## 3.0 Radial Distribution Systems

Radial distribution systems (RDS) are the most common design used by electric utilities, and are the least expensive to plan, construct, and maintain. They generally consist of an electrical substation (typically at medium voltage in the 15 kV class), radial feeders for energy delivery (which may be a few miles to a few dozen miles in length), and eventually tie to transformer(s) that convert the 15 kV voltage to a utilization level (120/240, 120/208 or 277/480). There are typically several hundred to several thousand electric utility customers on a feeder, and anywhere from one to twenty customers who may be served by selective transformers. Depending on the type of service agreements, these customers may be metered at either the primary voltage level (e.g. 15 kV class) or the utilization level.

Radial distribution systems are the simplest systems to plan, construct, and maintain, but are also the least reliable because of the radial nature of the design being served from a single source at a time. If any part of the system experiences a failure, some or all of the customers served by the radial feeder will be without power until a repair is completed. Straightforward design, lower cost, and decent reliability are the distinguishing characteristics of the RDS.

An auto-loop distribution system is a special type of radial distribution system and is differentiated by having two feeders that tie to a customer load. The auto-loop system automatically senses the loss of one source of voltage and quickly and automatically switches the load to the second feeder. This type of system adds reliability benefits by keeping outages to a few seconds (or less) but the added cost of having two sets of utility equipment at one location, could be as high as hundreds of thousands of dollars for each installation.

## 4.0 Network Distribution Systems

Networks are among the most sophisticated type of distribution system used by larger electric utility companies. A network is designed so that each load receives its power and energy from several transformers that are simultaneously supplied from different primary feeders. This is usually achieved by interconnection of the secondary windings of this transformer in a parallel configuration to form what is known as a "secondary grid system." The loads are then served from this grid. If a secondary system is comprised of only a few network transformers at a particular location in order to serve a unit building, it is known as a "spot network." Alternatively, if the secondary windings of many transformers in a wide area (up to several blocks) are connected together, the configuration is called an "area" or "street" grid system.

Engineers design spot networks and grid networks to provide power to their customers through redundant transformers and redundant feeders. This is a distinguishing characteristic of a network, as redundant feeders and transformers can be taken out of service without an electric consumer being affected. Network feeders, transformers, and NPs can be taken out of service for maintenance, adding new equipment, or when there is an equipment failure that causes a feeder or transformer outage, and when there is a significant drop in load on the network. Assuming "n" separate sources of power for a network, the engineers often design the network to operate at "n-1" or "n-2" outage contingency. The designation n-1 indicates that the network will be fully functional with one less feeder in service, where n-2 indicates that the network will be fully functional with two less feeders in service.

By design, network protectors are to remain closed unless there is a power outage on the primary side of the NP. If an NP opens because the load drops to a low level on a network, there is a minimized level of reliability because of the absence of part of the network. If multiple NP open because of low load levels, there is a risk of a complete outage, and therefore must be avoided.

Networks have been in operation in the United States for roughly 90 years, and are typically found in larger metropolitan areas such as New York City; Chicago; Seattle; Baltimore; Kansas City, Missouri; Boston; San Francisco; Washington, D.C.; Denver; Portland, Oregon; and even some smaller metropolitan areas such as Knoxville, Tennessee, and Syracuse, New York. Some large cities, such as San Diego, have significant loads in a dense area, but do not employ networks. Because of the high level of adaptability and reliability of networks, they are expected to be employed for many decades to come.

## 4.1 Spot Networks

A spot network is a type of secondary network distribution system that is frequently used to serve a single customer or multiple customers in a single building. Spot networks will have two or more feeders and two or more transformers networked together at an electric consumer's site. Electric consumers who are served by spot networks are typically located in very large buildings with major electric loads. Three of the case study locations are served by spot networks, including systems in Colorado, California, and Washington, D.C. Figure 2 illustrates a schematic diagram of a typical spot network.

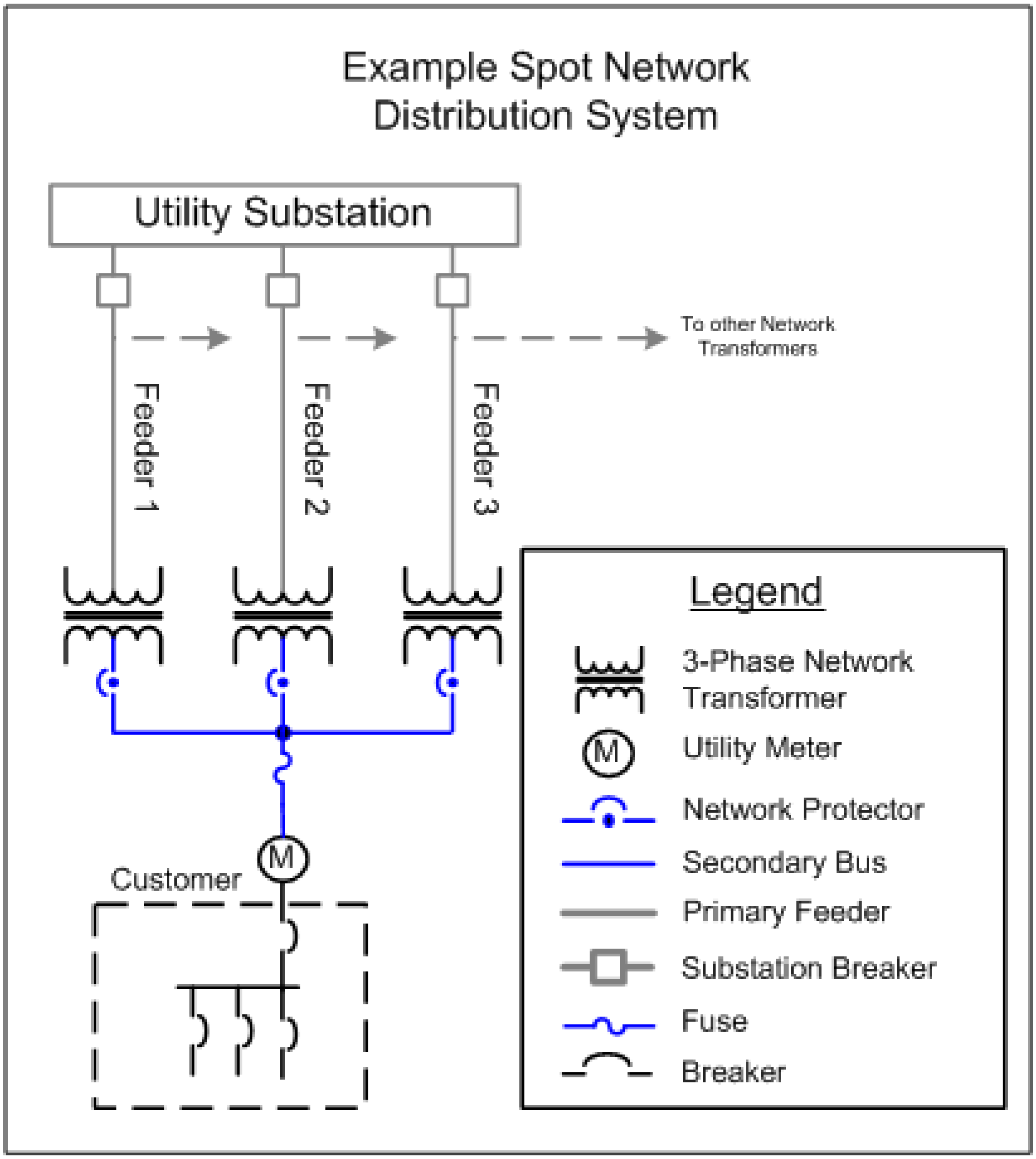


**Figure 2. Typical Spot Network System Diagram**

## 4.2 Area Networks

Area networks are a type of secondary network distribution system that are typically used in larger metropolitan areas, and may serve all sizes of electric customers (residential, commercial, and industrial). Area networks are also known as “street networks” or “grid networks.” Similar to the spot network, the area network has redundant feeders and transformers, and may serve hundreds to thousands of customers. The area network may include as many as ten transformers to more than a thousand transformers, and be served by three to thirty five distinct electric distribution feeders. The typical area network voltage is 120/208 and is always three-phase, although there are typically many single-phase loads served by the network. Some area networks can serve up to several square miles. Area networks are designed to serve all network customer loads, during a peak-demand day, with one to two feeders out of service depending on the design criteria used. Many networks could operate with additional feeders out of service during nonpeak loading conditions. See Figure 3 for a one-line diagram representing an area network.

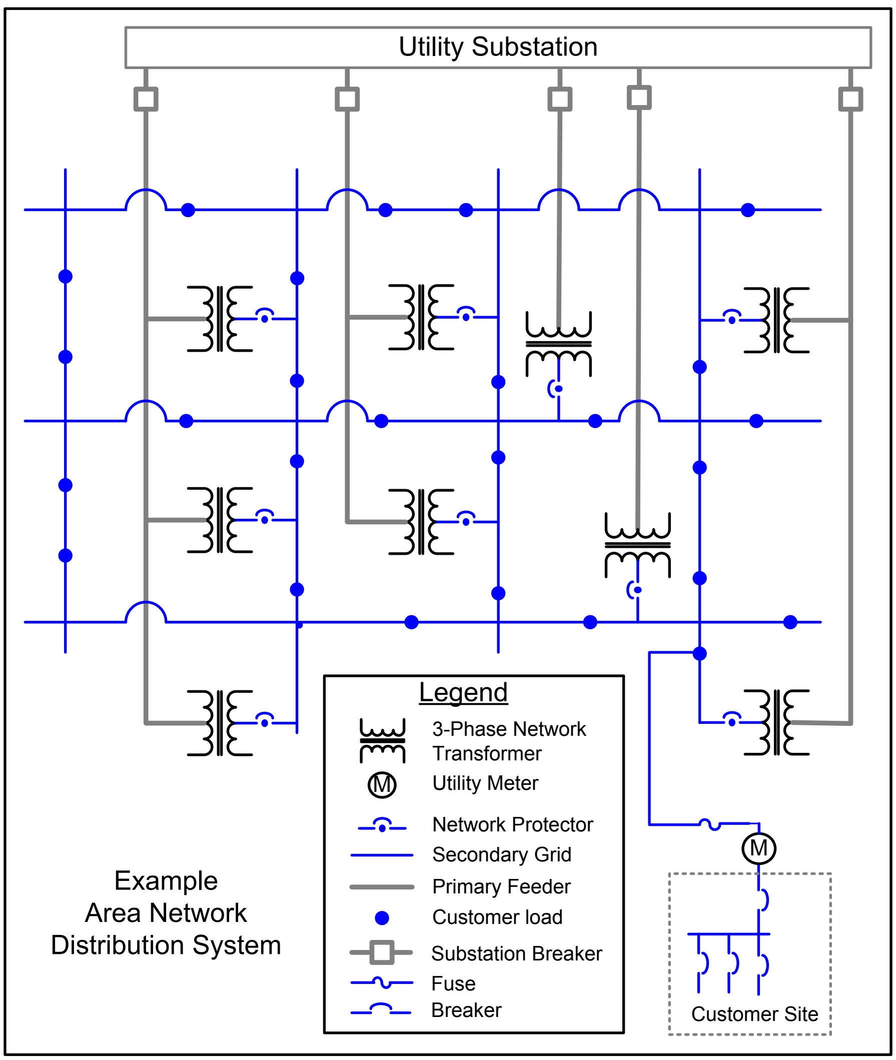


**Figure 3. Example Area Network System Diagram**

## 4.3 Network Protectors

A unique feature of any secondary network distribution system, compared to a radial distribution system, is the addition of the NP. The NP is a relay and breaker pair that senses reverse-power flow toward the utility (from either a faulted component or a planned outage) and is designed to interrupt the power from flowing back toward the utility system by opening its contacts for this condition. Usually, the power reversal is either planned by the utility, such as during a feeder clearance, or it occurs during a fault on a primary feeder or during a primary feeder fault. Therefore this NP opening ensures isolation of the faulted or cleared feeder from other energized feeders. This is an important design feature that ensures reliability and continuous operation if one or more feeders are lost due to a device failure or if the utility must conduct maintenance activities (planned outages on a feeder). Network protectors are normally closed devices, but may open during light-loading conditions, often during early-morning hours or weekends when loads are at a minimum. Such light-loading operation is considered normal and expected from time to time.

Network protectors consist of a low-voltage circuit breakers with relays, backup fuses, and auxiliary devices, all enclosed within a metal case mounted on the secondary side of the transformer (submersible type) or separately mounted (frame type). The function of the relay is to open the breaker on power flow reversal (as low as that caused by reverse magnetization of its associated transformer or as high as that caused by a fault in the primary feeder or the transformer itself). The relay will also reclose the breaker when the voltage and phase of the primary feeder are such that power will flow into the network, when the breaker is reclosed. It is also designed to recognize a cross-phase condition (caused by improper feeder re-splicing**),** which prevents the breaker from closing.

Networks were originally designed for one-way power flow from the electric utility to the consumer. The NP is designed to sense and open its contacts under reverse power flow conditions (among other functions). While The NP can be set to allow low levels of reverse power for a short period of time to accommodate power swings it is generally not acceptable in a network system, and net metering poses additional complications and is often difficult to implement.

It is important that a PV system disconnect from the network in the event of a power outage to avoid a situation known as “unintentional islanding.” If an unintentional island were to occur, it is possible that some network protectors may experience cycling problems or could damage the utility or PV system as the systems move out of phase. IEEE Std 1547-2003, Standard for Interconnecting Distributed Resources with Electric Power Systems, contains specific language to address this potential problem[3].

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3 IEEE std 1547-2003, Section 4.4.1 page 10 (ISBN 0-7381-3720-0)

### 4.4 Standards of Interconnection for Secondary Networks

The Institute of Electrical and Electronic Engineers (IEEE) Standards Coordinating Committee 21 currently sponsors a working group that is drafting recommended practice for interconnection of DG (which includes PV) onto distribution secondary networks (see P1547.6[4] – Draft Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks). The working group has been meeting for several years and the recommended practice is expected to be ready for ballot in 2010. This important recommended practice will complement IEEE 1547-2003, Standard for Interconnecting Distributed Resources with Electric Power Systems, which is currently incorporated into most state rules in the United States and has been cited by the Federal Energy Regulatory Commission (FERC).

### 4.5 Interconnecting Photovoltaic (PV) Systems with Secondary Networks

There are several electric utilities in the United States that are working with PV system integrators and allowing interconnection and even net metering onto area networks. Four cities, and four electric utilities, are examined in the six case studies within this report in which there are PV systems interconnected to spot networks and area networks.

## 5.0 Case Studies

### 5.1 Purpose and Objectives

There are many electric utilities that operate secondary network distribution systems, but relatively few that have PV systems installed and interconnected to those secondary network distribution systems.

The main objectives of these case studies were to:

- Record all interconnection requirements that were implemented by each local utility to interconnect each PV system to the spot network or the area network
- Evaluate the performance of these systems to date with respect to their integration with the electric utility.

Our purpose was to illustrate successful installations of PV systems on secondary network distribution systems. The case studies show that it is not only possible to interconnect PV systems to secondary network distribution systems, but with implementation of proper modifications and requirements, PV systems can operate safely, efficiently, and reliably on secondary network systems.

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4 http://grouper.ieee.org/groups/scc21/1547.6/1547.6_index.html