Smart Grid for Smart City Activities in the California City of Riverside

Hamed Mohsenian-Rad[1(✉)] and Ed Cortez[2]

[1] Department of Electrical and Computer Engineering, University of California, Riverside, CA 92521, USA
hamed@ece.ucr.edu

[2] Riverside Public Utilities, Riverside, CA 92522, USA
ecortez@riversideca.gov

Abstract. In this paper, we overview various urban smart grid development activities in the City of Riverside in Southern California. Challenges and opportunities as well as potentials for university-industry collaborations are discussed. The following smart grid topics are covered: energy efficiency and demand response, renewable power generation, energy storage, electric vehicles, and monitoring and automation.

Keywords: Smart grid · Smart city · City of riverside

1 Introduction and Background

A "smart" city uses information and communication technologies (ICT) to enhance energy, water, transportation, public health, public safety, and other key services to make the urban environment more sustainable, increasing quality of life, and improving efficiency of urban infrastructure and operation. A smart grid, c.f. [1,2], sits at the heart of the smart city paradigm to ensure sustainable and resilient delivery of energy to support the many functions of all other critical urban services under normal and extreme operational conditions [3].

In this paper, we overview some of the recent and ongoing smart grid development activities and their related challenges in the City of Riverside in the State of California in the United States. With a total population of 321,786, Riverside is the 12th most populous city in California and the 59th most populous city in the United States [4]. Riverside is part of the Greater Los Angeles metropolitan area in Southern California. It has a semi-arid Mediterranean climate. The average high temperature is more than +30 degrees Celsius during June, July, August, and September. The average low temperature is less than +10 degrees Celsius during December, January, February, and March [5].

The City of Riverside is served by the Riverside Public Utilities (RPU), which is a municipal electric and water utility company: http://www.riversideca.gov/utilities. The service area for RPU is 82 square miles. RPU serves electricity to over 107,000 metered electric customers and water to over 65,000 metered water customers [6]. The RPU subtransmission network is shown in Fig. 1. In total,

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RPU has 14 substations, 91 circuit miles of transmission lines, and 1,323 circuit miles of distribution lines [7]. The RPU substransmission system is connected to the California grid at the 230 kV Vista substation that is operated by Southern California Edison (SCE). The RPU historical peak demand is 612 MW that was recorded on September 14, 2014 during a summer heat wave [7].

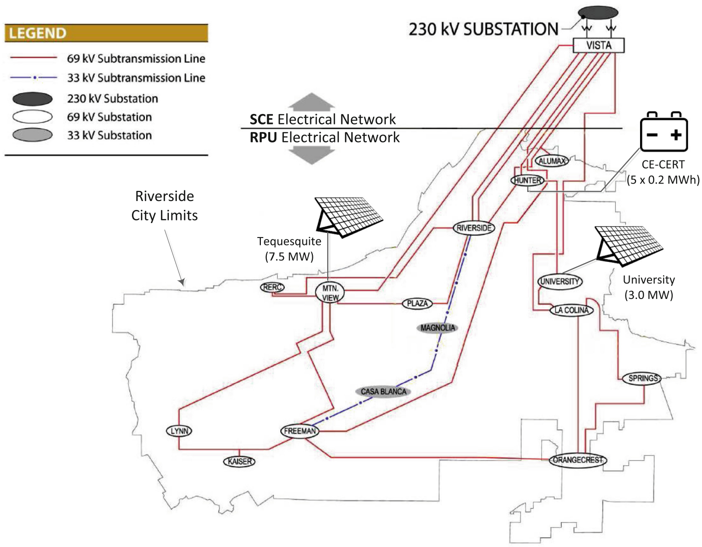

Fig. 1. The RPU subtransmission system [8].

In the sections that will be followed, we will briefly summarize some of the key smart grid activities in the City of Riverside. Specifically, the following smart grid topics will be covered: energy efficiency and demand response, renewable power generation, energy storage, electric vehicles, and monitoring and automation.

2 Energy Efficiency and Demand Response

Demand Side Management (DSM) is a global term that includes a variety of activities that aim at changing the *level* or *timing* of electricity demand among consumers [9]. The former often involves programs that seek to improve energy efficiency of appliances, equipment, etc. The latter often involves demand response (DR) programs that seek to alter electric users' normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower consumption at peak hours and when the system reliability is at risk. The United States National Assessment of Demand Response Potential report has identified that DR programs have the potential to reduce up to 20 percent of the total peak load demand in the U.S. [9,10].

RPU has developed a portfolio of programs for its residential and small commercial customers to encourage energy conservation and to meet its long-term energy reduction goals. Some of the current residential energy efficiency programs include: (1) air conditioning rebates for new or replacement units: offering incentives for replacement or installation of central HVAC (heating, ventilating, and air conditioning) units and/or room units with high efficiency equipment; (2) energy star appliance rebates: offering incentives for replacement or installation of qualifying home appliances, such as energy star refrigerators; (3) home energy analysis and weatherization incentive rebates: offering an analysis of home energy that identifies energy efficiency measures and savings, potentially following by a whole house approach to improving energy efficiency through attic insulation, duct insulation, duct sealing, window replacement, window shading, whole house fans, programmable thermostats, and evaporative coolers [11].

Also, RPU's commercial energy efficiency programs include: (1) air conditioning rebate: offering incentives for replacement or installation of HVAC units with high efficiency equipment; (2) energy efficiency incentives for lighting: offering incentives for replacing older inefficient lighting with high efficiency units [12–14]; (3) efficient motors: offering incentives for the replacement or purchase of new premium motors; (4) energy management systems assistance: offering incentives for energy management system upgrades for non-residential customers.

Besides the above energy conservation programs, RPU has also implemented various demand response programs. The RPU DR programs can be classified into three groups: *off-line*, *online manual*, *online automated*. An example offline DR program is the Pool Saver Swimming Pool Pump Incentive that is offered to residential customers. This program offers swimming pool owners a $5 credit on their monthly electric bill for setting their pool pump timers to operate at off-peak hours. The typical peak hours are identified as 12:00 PM to 8:00 PM.

An example online manual DR program is the Power Partner Program [15]. It was initially put in place in response to the temporary closure of San Onofre Nuclear Generating Station, a key Southern California energy resource. This program has since been used by RPU to reduce the demand on the regional energy grid and lessen the likelihood of temporary planned outages, e.g., during the heat wave in September 2014 when RPU reached its record high demand, see Sect. 1. In this program, local businesses are encouraged to sign up to be Power Partners, and agree to shed or shift a specific amount of their energy use during peak demand times when requested from July through September, or when they are notified by RPU. All RPU commercial electric customers with peak demands of at least 150 kilowatts per month (about the size of a small restaurant or larger) are eligible to participate in this program. During the heat wave in September 2014, the power reduction notifications were sent by RPU, in form of emails and phone calls, to several Power Partners, including the University of California at Riverside (UCR), which is one of the largest RPU customers. The notification was then disseminated among the university faculty, staff, and students.

Finally, RPU has also implemented online automated DR programs, e.g., in form of non-flat pricing tariffs. Specifically, RPU currently practices *peak pricing*

(PP) and *time-of-use pricing* (ToUP) programs, which are among the most effective pricing models in smart grid, c.f. [16]. Peak pricing is mainly intended for commercial customers. Specifically, RPU uses *automated meter reading* (AMR), c.f. [2,17], to monitor the electric load on 15-min intervals. The program allows non-residential customers the ability to view, via the Internet, their usage patterns [11]. As for time-of-use pricing, it is available to both commercial and residential customers. The rates depend on both *season* and *tier*, as follows [18]:

- Summer On-Peak:
  - Tier 1 (0–145 kWh): 18 cent per kWh,
  - Tier 2 (over 145 kWh): 45 cent per kWh.
- Summer Off-Peak:
  - Tier 1 (0–1125 kWh): 8.5 cent per kWh,
  - Tier 2 (over 1125 kWh): 12 cent per kWh.

- Winter On-Peak:
  - Tier 1 (0–60 kWh): 20 cent per kWh,
  - Tier 2 (over 60 kWh): 35.5 cent per kWh.
- Winter Off-Peak:
  - Tier 1 (0–500 kWh): 9.5 cent per kWh,
  - Tier 2 (over 500 kWh): 15.2 cent per kWh.

Note that, the above tier-based rates have inherently incorporated the idea of inclining block rates (IBRs) into the basic ToUP tariff, see [16].

3 Renewable Power Generation

The County of Riverside is home to San Gorgonio Pass Wind Farm, which is the second largest wind farm in California with a nameplate capacity of 615 MW [19]. The County of Riverside is also home to the Joshua Tree Solar Power Plant, which is one of the largest solar farms in the world with a nameplate capacity of 550 MW [20]. However, within the City of Riverside, the existing and planned renewable energy generation installations are primarily solar and in the following two forms: *behind-the-meter* installations and small *solar farms*.

As of 2014, the total installed behind-the-meter capacity of solar panels in the City of Riverside has been 13 MW [7]. This number is expected to grow significantly over the next few years. RPU does not operate behind-the-meter solar panels. However, RPU does offer to purchase electricity from the owners of behind-the-meter solar panels once they sign and execute a Power Purchase Agreement (PPA) with RPU. The purchase is at an applicable price for metered energy delivered on a Time-of-Delivery (TOD) basis. The TOD time periods are defined in form of *on-peak*, *mid-peak*, and *off-peak* hours [21]:

- Summer:
  - On-Peak: 12:00 PM to 6:00 PM on weekdays,
  - Mid-Peak: 8:00 AM to 12:00 PM and 6:00 PM to 11:00 PM on weekdays,
  - Off-Peak: All other hours on weekdays and any hour on holidays.

– Winter:
  • On-Peak: 5:00 PM to 9:00 PM on weekdays,
  • Mid-Peak: 8:00 PM to 5:00 PM on weekdays,
  • Off-Peak: All other hours on weekdays and any hour on holidays.

There are currently two solar farms under construction in the City of Riverside. The locations of these projects are marked in Fig. 1. The Tequesquite Landfill Solar PV Project is a 7.5 MW solar farm that is being built on the decommissioned Tequesquite landfill, east of Downtown Riverside. The point of interconnection for this solar farm is a primary 12 kV at Mountain View substation. The University Solar PV project is a 3 MW solar farm that is being built on the campus of the University of California at Riverside [22]. The point of interconnection for this solar farm is a primary 12 kV at University substation.

From a distribution system planning viewpoint, RPU has identified three barriers to the study of integrating large PV systems: (1) inadequate tools that simulate high-penetration levels; (2) inaccurate models, due to limited availability of data; (3) limited accuracy of measured data sources [7]. Nevertheless, RPU has recently conducted a solar integration analysis at its Circuit 1364, where the Tequesquite Landfill Solar PV Project will be interconnected. It is identified that during off-peak hours in winter, the 7.5 MW PV exceeds the load on the circuit, causing *reverse power flow* into the substation and *voltage increase* along the distribution feeder. This problem is illustrated in Fig. 2, where the voltage versus the distance from substation is plotted under typical one-direction power flow assumption as well as for the actual case in presence of a large solar farm. RPU is currently working on improving the existing distribution infrastructure by reconduction, load transformation, and capacitor bank relocation [7].

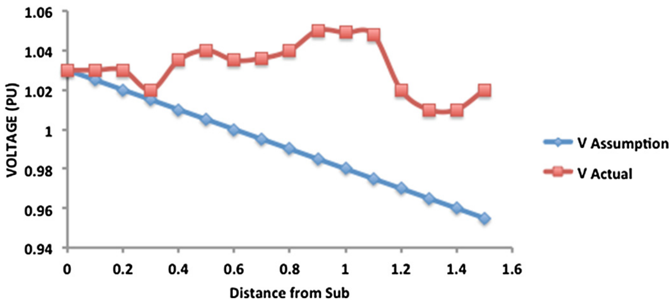

Fig. 2. Voltage as a function of distance to substation in presence of a large solar farm.

4 Energy Storage

The large-scale deployment of energy storage systems is one of the priority areas to build a smart grid, as identified by the U.S. Department of Energy and the National Institute of Standards and Technology [23,24]. The applications of grid-scale battery systems are diverse and include peak-load shaving, synchronous reserve, non-synchronous reserve, voltage support, and frequency regulation [25].

RPU has recently funded two battery energy storage projects in the City of Riverside to demonstrate peak-load shaving. In general, peak-load shaving can target reducing the load at the *meter level* [26,27], *feeder level* [28,29], and *grid level* [30–32]. The current battery energy storage projects in the City of Riverside address the first two cases. Specifically, RPU has funded Pacific Energy Inc. with a project entitled "Demand Response and Peak Shaving Advanced Energy Storage System" to address peak-load shaving at meter level. RPU has also funded the University of California at Riverside with a project entitled "Monitoring and Control of PVs and Energy Storage Systems at a 12 kV Industrial Substation" to address peak-load shaving at feeder level.

The goal in the Pacific Energy battery project is to design, implement, and test a 100 kWh peak-shaving, advanced energy storage system to be integrated into an existing commercial building utilizing lithium ion batteries, advanced controls and measurement equipment. The objective is to reduce the peak-to-average ratio in the load of a commercial building. This project uses a 100 kW inverter which allows charging or discharging the battery system in one hour.

The goal in the UCR battery project is to assess feasibility and test the idea of conducting peak-load shaving (congestion control) at Circuit 1224 in Hunter substation using the energy resources, namely batteries and solar panels, at the UCR College of Engineering - Center for Environmental Research and Technology (CE-CERT). The location of this project is marked in Fig. 1. The size of the battery system in this project is 1 MWh. It is divided into two 500 kWh battery stations, where each station uses a 100 kW inverter to charge and discharge the batteries. Accordingly, the battery system in this project can support 200 kW power for five hours. The battery system in this project is also connected to three solar PV units, with a total power generation of 480 kW.

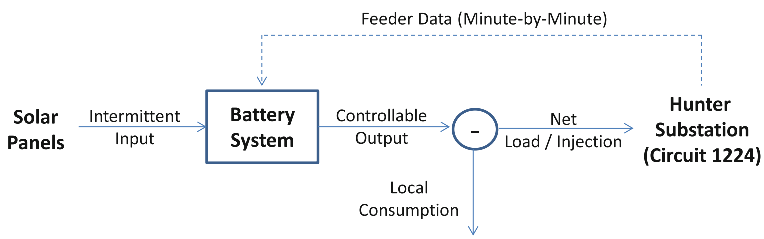

Fig. 3. The operational block diagram in the UCR battery project. Power flow is shown with solid line. Information flow is shown with dashed line.

The block diagram of the UCR battery project is shown in Fig. 3. A unique feature of this project is the communications between the battery controller and the RPU Supervisory Control and Data Acquisition (SCADA) system. Specifically, the RPU SCADA system sends a stream of minute-by-minute measurements from Circuit 1224 to the battery controller. This data stream, which provides various measurements including the feeder load, allows the battery system to adjust its output in response to congestion or other events on Circuit 1224.

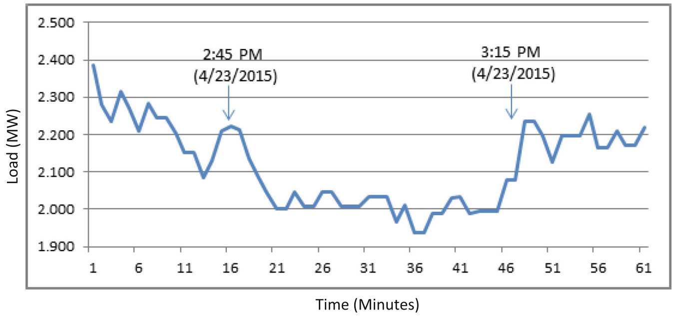

Fig. 4. The load on Circuit 1224 during an experiment in the UCR battery project.

The results for a recent experiment in the UCR battery project is shown in Fig. 4. In this experiment, which was done on April 23, 2015, the two battery stations at the CE-CERT facility were charged during the typical RPU off-peak hours from 10:00 PM to 6:00 AM. After that, the battery control system was programmed to discharge both stations at their maximum discharge rate from 2:45 PM to 3:15 PM, resulting in injecting 200 kW power into Circuit 1224 for a duration of 30 min. We can see in Fig. 4 that the load on Circuit 1224 dropped by 200 kW at 2:45 PM and then it went back to its normal trend at 3:15 PM. The signature of the battery discharge is evident in this figure.

5 Electric Vehicles

Transportation electrification is another priority area to build a smart grid, as identified by the U.S. Department of Energy and the National Institute of Standards and Technology [23,24]. Increasing the use of electric vehicles (EVs) is particularly critical for the Southern California region due to the severe air pollution in the Greater Los Angeles area that includes the City of Riverside. In 2013, the Los Angeles-Long Beach-Riverside area ranked the 1st most ozone-polluted city, the 4th most polluted city by annual particle pollution, and the 4th most polluted city by 24-h particle pollution [33]. Among other factors, motor vehicles are the main sources of air pollution in this region [34].

Due to the above concerns, and also partly because of the high price of gas in California, the State of California is currently the largest plug-in car regional market in the country, with almost 143,000 units sold between December 2010 and March 2015, representing over 46 % of all plug-in cars sold in the United States [35,36]. The exact number of electric vehicles in the City of Riverside is not currently known; however, it is known that over 5500 electric vehicles are owned in the County of Riverside, where the City of Riverside is the county seat [37]. Compared to over 200,000 total registered vehicles in County of Riverside [38], this suggests an EV penetration rate of about 2.7 %.

Given the still-low penetration of electric vehicles, the impact of EVs on the RPU power network is currently negligible. However, the role of EVs and their charging load may gradually start to become significant when it comes to urban distribution system planning. For example, as of June 2016 and according to Charge Point, there are 55 Level 2 and three Level 3 DC Fast charging stations installed in the City of Riverside: www.chargepoint.com. The typical charging load of Level 2 and Level 3 chargers are 3.3 kW and 50 kW, respectively. As for the Level 1 residential chargers, the typical charging load is 1.2 kW [39].

The studies on the integration of EVs into smart grid often address two different directions. First, there are studies that examine the adverse impact of EV charging load on distribution feeders, e.g., with respect to increasing power loss, line overflow, and substation congestion [40–43]. Second, there are also studied that examine the new opportunities that the EVs may offer to better operating the electric grid. In fact, while PEVs are expected to provide economic and environmental benefits to the transportation sector, they may also have a lot to offer to the electric grid, in particular at the distribution level, whether as a potential source of energy storage or as a means to improve power quality and reliability. The possibility of using PEVs to discharge electricity back to the grid has been studied in vehicle-to-grid (V2G) systems [44–49]. More recently, it has been have shown that PEVs may also offer reactive power compensation, not only in a V2G mode but also during a regular charging cycle, with minimum impact on the EV battery lifetime [50–54].

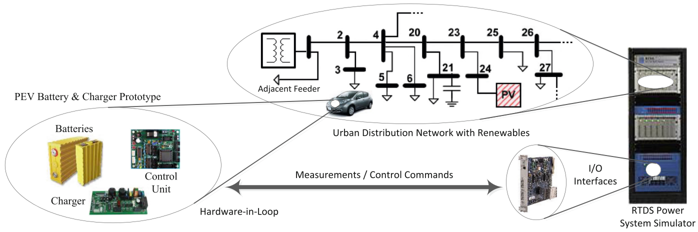

Fig. 5. The setup of the EV integration testbed at UCR Smart Grid Research Lab.

To study the impact of EVs on urban distribution networks, the Smart Grid Research Lab at the University of California at Riverside is currently building a hardware-in-loop (HIL) EV smart grid integration testbed using the RTDS Real-time Digital Power System Simulator (www.rtds.com), as shown in Fig. 5.

6 Monitoring and Automation

Monitoring and communications is the heart of the smart grid paradigm [1,2]. For example, a critical component in the UCR battery project that we discussed in Sect. 4 is the live data stream that is provided to the battery controller from the RPU SCADA system. This is done by establishing a secure FTP connection between UCR and the City of Riverside. Currently, the following quantities are measured and streamed from Circuit 1224 on a minute-by-minute basis:

– Active Power
– Reactive Power
– Apparent Power
– Voltage Magnitude
– Average Phase Current
– Neutral Amps.

A one day sample of the above data streams is shown in Fig. 6. As explained in Sect. 4, the primary data that is currently used in the UCR battery project is the Active Power measurement. However, in the future, other data types such as voltage and reactive power can also be integrated into the analysis to investigate the impact of battery operation on, e.g., voltage regulation.

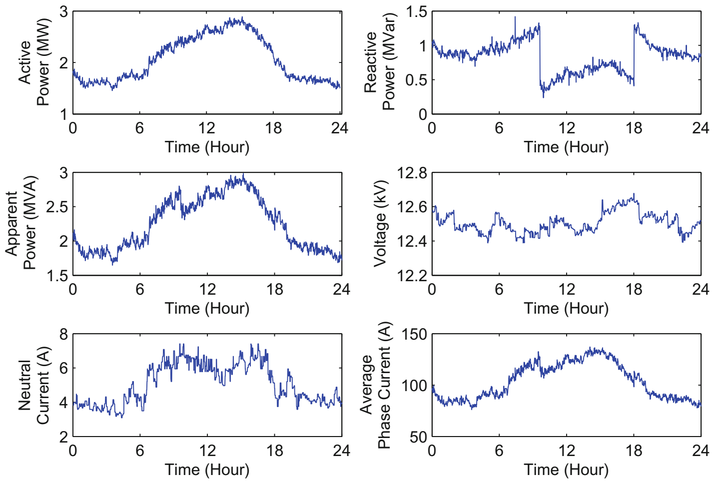

Fig. 6. Sample SCADA data at RPU Circuit 1224 on May 28, 2015.

RPU is also currently in the process of installing a few micro Phasor Measurement Units (PMUs) [55] across its distribution networks. Micro-PMUs allow recording detailed measures for AC power at high time resolutions. Some of the applications of micro-PMUs include topology detection, state estimation, performance evaluation, and fault detection at distribution level. The RPU mirco-PMU project is in partnership with the California Institute for Energy and Environment and Lawrence Berkeley National Lab, see [56] for details.

7 Conclusions

Sitting at the heart of the smart city paradigm, a smart grid can bring new opportunities to urban environments to improve stainability and infrastructure efficiency and reliability. The City of Riverside in Southern California has particularly taken important steps towards developing an urban smart grid foundation, through private-public partnerships and university-industry collaborations. In this paper, an overview of some of the existing and emerging smart grid development activities in the City of Riverside was provided, covering different smart grid topics, including energy efficiency and demand response, renewable power generation, energy storage, electric vehicles, and monitoring and automation.

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