Monitoring large-scale power distribution grids

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Power grid networks are distributed over vast geographical areas and have a sophisticated multilayered architecture. While the exact structure of the upper levels is well known, the structure of the lower levels, responsible for delivery of power to individual consumers, is often poorly documented and sometimes even unknown. This lack of information presents challenges in the development of systems for automated monitoring of power delivery to consumers.

The proposed system performs the simultaneous functions of establishing the power grid topology (grid map) and monitoring the grid operation. The core of the system is the network of inexpensive sensors installed at all branching points of electrical conductors and synchronized by GPS. These sensors periodically and synchronously measure and report the following parameters: the RMS current in the conductor, the phase shift (between current and voltage), the direction of the energy flow, and the 3D GPS coordinates of the sensors themselves.

An important issue is appropriate clustering of the sensors. This is accomplished as follows. The sensors communicate over the ac powerline itself using frequencies that substantially exceed the standard 60 Hz. Because of that frequency disparity, the transformers used for voltage conversion attenuate the communication signals and naturally separate the distribution grid into relatively small segments, which we call "clusters". Each sensor communicates data only within its own cluster and the data are further relayed by a network of communication modules, one module per cluster. The information received by the central processing server from each sensor includes the ID of the communication module used to relay the data and thus identifies the cluster to which it belongs. The map of the power grid is created by separately mapping the individual clusters and then connecting these maps into a multilayered map of the network.

In selecting the map topology we are guided by an ac version of Kirchhoff's current law (KCL) generalized to ac networks. In this approach, the currents are characterized by their RMS values and their phases, with current directions taken to coincide with the local energy flow. Synchronous measurement of these parameters is essential for the validity of this approach. The initial maps are generated by selecting the network topology that most closely satisfies the generalized KCL for all the branching points. The maps are therefore generated without any prior knowledge of the local network topology. Once the map of a particular cluster is in place, the new data reported by that cluster's sensors can be used for real-time monitoring of inconsistencies in the grid behavior to detect conductor breakage, powerline overload, and even electricity theft.