of commitment or the commitment type.

	e.g., DER that shall provide distribution service (through a grid code mandate) over that may provide distribution service (through a DR program)
WDP – Cost based	Weighting factors are based on the cost of service provided by the DER e.g., cost of service of ES may be higher than PV
WDP – Last-In-First-Out	Weighting factors are based on order of interconnection of the DER to the grid, the most recent interconnection being given the highest weighting factor.
WDP – First-In-First-Out	Weighting factors are based on order of interconnection of the DER to the grid, the oldest interconnection being given the highest weighting factor.
Combination of above methods	Weighting factors are based on a combination of the parameters described above, and/or other parameters.

Description of the control method

The method is developed for a DER group of N members

- Each group member i is assigned a weighting factor k_i by the operator, $i = 1..N$.
- This factor is used to calculate the individual setpoint a_i (in % of individual capability P_i^{max} such that $\frac{a_i}{k_i}$ remains a constant quantity across all group members i.
- Additionally, if P_G (in kW) is the group-level active power command assigned to the DER group, the sum of all individual real power setpoint, $P_i = a_i \cdot P_i^{max}$ must equal P_G.

Each group member i can set its active power between 0 and P_i^{max} (in kW). This information can be obtained using a dedicated method (see chapter on *DER Group Status Monitoring*).

The problem of selecting the individual setpoints a_i can be formulated as a system of N linear equations with N unknowns (the a_i's):

$$\begin{cases} \frac{a_1}{k_1} = \frac{a_2}{k_2} = \cdots = \frac{a_N}{k_N} & (N-1 \text{ equations}) \\ a_1 P_1^{max} + a_2 P_2^{max} + \ldots + a_N P_N^{max} = P_G & (1 \text{ equation}) \end{cases}$$

This system can be re-written as:

$$A \cdot a = b$$

With:

$$A = \begin{bmatrix} 1/k_1 & -1/k_2 & 0 & \ldots & 0 \\ 1/k_1 & 0 & -1/k_3 & \ldots & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ 1/k_1 & 0 & 0 & \ldots & -1/k_N \\ P_1^{max} & P_2^{max} & P_3^{max} & \ldots & P_N^{max} \end{bmatrix} \; ; a = \begin{bmatrix} a_1 \\ \vdots \\ a_N \end{bmatrix} \quad ; \quad b = \begin{bmatrix} 0 \\ \vdots \\ 0 \\ P_G \end{bmatrix}$$

Individual real power setpoints can be calculated from the a_i if desired:

$$P_i := a_i P_i^{max}$$

Note that this method assumes that there existing at least one feasible set of device-level setpoints that meet (1) the capability of each individual DERs, (2) the proportionality as defined by the weighting factors, and (3) the group-level requirement.

Illustrative Example

Requested real power level, P_G	100 kW
DER Weighting Factors, k_i	[0.33, 0.33, 0.33]
DER Capability, P_i^{max}	[60 kW, 50 kW, 40 kW]
Calculated setpoint a_i (in % of individual capability P_i^{max})	[67%, 67%, 67%]
Calculated device-level commands, P_i	[40 kW, 33 kW, 26.4 kW]

The example presented illustrates the relative roles of the DERMS at different levels of the hierarchy, interface to DMS at the distribution management level, and interfaces to detailed device controls at the device level. This is the type of specification and coordination that is required across the full range of DERMS functions. There is considerable work to be done to define these functions so that the basic capabilities can be implemented in a way that assures a basic level of interoperability at all levels of the system operations.

Conclusion

Distribution resources, including control devices, small generators and dispatchable loads, have been connected and managed by utilities for many years, but the scale of integration and the central role that is now envisioned with DERMS is new. Available DERMS products are typically recent creations or otherwise have undergone substantial changes to position them to support smart solar inverters.

This paper highlighted the need for DERMS to integrate DER with distribution management systems in a cohesive way by providing practical, sustainable, interoperable and extensible services. It also described the results of industry efforts to develop a reference set of control methods to manage these DER using DERMS.

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