Distributed Generation Architecture and Control

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The traditional roles of utilities as energy suppliers, and consumers as energy users, are morphing rapidly. The confluence of deregulation with advances in telecommunications and information technology has opened new opportunities to decentralize generation.

For example, power generation is no longer limited to centralized power plants. The technology is available to generate power at all levels, whether at the transmission, distribution, or at the end user levels. As the interconnections

SOURCE: Cal-ISO website.

Figure 1—Deregulated Power Production, Transmission, and Distribution

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become more complex, and many actors produce and consume power simultaneously, traditional SCADA (Supervisory Control And Data Acquisition) is inadequate to handle, let alone optimize, all possible combinations of power production and consumption.

Below we will review some of the control issues arising from this brave new world of distributed power generation and some of the technologies that make its control possible.

**Distributed Generation Controlled Using the Internet**

With progressing utility deregulation we are witnessing a transformation in energy production, where small engines, microturbines, fuel cells, and renewable systems are deployed locally to generate power close to where it is used. Hospitals and grocery stores have maintained backup power generators for a long time. Co-generation has been used as an on-site source of power for decades. Heat recovered from co-generators is harnessed to offset on-site heating loads and thus adds to the economic benefits.

But only the recent utility restructuring and market deregulation has brought local power generation into the realm of economic competitiveness. New schemes are being tried to resell power from traditional backup generators to secondary markets. Power and heat from co-generation is made available to facilities organized into a Power Park. These schemes mark the trend from traditional, Central Generation to new, Distributed Generation.

Distributed Generation (DG) is defined as the integrated or stand-alone use of small, modular electric generation close to the point of consumption. Power sources that fit the definition of DG, also termed GenSets, are:

- Internal combustion engines coupled with generators;
- Gas turbines powering generators;
- Microturbines (small, cheaper gas turbine packaged with a generator);
- Fuel Cells;
- Renewable Systems (PV, wind turbines);
- Loads that can be curtailed on demand (interruptible lighting circuits, chillers, etc.).
As the number and diversity of DG on the grid increases, dispatching these resources at the right time and accounting for the flow of energy correctly become complex problems that require reliable monitoring and tele-metering equipment, as well as an independent entity to settle billing for power trades. Another challenge is to ensure reliable communication and control between distributed resources and loads. Traditional SCADA (Supervisory Control And Data Acquisition) systems with centralized control rooms, dedicated communication lines, and specialized operators, are not cost effective to handle a large number of DG resources spread over the grid.

New communication technology and software has become available to transform traditional SCADA systems in a way reminiscent of Personal Computers transforming Mainframes. The Internet provides a convenient point-to-point communication network that replaces dedicated telephone lines. Inexpensive computers equipped with suitable communication and control software manage the distributed resources. The necessary control software is installed on a single server. Its functions are:

- monitor the operational health of a large number of GenSets;
- issue alarms and shut down GenSets if alarms go unheeded by human operators;
- automatically schedule and dispatch GenSets in an economically optimal manner;
- accept manual input from human operators.

A human DG operator need not be in physical proximity to the server with the control and monitoring software. All she requires is a PC with Internet access. Using a regular browser she can review the status of all GenSets, resolve alarm conditions, and issue manual dispatch commands to selected GenSets if needed. This can be done from an office, a home, or an airport lounge, as shown in the figure below.

While managing servers connected to GenSets over the Internet may appear to be the modern solution of choice to control Distributed Generation, it is not without problems:

- Despite its overall reliability, the Internet is a public communication network subject to local congestion or ISP server outages that can temporarily interrupt the connection between Controllers and GenSets—therefore, any control strategy must be designed with fail-safety in mind such that the
GenSet at the end of the line “knows how to do no harm” while temporarily off-line;

- There are currently many communication protocols by which GenSets report their operating conditions and accept control commands—a Controller must be able to speak many GenSet control languages in order to be effective;
- To perform a complete optimization, in real time, of the economically optimal dispatch level of each GenSet on a grid can be a daunting.

**Economic Dispatch as a Means to Control DG**

In what follows we will variously refer to GenSets and to Controllers. GenSets are power-producing devices. Controllers are software suitable to monitor, dispatch, and optimize the operation of GenSets. When optimizing the operation of many distributed GenSets on a grid, it is useful to distinguish between several hierarchical levels of control, each described in the following sections.

**Device Level Control**

This level is at the GenSet itself. In order to be usable as DG resources operated remotely, GenSets must possess a local, on-board firmware controller with some built-in intelligence. The logic in this on-board controller gives the GenSet the
ability to run in an “Autopilot” mode for periods of time when no communication exists with a remote software controller. Note the use of the word “controller” both for local, on-board logic at the device level (on-board controller), as well as for control software running on a remote server (software controller).

A typical Autopilot mode for an on-board controller is Threshold Load Control, whereby the GenSet adjusts the power supplied to the connected load such that the residual power requirement from the utility grid never rises above a constant level, called the Threshold. This Threshold level is periodically adjusted upward or downward by the software controller in response to a drop or a rise in utility grid power price, respectively.

On-board controllers also monitor the health of the GenSet, such as:

- exhaust temperatures and rotation speed in turbines and internal combustion engines;
- operating temperature in fuel cells;
- output power, voltage, and frequency, for all GenSets.

If any monitored quantities exceed pre-programmed limits, an alarm message is issued and sent to the software controller, as soon as in communication with the onboard controller. If the software controller fails to respond, or if human intervention is required but none is forthcoming after a set period of time, the on-board controller can shut down the GenSet.

Thus the on-board controller fills operational safety and dispatch requirements in the case of temporary loss of communication with the software controller.

*Site Level Control*

A Site is defined as one or more facilities connected to one master meter. Examples of sites are:

- Single buildings;
- Clusters of buildings, or Campuses with multiple buildings all belonging to the same organization;
- PowerParks with multiple facilities that buy their power in common, as depicted below.

At the Site level a number of DG resources must satisfy the power needs of many diverse loads. Physical proximity may enable the utilization of heat recovered
from DG to offset thermal loads within the site. It may be useful to picture the interplay of DG and loads within a site as a network.

In the figure, natural gas flows both to drive DG and to satisfy building loads. Electricity is produced by DG and consumed by building loads. Heat recovered from DG is used to offset thermal loads in buildings and thus decreases the gas or electricity requirements at the building level.

Emissions are also produced by both DG and by building equipment. Generally speaking, additional emissions are offset by reduced emissions at the building and at the remote power plant used to produce power for the buildings.

accomplished by minimizing overall energy costs in real time. Schematically the overall energy cost at a Site with $N$ GenSets and $M$ facilities can be computed as:

$$Total = \sum_{i=1}^{N} GenSetTot_i + \sum_{j=1}^{M} FacilityTot_j$$

At the site level, economically optimal dispatch of the DG resources is Each GenSet cost in this equation results from adding the cost of fuel consumption, of capital depreciation, and of O&M costs:
Figure 4—Schematic Representation of Site-Level DG: Building loads draw power from grid or from DG. Natural gas is used to drive DG or building loads. Heat recovery from DG offsets thermal loads.

\[ \text{GenSetTot}_1 = \text{GenSetFuel}_1 + \text{GenSetCap}_1 + \text{GenSetO&M}_1 \]

Each facility cost in this equation is the result from adding electricity and natural gas:

\[ \text{FacilityTot}_1 + \text{FacilityElec}_1 + \text{FacilityGas}_1. \]

If there were only one GenSet and only one facility at the site, and the one GenSet were dispatched by itself, the cost of running the facility would decrease while the cost of running the GenSet would increase. On which side the balance of costs tips is a function of:

- the relative prices of electricity, of natural gas, and of the GenSet fuel;
- the GenSet electrical and thermal efficiencies;
- the degree to which the heat recovered from the GenSet can be utilized to offset thermal loads in the facility.

Cheap fuel costs, high electrical and thermal efficiencies, and high degree of heat recovery, all favor operating the GenSet.

The same optimization can be effected when many facilities on a common master meter are connected to a network of many GenSets. The cost equation to be minimized may have more terms, but the principle is the same: operate the GenSets whenever the incremental cost of DG-produced electricity, taking into account capital depreciation and O&M, equals or exceeds the savings in utility-
supplied power and natural gas to the facility. The savings are the result of the following mechanisms:

- locally produced DG power displaces utility-supplied power, kWh for kWh;
- heat recovered from DG offsets thermal building loads and thus reduces electricity and/or gas use.

Retail gas and electric tariffs are often known many months ahead. Even in a fully deregulated market, they are known at least one day ahead, typically in the form of 24 hourly prices. Facility loads are a function of operating conditions and weather. Fairly reliable day-ahead load forecasts can be made at a facility level for at one day ahead.

Thus, within the accuracy limit of the weather and operating condition forecasts, the dispatch of a GenSet can be planned at least one day ahead, in the form of up to 24 different part-load levels. This requires that the Threshold Load control for the GenSet be reset to a new threshold up to 24 times a day. In many practical cases (e.g., a TOU tariff), one or two threshold level resets per day will suffice.

**Control at the Utility Level**

There are distribution utilities that own a fleet of GenSets and want to dispatch them economically, as shown in the figure below.

Dispatch decisions will be made by comparing the additional cost of running DG assets, with the savings from purchasing less peak power from producers. Market prices paid for primary power vary by season, time of day, and with the degree of congestion on transmission line paths required to deliver the power. In an economic sense, local DG affords the utility some hedging capabilities.

But DG dispatch decisions at the utility level are rarely made with economics alone in mind. Other factors, such as power quality at the microgrid and ancillary services required by the ISO, play a role at least as important. For a utility the timely response to alarms and the scheduled dispatch of DG resources are often deemed too important to be left to an automatic dispatch controller, as can be done on a Site level.

**Mixed Site-Level and Utility-Level Control**

An interesting hybrid of control is provided by the following arrangement: GenSets are distributed over many sites in one distribution utility service territory where they are automatically scheduled day-ahead by site-specific controllers.
As the distribution utility requires additional, unscheduled power in specific parts of its service territory, it can call upon selected resources not currently dispatched to meet local loads. Economic tradeoffs between additional electric consumption at the site level and reduced power purchased by the utility can be made to decide on which resources to “hijack” in this way.

**Distributed Energy Network**

To obtain the full benefit of local generation, we may have to change our thinking from the existing order of a software controller dispatching DG, to a Distributed Energy Network of loads and GenSets. In a Distributed Energy Network power can be generated and consumed at every node of the network, and many resources can meet the loads on the network. In this context an energy resource is any device which can produce energy, shift load through storage, or curtail the demand for energy.

In a Distributed Energy Network there is no central controller optimizing dispatch schedules of all GenSets. Instead, each GenSet and each Load is
Barriers to Distributed Generation

Considerable technological and regulatory hurdles lie in the way of the brave new world of Distributed Generation and Distributed Energy Networks. Current transmission grid and switching hardware is ill suited to “running in reverse,” that is, to allow DG power to flow from end use points back into the grid. The complexity of grid interconnection increases in the order listed below, from easiest to most complex:

- Run DG in isolation—no grid interconnection;
- Run DG in isolation but allow load to switch from DG to grid and back;
- Connect DG to grid without power export to the grid;
- Connect DG to grid with export (bi-directional power flow).

Current buyback tariff structures (Net Metering and Flat Rates) provide little economic incentive to DG owners to sell back excess power to the utility.

Among the recommendation to advance DG are:

- to promote market mechanisms by which power produced locally by DG is fairly paid for at a price that reflects its actual value to the utility, for example in terms of avoided transmission costs;
- to promote uniform requirements under which DG is permitted to supply power to the grid;
- to extend existing ISO and PX entities to promote an active market of DG buyers and producers within utility service territories and across different utilities.