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Cost-effective telemetry for energy network of an electricity distribution company: part I

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Abstract: We present a novel application of radio frequency wireless mesh network and general packet radio service technologies in a telemetry solution to measure power flow in the energy network of an electricity distribution company. The telemetry solution utilizes some selected circuits of grid stations and calculates total power consumed, total power imported, and total power exported by the distribution company. The selection of circuits for sensors installation is the key for reducing solution cost as compared to the case when sensors are installed on all the power output points. The framework involves installation of specially developed energy sensors (smart energy meters) and data concentrator units at the selected grid stations for measurement of energy data that include active energy, reactive energy, active power, apparent power, current, voltage, and power factor. The measured data reach the data concentrator unit using a 433-MHz wireless mesh network and are transmitted to a remote power control center using general packet radio service. Energy data from different grid stations across the energy network are collected at the power control center and utilized in calculation of total power consumed, total power imported, and total power exported. The approach has been tested on two electricity distribution companies of Pakistan: the Islamabad Electric Supply Company and Peshawar Electric Supply Company. Also in this work, the result of overload detection based on a generalized likelihood ratio test for an industrial feeder of the Islamabad Electric Supply Company is included. Detection probability of 0.96 with a false alarm probability of 0.04 has been achieved for a 30-min data interval.

Key words: Cost-effective, detector, energy measurement, generalized likelihood ratio test, power grid, remote monitoring, telemetry, wireless mesh network

1. Introduction

Most utilities (electricity distribution companies) in developing countries are neither able to remotely measure power usage of individual consumers nor to calculate real-time total power consumption of the complete region serviced by that utility [1]. Lo and Ansari in [1] presented a detailed survey on progressive smart grid systems. They reported that smart energy meters have multiple built-in interfaces, supporting various wireless and wired communication protocols. These smart meters, together with RF and power line communication technologies, may constitute a mesh communication network and get utilized in smart grid solutions. They also reported that WMN is considered as one of the foreseeable approaches to support smart grid applications and can also

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manage other nonsmart grid uses at the same time. Further, the authors included results of a survey finding that telecommunication technologies are quite mature and readily deployed these days. Therefore, the Global System for Mobile communications (GSM) and general packet radio service (GPRS) have become technology candidates for supporting wireless communication in grid stations. They can be used for purposes of remote monitoring and control of substations and distributed energy sources. Also, from the work in [2–4], it can be concluded that present electric power systems can be modernized into next-generation power systems (smart grids) by incremental inclusion of technology and intelligence.

In smart grid stations, real-time system monitoring and load control can also be achieved using any WMN, like ZigBee. These WMNs are also being recognized as promising technology for present grid stations. In [5], ZigBee deployment guidelines, under the interference of wireless local area networks, were presented. The authors of [6] present an experimental study on communication channels of wireless sensor networks in environments of industrial power control rooms and 500-kV substations.

In [7], 2.4-GHz ISM band parameters (RMS delay, coherence bandwidth, and electromagnetic interferences) under different conditions of line-of-sight and polarizations were investigated for a 400-kV substation. In [8], a real-time monitoring system was presented that monitors electrical quantities of a nationwide electricity transmission network. The system was developed through the National Power Quality Project of Turkey. Detailed study on wireless communication systems for grid stations was also presented in [9–11], whereas work on modeling of customer load consumption patterns in power distribution systems was discussed in [12–14].

In this paper we present a telemetry solution for an electricity distribution company. The telemetry solution architecture utilizes both radio frequency (RF) and GPRS technologies. This hybrid combination of RF and GPRS technologies has been used in remote energy metering of industrial, commercial, and residential consumers throughout the world. The proposed telemetry application for electricity distribution company (EDC) energy networks has not been considered before to the best of our knowledge. It utilizes sensors installed on power import circuits and power export circuits of an EDC energy network to calculate the total power consumed by the EDC's region. The result is a reduced number of required sensors (and also solution cost) as compared to the case where sensors are installed on every output feeder of an EDC network. The solution comprises a specially designed energy sensor (smart energy meter) and data concentrator unit (DCU). A developed computer server application is also installed in the power control center of the distribution company. The developed solution provides both telemetry of the distribution network and real-time total power consumption value of the complete region serviced by the EDC. Due to page limitations, designs of the energy sensor and DCU are not included in this paper. This paper only discusses the communication architecture. The proposed solution has been deployed for two electricity distribution companies of Pakistan under the USAID Energy Policy Program. These projects were part of an effort to modernize the present power system of Pakistan.

The contributions of the paper include the implementation of a real-time system for an EDC that measures and monitors power imported, power exported, and power consumed; the utilization of both RF and GPRS technologies in the proposed framework; and the identification of efficient sensor installation points, resulting in lower system cost. With these contributions, logged power consumption profiles are available for analysis that help in controlling, forecasting, and planning the consumption patterns, which results in buying cheaper power from the generation company.

The remaining part of the paper is structured as: Section 2 presents the background for the problem statement. Section 3 describes constituent modules of the proposed solution. In Section 4, the architecture and functional description of the proposed telemetry solution are discussed. Section 5 presents the design of a detector for overload detection based on the generalized likelihood ratio test. Section 6 discusses deployment of the proposed telemetry solution in two electricity distribution companies of Pakistan, namely the Islamabad Electric Supply Company (IESCO) and Peshawar Electric Supply Company (PESCO). Section 7 concludes this work.

2. Background

Many developing countries are unable to completely meet their growing energy needs. In these countries, there may be a shortage of power generation for different reasons. In such situations, there is a government or privately administered office that regulates and monitors total power (megawatts) generated on a national level and distributes this generated power based on an allocated quota to the country's electricity distribution companies.

As power generation is limited and electricity distribution companies are provided an allocated quota of this power, often a circumstance arises in which electricity distribution companies face power shortfalls. Power shortfall situations arise when power demand from an EDC's end consumer exceeds the EDC's allocated quota, or the quota allocated to the EDC is already inadequate to fulfill the end consumers' actual power needs.

To manage EDCs' power shortfalls, the power monitoring office issues load-shedding schedules on a daily or weekly basis, in which each EDC disconnects its end consumer power (electricity) supply for the duration of load-shedding. This electricity shutdown helps the EDC remain within the received allocated power quota.

An accurate load-shedding schedule may be formulated using the EDC's allocated power quota and real-time total power consumption values. This schedule can help EDCs remain compliant with allocated power quotas and also to not shut down consumer electricity for unnecessary time durations.

For the case in which no automatic, real-time mechanism is in place for EDCs that could measure and monitor actual, real-time EDC total power consumption (i.e. power consumed by EDC end consumers), the EDC employs a manual mechanism, in which energy readings are read from electromechanical and digital energy meters (installed in different grid stations of the EDC's distribution network) by human meter readers. Human operators from different grid station locations convey these energy readings to the power control center (PCC) via telephone calls. In the PCC, all the energy readings are manually summed up to calculate EDC total power consumption. For example, this manual mechanism of EDC total power consumption measurement and calculation in some EDCs of Pakistan involves receiving about 40 telephone calls at the PCC from different grid stations. Also, in some cases, a total time period of 30–45 min is required to manually read all the energy meters from different grid stations and then to calculate one value of EDC total power (MW) consumption in the PCC.

EDC power consumption values worked out by this manual mechanism do not represent true real-time values and also at times are inaccurate, due to human involvement at different stages of this power measurement-calculation mechanism.

Eventually, as EDCs' manually calculated power consumption values are often inaccurate and delayed, the power monitoring office ends up preparing load-shedding schedules, which either disconnect end consumer power for extra time durations or make EDCs go beyond their allocated power quotas.

The above discussed mechanism for EDC power (MW) consumption measurement and calculation and load-shedding schedules formulation can be improved by developing a solution that remotely measures power flow in EDC energy distribution networks. As the developed solution is to be implemented in developing countries, it should be cost-effective and swift in installation with the primary objective of obtaining real-time EDC total power consumption in PCCs.

This paper presents a telemetry solution for electricity distribution company energy networks. The paper discusses the implementation and solution architecture model of a wireless telemetry solution. The solution operates in real time and accurately measures both power flow in the EDC distribution network and EDC total power (MW) consumption. Details of the developed solution are presented in subsequent sections of this paper.

3. Proposed solution

Before presenting the architecture and functionality, the constituent modules for the EDC energy network solution are described.

3.1. Import circuit

The import circuit is a circuit within a grid station of an EDC distribution network from which electrical power is imported by the EDC from a power generation facility, or from another electricity distribution company. An EDC distribution network may have more than one import circuit, and also multiple import circuits may exist in one grid station. An import circuit that delivers power to EDC end consumers through an output feeder is categorized as an import circuit of type I, whereas an import circuit that steps down voltage and distributes power to another grid station of the EDC is categorized as an import circuit of type II.

For example, in Pakistan, a power transformer of required specifications is installed in an import circuit that steps down voltage either from 220 kV to 132 kV, or 132 kV to 66 kV, or 66 kV to 33 kV.

3.2. Output feeder

An output feeder is a circuit with a power transformer that steps down voltage and delivers power to EDC end consumers. For example, in Pakistan, power is delivered to EDC end consumers through an output feeder at 11 kV.

3.3. Export circuit

An export circuit is a circuit within an EDC distribution network grid station that steps down and delivers power to the grid station of another electricity distribution company. An EDC distribution network may have more than one export circuit, and also multiple export circuits may exist in one grid station. Also, both import circuits and export circuits may be present in a single grid station.

3.4. Common distribution point

An EDC grid station is called a common distribution point (CDP) if it distributes power to another two or more grid stations. The other grid stations may be all of the same EDC, or all of another EDC, or one/some of the same EDC and one/some of another EDC, i.e. the CDP may consist all import circuits of type II, or all export circuits, or a combination of both import circuits of type II and export circuits.

3.5. Power flow in an electricity distribution network

Figure 1 demonstrates the general flow of electric power from a power generation facility (PGF) to end consumers through EDCs' energy (distribution) networks. Figure 1 shows grid stations of two electricity distribution companies, namely electricity distribution company 'A' (EDC 1A') and electricity distribution company 1B' (EDC 'B'). The grid station of EDC 'A' is represented by G1, whereas the grid station of EDC 'B' is represented by G2. CDPs, power import, and power export circuits (branches) in the distribution network of EDC 'A' are also highlighted in Figure 1.

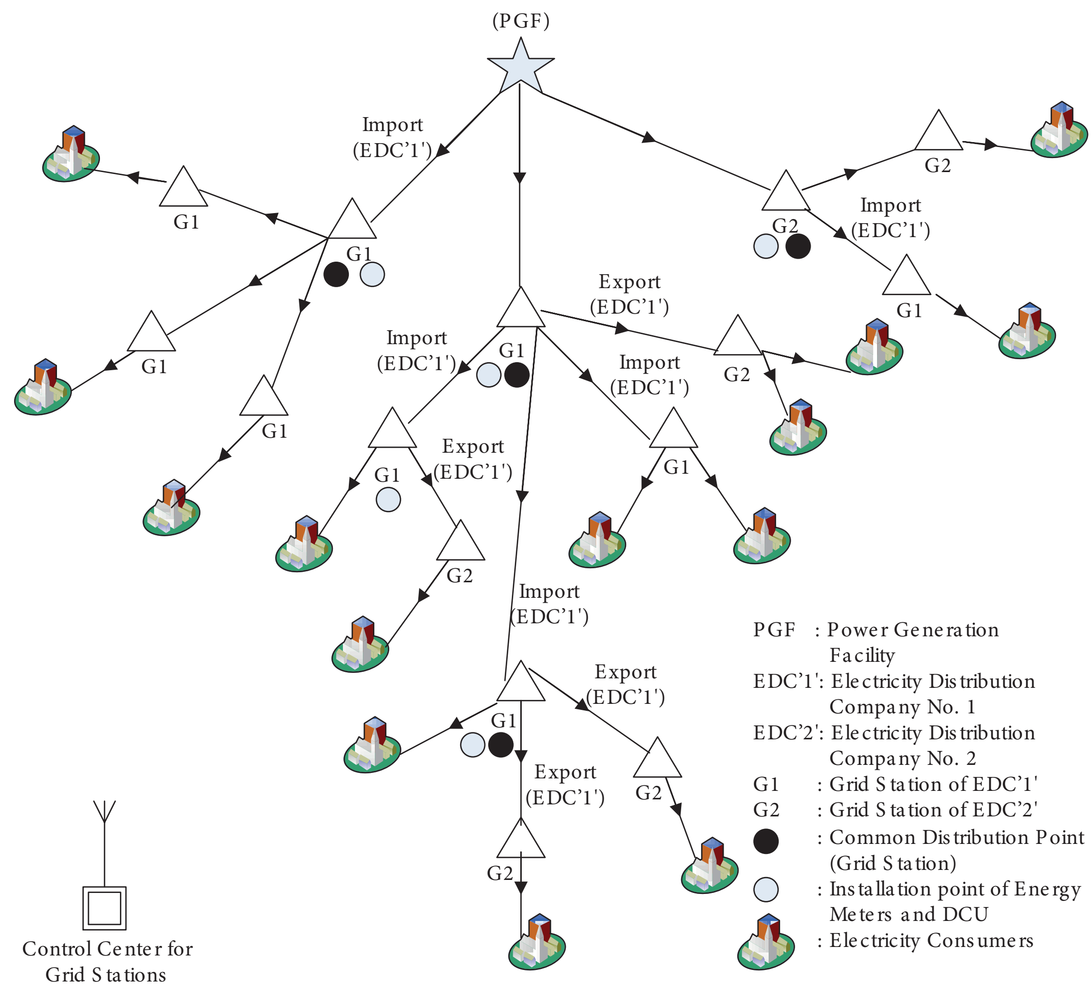

Figure 1. General flow of electric power from power generation facility to end consumers of EDC 'A' and EDC 'B'.

4. Solution architecture and functional description

In this section, the overall architecture and functional description of the developed telemetry solution are presented. As discussed earlier, the primary objective is to remotely measure from a PCC the real-time EDC total power (MW) consumption (i.e. real-time total power consumed by EDC end consumers). The secondary requirement from the telemetry solution is to provide in the PCC energy parameters of power flowing in different circuits of the EDC distribution network.

In the proposed developed solution, an energy sensor (smart energy meter) is installed on every import circuit and export circuit of the EDC distribution network. This results in a smaller number of circuits and reduced solution cost as compared to the case where every output feeder circuit of the EDC is selected for sensor installation. Figure 2 demonstrates circuits selected for an EDC. Energy parameters (active energy, reactive energy, active power, apparent power, current, voltage, power factor) of EDC import/export circuits, measured by each sensor, are wirelessly transmitted to the EDC power control center via the DCU. The DCU is also installed in the grid station. The solution utilizes a hybrid combination of RF 433-MHz WMN and GPRS technologies.

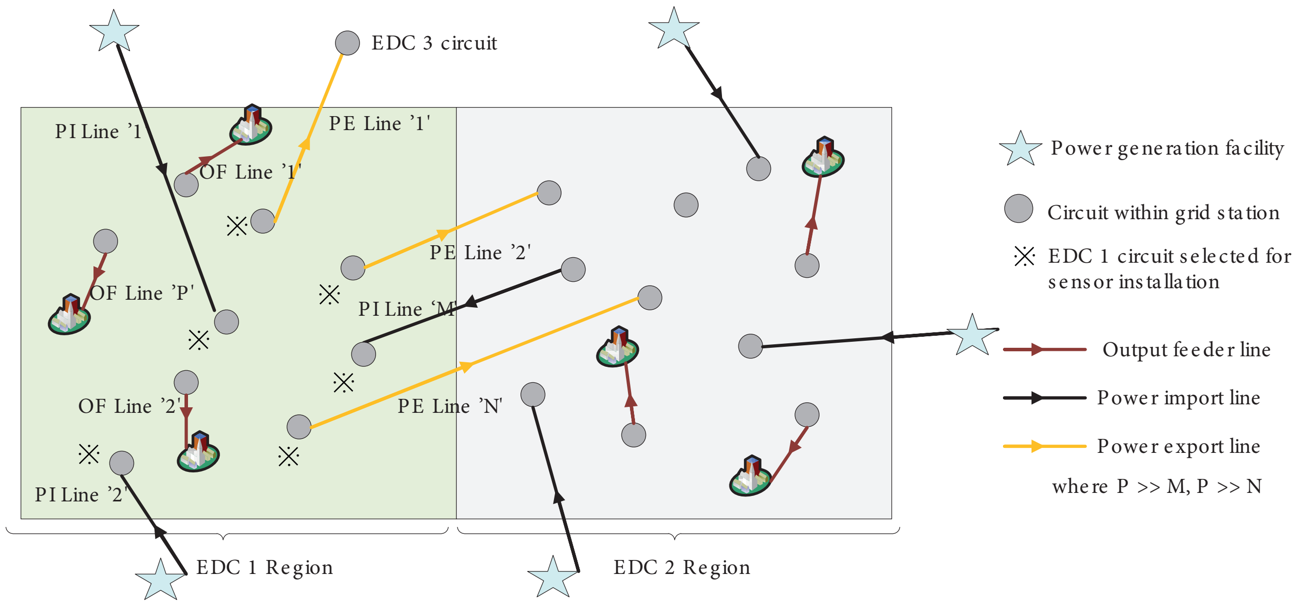

Figure 2. Illustration of selected circuits for EDC '1'.

In the PCC, real-time total EDC active power (MW) consumption is calculated by obtaining the difference between EDC real-time values of total active power (MW) imported and total active power (MW) exported:

Active power (MW) imported by EDC via 1st import circuit at time instant t = $P_{(i,1|t)}$

Active power (MW) imported by EDC via nth import circuit at time instant t = $P_{(i,n|t)}$

Active power (MW) exported by EDC via 1st export circuit at time instant t = $P_{(e,1|t)}$

Active power (MW) exported by EDC via mth export circuit at time instant t = $P_{(e,m|t)}$

Real-time power import $(P_{(i,1|t)},\ P_{(i,1|t)}, \cdots, P_{(i,n|t)})$ and export $(P_{(e,1|t)},\ P_{(e,1|t)}, \cdots, P_{(e,m|t)})$ values are remotely obtained at the EDC power control center, where real-time total power import and total power export are calculated as:

$$\text{Total power import} = \sum_{a=1}^{n} P_{(i,a|t)}; \quad \text{Total power export} = \sum_{b=1}^{m} P_{(e,b|t)}.$$

Real-time total active power (MW) consumption by the EDC is calculated using real-time values of total power (MW) consumption $= \sum_{a=1}^{n} P_{(i,a|t)} - \sum_{b=1}^{m} P_{(e,b|t)}$.

Parameter t, i.e. the time interval after which energy parameters (active energy, reactive energy, active power, apparent power, current, voltage, power factor) from each sensor are remotely retrieved, is programmable and can have any value greater than 10 s.

All import and export circuits in the EDC distribution network are identified with the help of the related EDC office. For telemetry of the EDC distribution network, energy sensors are installed on circuits of importance, which are also selected with the help of the EDC office. These circuits may include circuits that deliver power to industries, or deliver power to populated areas of high power consumption. Energy measurements from these sensors also reach the EDC power control center via the DCU and are utilized in power monitoring of the distribution network.

4.1. Architecture description

Figure 3 presents the architecture of the developed telemetry solution. A grid station may have any number of import circuits, export circuits, and other circuits of interest. Within a grid station, the installed sensors and DCU form a wireless mesh network. Each DCU in a grid station acquires energy data from sensors installed on circuits using RF 433 MHz and uploads them onto the server in the EDC power control center via GPRS provided by a cellular company. Energy data from all sensors are acquired by the DCU, and after packet formation they are uploaded onto the PCC server. The DCU continues with this dedicated task of data acquisition, packet formation, and uploading on the PCC server.

As import/export circuits and other circuits of interest are present in more than one grid station, and also at different locations in the EDC distribution network, a DCU is installed in each grid station from which circuit energy data are intended to be remotely read from the EDC power control center. Figure 3 demonstrates telemetry of 'N' grid stations of an EDC distribution network. A grid station may have 'N' number of circuits (sensors). Each grid station DCU acts as a gateway for sensor energy data and uploads sensor data on the PCC server.

In the PCC, the sensor data are monitored and logged in files with date-time stamps. Also, these data are used to calculate real-time EDC total power (MW) consumption, as discussed earlier. As shown in Figure 3, monitoring of energy data is also possible from remote multiple client (node) positions. These multiple clients access the PCC server data via the Internet.

Figure 4 demonstrates installation of energy sensors and the DCU within an EDC grid station. The sensor is installed in the grid station circuit to output the current transformer (CT) and potential transformer (PT), whereas the DCU operates on single phase AC voltage of 100–250 V. The two types of import circuits and export circuits are highlighted in Figure 4.

5. Detector implementation

Each sensor (energy meter) also provides overload protection at the installed circuit. The circuit may be of any type: import, export, or a branch of the EDC energy network. As the energy sensor measures power (kW) consumed through each circuit, a detector is implemented in the energy meter software that generates an alarm signal when power consumed reaches a predefined threshold value. The alarm signal triggers a specific circuit that disconnects all or a particular output load of that circuit, depending on EDC requirements. The EDC's concerned authorities set a predefined threshold value for each energy sensor detector.

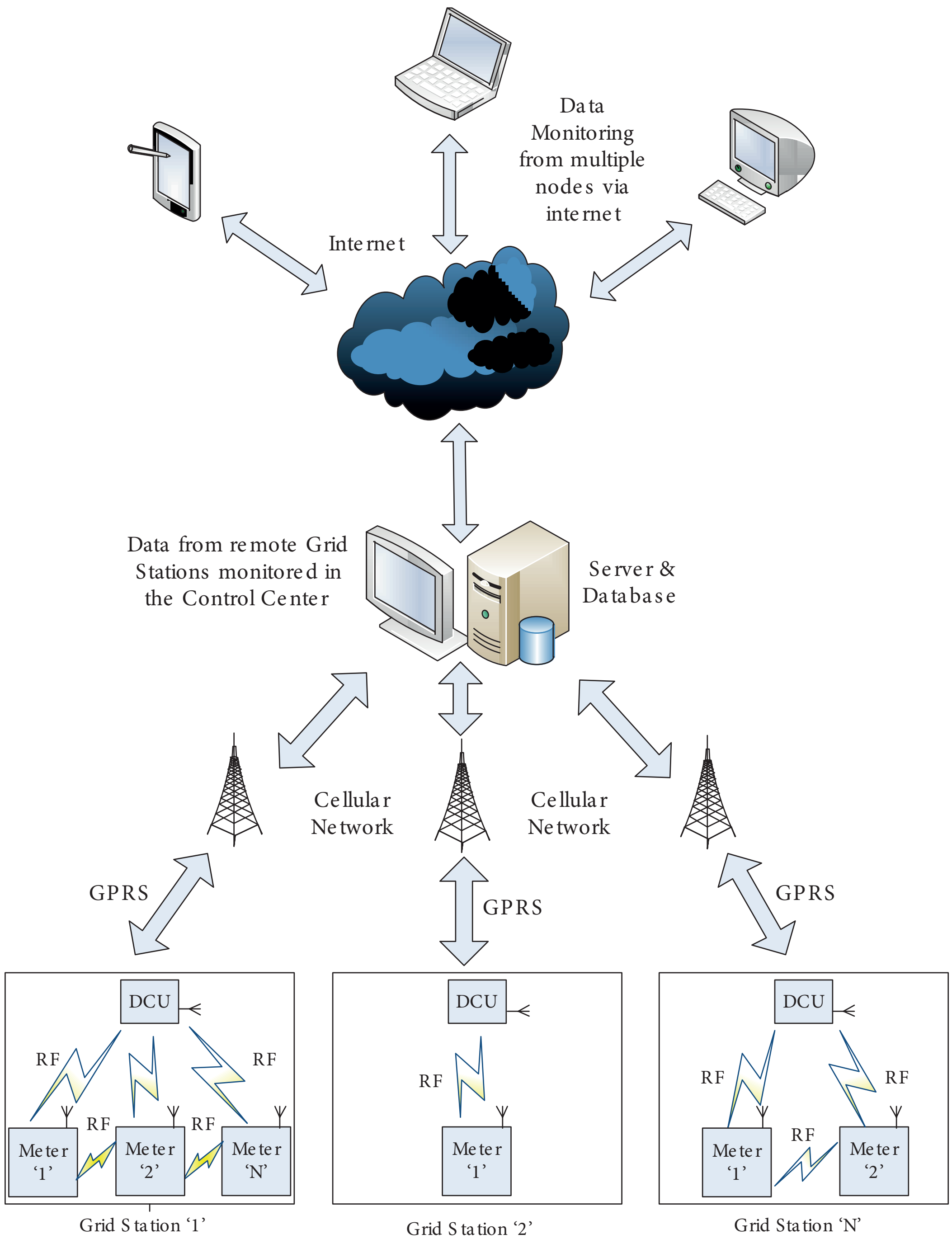

Figure 3. Architecture of developed telemetry solution.

5.1. Load consumption model for detector implementation

The measured power consumed is modeled to have an average or mean value of A_N, for an interval N, with load variations (random values over a mean) modeled as additive zero mean white Gaussian noise with variance σ^2, represented by $\mathcal{N}(0, \sigma^2)$. The notation $\mathcal{N}(\mu, \sigma^2)$ denotes a Gaussian probability density function with

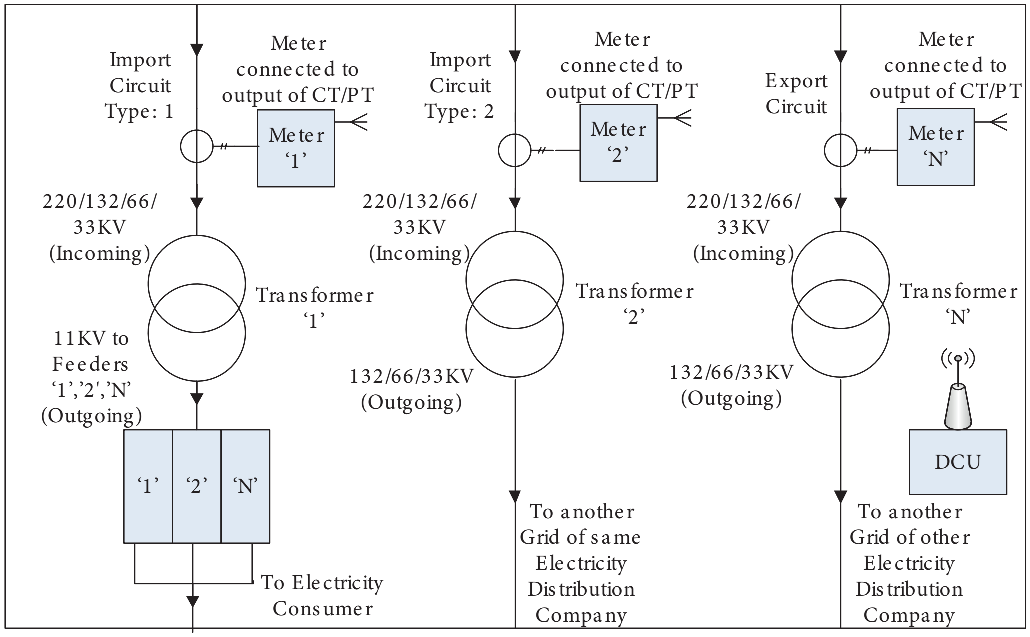

Figure 4. Energy sensors installed on circuits within 220/132/66/33-kV grid station.

mean μ and variance σ^2. The load consumption model utilized by the sensor detector is $x[n] = A_N + w[n]$, where $x[n]$ represents load consumption values at time step n, $n = 0, 1, 2, \ldots, N-1$, and N is the maximum number of samples. The circuit power readings are being measured at sample times of 2 ms by each energy sensor; for detector implementation, power readings in the sensor memory are updated after every 2 s.

5.2. Problem formulation

The signal (overload) detection problem is a binary hypothesis test, i.e. a single hypothesis must be chosen between two competing hypotheses H_0 (null hypothesis) and H_1 (alternative hypothesis). The goal of the detector is to decide either H_0 or H_1 based on the observed (measured) set of data $\{x[0], x[1], \ldots, x[N-1]\}$. This is a mapping from each possible dataset value into a decision. The following detector hypotheses are defined [15,16]:

$$H_0 : x[n] = A_N + w[n] < \gamma, \qquad H_1 : x[n] = A_{th} + w[n] > \gamma, \tag{1}$$

where $n = 0, 1, 2, \ldots, N-1$. A_{th} is set by the EDC on the basis of circuit load consumption history. The situation of deciding H_1 when H_0 is true is called a false alarm. $p(H_1; H_0)$ is referred to as the probability of false alarm and is denoted by P_{FA}. Overload detection is defined as the case where the measured load consumption value reaches the predefined value of A_{th}, i.e. deciding H_1 when H_1 is true. $p(H_1; H_1)$ is referred to as the probability of detection and is denoted by P_D. The design goal for the required detector is to maximize $P_D = p(H_1; H_1)$ subject to constraint $P_{FA} = p(H_1; H_0) = \alpha$.

5.3. Neyman–Pearson theorem

The Neyman-Pearson (NP) approach [17,18] has been used, which gives a test statistic that is a function of measured load consumption $x[n]$ and a threshold value. The detector decides H_1, and a signal is generated, which is used to disconnect the output load, when the test statistic value exceeds the threshold value. The NP approach to signal detection (hypothesis testing) states the following: to maximize P_D for a given $P_{FA} = \alpha$, decide H_1 if

$$L(x) = \frac{p(x; H_1)}{p(x; H_0)} > \gamma, \tag{2}$$

where the threshold γ is found for a given value of P_{FA} from $P_{FA} = \int_{x:L(x)>\gamma} p(x; H_0)dx = \alpha$ (right tail probability) and complementary cumulative distribution function [15] $Q(x)$, given by $\frac{1}{\sqrt{2\pi x}} e^{-\frac{1}{2}x^2}$.

The function $L(x)$ is called the likelihood ratio since it indicates for each value of x the likelihood of H_1 versus the likelihood of H_0. $p(x; H_0)$ and $p(x; H_1)$ are the probability density functions of $x[n]$ under hypothesis H_0 and H_1, respectively.

As in Eq. (1), A_N and random variation in load (variance) σ_0^2 are unknown for hypothesis H_0 and change with time. For hypothesis H_1, A_{th} is set by the EDC and therefore known, whereas random variation in load (variance) σ_1^2 is unknown. The detector is to be designed when the signal (load mean) is unknown but deterministic for hypothesis H_0, and known for hypothesis H_1. Noise (load variation) is Gaussian for both hypotheses, with unknown variances.

The problem thus becomes to decide between H_0 and H_1 when the PDFs depend on a set of unknown parameters. These parameters are not the same under each hypothesis. Under H_0 the vector θ_0 represents the unknown parameters, whereas θ_1 represents the unknown parameters under hypothesis H_1. θ_0 and θ_1 are defined as $\theta_0 = \{\sigma_0^2, A_N\}, \theta_1 = \sigma_1^2$. The PDFs of H_0 and H_1 are represented by $p(x; \theta_0, H_0)$ and $p(x; \theta_1, H_1)$, respectively. The approach now is to estimate the unknown parameters for use in a likelihood ratio test.

5.4. Generalized likelihood ratio test (GLRT)

The GLRT [19,20] replaces the unknown parameters by their maximum likelihood estimates (MLEs). From Eq. (2), the GLRT decides H_1 if

$$L_G(x) = \frac{p(x; \hat{\theta}_1, H_1)}{p(x; \hat{\theta}_0, H_0)} > \gamma, \tag{3}$$

where $\hat{\theta}_1$ is the MLE of θ_1 assuming H_1 is true (maximizes $p(x; \theta_1, H_1)$), and $\hat{\theta}_0$ is the MLE of θ_0 assuming H_0 is true (maximizes $p(x; \theta_0, H_0)$). The GLRT approach has been used, as it provides information about the unknown parameters. In this work MLEs are determined before determining $L_G(x)$.

5.5. Detector design

The probability density functions of $x[n]$ under hypotheses H_0 and H_1 with unknown parameters have distributions $\mathcal{N}(\hat{A}_N, \hat{\sigma}_0^2)$ and $\mathcal{N}(A_{th}, \hat{\sigma}_1^2)$, respectively, and are found as:

$$p(x; \hat{\theta}_0, H_0) = \frac{1}{(2\pi\hat{\sigma}_0^2)^{N/2}} exp\left[\frac{-1}{(2\hat{\sigma}_0^2)} \sum_{n=0}^{N-1} (x[n] - \hat{A}_N)^2\right],$$

$$p(x; \hat{\theta}_1, H_1) = \frac{1}{(2\pi\hat{\sigma}_1^2)^{N/2}} exp\left[\frac{-1}{(2\hat{\sigma}_1^2)} \sum_{n=0}^{N-1} (x[n] - A_{th})^2\right],$$

where the Gaussian probability density function for a scalar random variable x is defined as $p(x) = \frac{1}{\sqrt{(2\pi\sigma^2)}} e^{\frac{-1}{2\sigma^2}(x-\mu)^2}$, with μ and σ^2 as mean and variance. $\hat{A}_N$, the estimated value of mean A_N, is calculated as $\hat{A}_N = \frac{1}{N}\sum_{n=0}^{N-1} x[n]$.

The load consumption $x[n]$ variances (σ_0^2, σ_1^2) under hypotheses H_0 and H_1 are estimated as $\hat{\sigma}_0^2 = \frac{1}{N}\sum_{n=0}^{N-1}(x[n] - \hat{A}_N)^2$ and $\hat{\sigma}_1^2 = \frac{1}{N}\sum_{n=0}^{N-1}(x[n] - A_{th})^2$. The PDF under each hypothesis has been presented above, with the difference in means causing the PDF under H_1 to be shifted right (as $A_{th} > A_N$). Evaluating Eq. (3) using expressions for $p(x;\theta_0, H_0)$ and $p(x;\theta_1, H_1)$:

$$\frac{\frac{1}{(2\pi\hat{\sigma}_1^2)^{\frac{N}{2}}} exp[\frac{-1}{2\hat{\sigma}_1^2}\sum_{n=0}^{N-1}(x[n] - A_{th})^2]}{\frac{1}{2\pi\sigma_0^2)^{\frac{N}{2}}} exp[\frac{-1}{2\hat{\sigma}_0^2}\sum_{n=0}^{N-1}(x[n] - \hat{A}_N)^2]} > \gamma,$$

and simplifying:

$$\left(\frac{\hat{\sigma}_0^2}{\hat{\sigma}_1^2}\right)^{\frac{N}{2}} > \gamma. \tag{4}$$

6. Telemetry of IESCO and PESCO energy networks

The deployment of proposed telemetry solution completed in September, 2015 and October, 2016 for IESCO (Islamabad Electric Supply Company) and PESCO (Peshawar Electric Supply Company) respectively. To date the developed solution is effectively providing both IESCO PCC and PESCO PCC, telemetry of energy network and real-time total power (MW) consumption of EDC consumers.

6.1. Telemetry of IESCO energy network

The electricity distribution network of IESCO delivers power to over 2.4 million consumers (www.iesco.com.pk). Fifty-two import circuits, 11 export circuits, and 20 other circuits of importance in 49 grid stations were identified to be used by the proposed solution to calculate the total power consumed by IESCO region consumers. For these 83 circuits in 49 grid stations of the IESCO distribution network, 83 energy sensors and 49 DCUs are installed. The IESCO region electricity consumers draw power through 929 11-kV output feeders, and if sensors were to be installed on output feeders, then a total of 929 sensors would be required.

Values of energy parameters, power imported, power exported, and power consumed are updated after every 15 s for the telemetry solution deployed in IESCO. Figure 5 demonstrates detector performance of Eq. (4) via receiver operating characteristics (ROC) curves for an output feeder of IESCO. Results show that detection probabilities of 0.96, 0.91, and 0.85 are obtained with a constraint of 0.04 false alarm probability at measured data (power) intervals of 30 min, 20 min, and 10 min, respectively.

Figure 6 briefly presents the impact of the proposed telemetry and detector work on IESCO scheduled and unscheduled load-shedding. Approximated averaged numbers of hours per day of load-shedding for months, January to December, are shown. Power shutdown time due to faults and maintenance of the IESCO distribution network has been excluded.

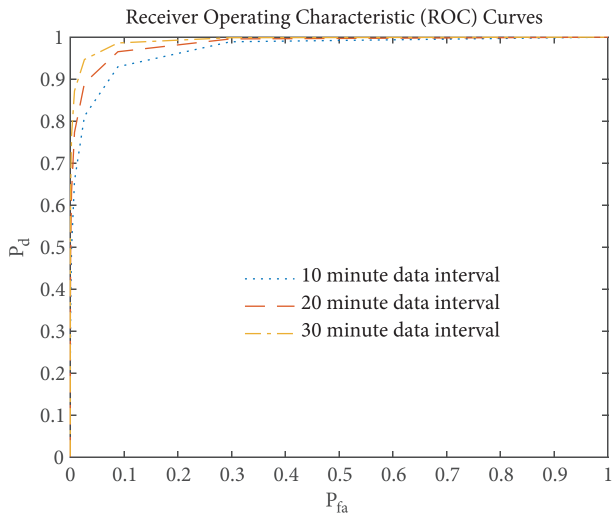

Figure 5. Detector receiver operating characteristics.

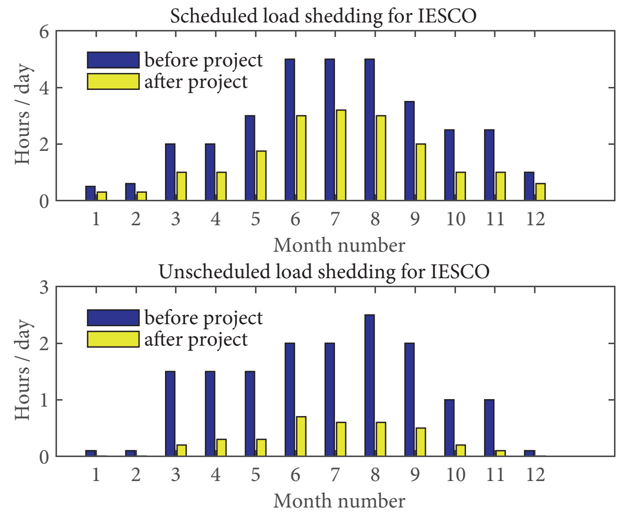

Figure 6. Impact of proposed solution on load shedding schedules of IESCO.

6.2. Telemetry of PESCO energy network

The electricity distribution network of PESCO delivers power to over 2.6 million consumers (www.pesco.gov.pk). Eighty-two import circuits, 30 export circuits, and 42 other circuits of importance in 68 grid stations were identified to be used by the proposed solution to calculate the total power consumed by PESCO region consumers. For these 154 circuits in 68 grid stations of the PESCO distribution network, 154 energy sensors and 68 DCUs are installed. PESCO region electricity consumers draw power through 969 11-kV output feeders, and if sensors were to be installed on output feeders, then a total of 969 sensors would be required. Figure 7 shows a picture of the PESCO PCC server LCD screen. Real-time values of total power imported, power exported, and power consumed by PESCO are displayed. These values are updated after every 15 s.

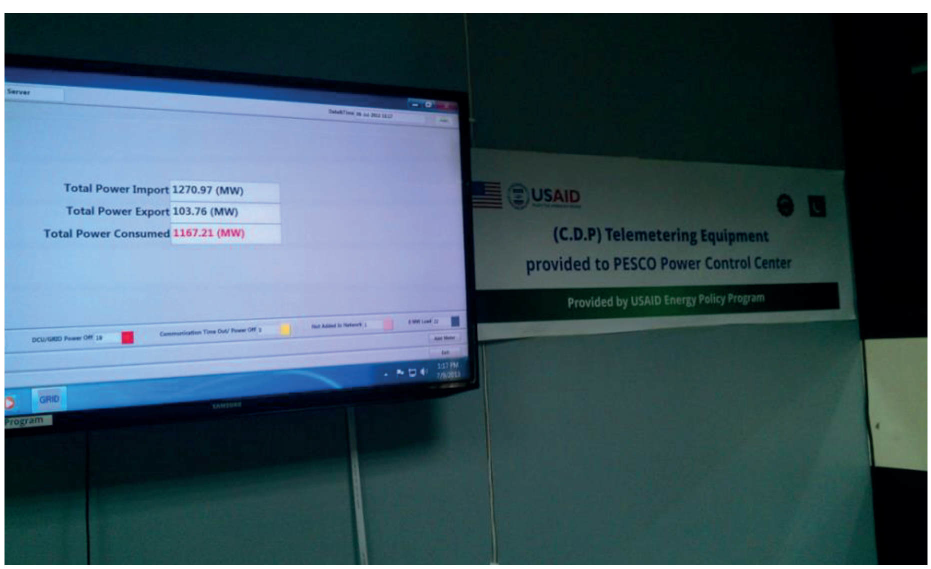

Figure 7. Photograph of PCC, PESCO server LCD screen.

7. Conclusion

This work has discussed installation of energy sensors on import and export circuits, as well as DCU installation in grid stations to remotely monitor real-time total power (MW) consumed by the region serviced by an electricity distribution company. Within a grid station, the installed energy sensors and DCU form an RF 433-MHz wireless mesh network. The proposed solution via the DCU offers GPRS-based telemetry of EDC energy circuits. The deployed telemetry solutions for IESCO and PESCO have helped in circuits' load balancing and quick identification of malfunctioning grid station equipment.

Part II of this work will discuss the impact of the telemetry solution and load detection on the power distribution system of Pakistan. Also, application of time series forecasting techniques for multistep, multivariable power demand forecasting will be presented.

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