An Enhanced Smart Control With Smart Meter Data For Centralized And Distributed Low Voltage Network

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ABSTRACT:

The rising issue of voltage regulation in distributed generation (DG) is being addressed through centralised voltage control (also known as active network management). Intelligent distributed voltage and reactive power regulation of DG has also been developed with positive results, allowing for the connecting of bigger generators to the distribution network with less voltage fluctuation and fewer voltage violations. Network operations will be tested when consumers give way to prosumers, who generate energy, particularly at the low voltage distribution level. To ensure power quality and safe device operation, voltage levels must be kept within permitted limits. In networks where renewable energy sources account for a considerable proportion of production, voltage regulation may soon be a necessity. Nearly every node now has access to power quality measuring equipment thanks to the widespread adoption of smart metres and other forms of automated metre reading. The network's voltage and power can be checked for synchronicity with the use of power snap shop analysis. Characteristics of the network and key nodes can be discovered through automated analysis of this massive data set. Using power snapshot data, this work demonstrates automatic evaluation of essential voltage nodes, a requirement for the creation of effectively run low-voltage grids.

Keywords. Advanced Metering Infrastructure, Smart Control, Low voltage grids, Voltage Control, Smart Meter.

1. INTRODUCTION

The collection of data from a wide variety of sources is now a difficult and time-consuming operation. If the same operation involves using energy, the user will need to set up more extensive connections between the various loads at each stage of the process. Internet-connected gadgets (IoT) are becoming increasingly important for users to rely on in order to overcome this obstacle. Embedded technology gives things the ability to change their behaviour in response to changes in their surroundings, whether those changes be internal or external. This, in turn, affects the decisions that are made [1].

A huge issue has emerged as a result of rapid economic growth and technological advancement: the energy crisis. It is important to set up a system to track and manage energy consumption effectively [2]. Current practises are inefficient, laborious, and fraught with errors [3]. Although the current system's pricing is determined digitally, a concerned member from the energy department still has to physically visit a customer base to remark on this information and make a mistake. Therefore, the alternative is a smart energy meter.

Figure 1. This illustration of a smart metering network includes wireless 2G/3G smart meters

The smart grid is crucial to the way we live today. The instability and unreliability of the power infrastructure will severely hinder the daily lives of tens of millions of people [4]. The Smart Meter is a user-friendly power control device that allows for real-time monitoring, automated data gathering, and human involvement [5]. As a result, both customers and service providers benefit from increased flexibility and productivity [6]. Power consumption can be managed with the help of real-time data [7]. Power to the customer is cut off by a smart energy metre if the load is too high [8]. A typical smart metre has a lifespan of 5–6 years under normal conditions and a typical operational load [9]. However, the intelligent energy metre runs into problems in the actual world and has a shorter lifespan than planned because of the unexpected energy it consumes [10].

The controller, Wi-Fi, and theft detection all play important roles in the IoT-based power metre system. The theft sensor uses the data it receives to identify the type of error or theft that has occurred and the subsequent cycle response. The controller is crucial to the system since it regulates the operation of each part.

As a result, IoT has the potential to improve the smart grid's effectiveness, particularly during its initial three stages. It promotes openness and trust, for starters. Second, it's concerned with facilitating [12-13] the gathering and processing of data to manage active devices inside a smart grid. Finally, the effect produced in phase two can be studied to provide the grid department more leeway in its decision-making for future expansion.

A large percentage of DGs necessitates an active distribution network, the smart grid, because of the volatile nature of renewable energy output. The network voltage is a critical indicator of other electrical parameters. When operating a network, it is the responsibility of the operator to keep voltage within safe parameters.

1.1. Voltage control

There have been many different distribution network control paradigms established and studied. Distributed control based on voltage measurements at crucial nodes, coordinated control, and the use of a tap changer to manage voltage at the transformer level all fall under the same umbrella (DGs provide reactive power, centrally coordinated).

1. ***Medium Voltage Networks:*** The use of on-load tap changers (OLTC) for automated voltage control (AVC) has become commonplace in today's medium-voltage networks. By adjusting the tap location (and consequently the number of primary windings), the secondary voltage can be held at a constant value. Since the voltage is regulated on a per-transformer basis, fluctuations in the grid's voltage owing to loads or generation are ignored. Using data from voltage sensors installed at critical nodes (CN), a centralized controller can optimize the tap location in response to the real grid state [14, 15]. A DG's reactive power might alter the voltage depending on the network node's impedance ratio or sensitivity. Independent voltage control utilising reactive power is occasionally used for DGs at the extreme end of feeders when the voltage rise would exceed permitted constraints. For maximum voltage or active power, the local controller uses a droop scheme [16]. The usage of reactive power in a coordinated fashion allows for greater control. It is possible to minimize the contributions' losses or maximize their gains on a global scale. Medium voltage (MV) networks with coordinated voltage control have been established and investigated for a number of years [17, 18].
2. ***Low Voltage Networks:*** When comparing a three-phase, four-wire MV network to a three-phase, four-wire LV network (including the neutral line), there are significant distinctions. Physically, HV networks are different from MV networks in terms of length and the reactance to resistance ratio (X/R). The imbalance of the LV network is another crucial distinction. When loads or generation are asymmetrical, the neutral point moves, resulting in voltage reductions in the neutral line or voltage increases on the other, less-taxed phases [19]. Voltage measurements are the backbone of voltage control theories, however in an unbalanced LV system, phase-to-phase variances make it difficult to settle on an accurate number; in fact, only the mean or the maximum can be wholly inaccurate. Smart meter-based control paradigms for LV networks are proposed in [20], and vehicle-to-grid applications are discussed in [21]. Different methods, such as power electronics (secondary side) and decoupling control, can be used to produce an LV transformer with on-load change capability. Power electronic switches have the benefit of allowing for phase adjustments to be made independently of each other. Additionally, the voltage step is different from medium voltage transformers and there are fewer tap places available.

2. ENERGY MANAGEMENT SYSTEM

Energy management in distribution systems considers how various conventional and renewable energy sources, as well as energy storage technologies, respond to base loads in concert with EMS operations and maintenance. By combining data from many sources, including weather forecasts and information from the energy market, as well as improved communication and control infrastructure, the optimal balance between productivity and load can be achieved. The management of power can be used on a grid that is connected to another power source. Direct control of energy resources or regulated loads is of interest to researchers because it can lead to time and usage controls for production, which in turn can reduce production costs. Distribution networks rely heavily on the monitoring, management, and conservation of energy that constitute energy management. Helps customers whose power needs are particularly great in the case of an emergency, scheduled maintenance, or closure of a choke point. Smart cities rely heavily on IoT-based EMS since it allows for the integration of several energy sources.

Power management on a large scale, resembling the intelligent grid in both structure and user interaction, may soon be a reality thanks to the Internet of Things (IoT). Since the internet is being used in every step of the power generation, transmission, storage, consumer, and smart energy market, power management systems are developing at a breakneck pace. Among their distinguishing characteristics are advanced technological devices, an abundance of electricity sources, a horizontal economic structure, open financial dealings, and a lack of centralised supply and demand.

Intelligent energy-efficient and energy-effective resources, such as online cloud-based platforms, intelligent coal mines, wind farms, photovoltaic stations, and other intelligent power production and energy facilities, are needed to improve management and raise revenues. Future intelligent structures are predicted to include novel and ground-breaking designs. Electrical and electronic systems (EMS) in smart buildings may be broken down into three broad categories: device-level, system-level, and inter-system-level.

Smart frameworks use context awareness to offer input data at the device level that is applicable to the operating context. At EMS, the forecasted power data is analysed by the IoT processing unit, and the results are then distributed to the relevant control and command systems. The following step involves completing the necessary processes with the help of the ultimate actuators. Intelligent design coordinates and integrates the efficiency of multiple power sources within a single system. With the use of a smart IoT interim system architecture, power plant infrastructure may be redesigned automatically so that it can be used to operate and regulate power units. When it comes to power plants, the vast majority of intelligent IoT solutions will also be of assistance. Smart building power management requires a few decentralized subsystems to function independently of the overall inter-tier infrastructure. Rather than having separate systems for each of these functions, smart buildings integrate them all into a single, unified whole. Ability to manage, coordinate, and adapt a wide variety of systems and procedures to achieve EMS is key to intelligence. Smart grid systems are an integral part of the renewable energy industry. The Internet of Things in an intelligent grid creates a new service connected to value-added electricity in addition to incorporating renewable energy and transportation power installations. Changes to energy management will be made based on use and the presence of an intelligent grid.

3. RELATED WORK

The traditional power grid has been transformed into a massive distributed generation system (DG) made up of thousands of generators of varying technologies, voltages, currents, and power levels as renewable energy generators have sprung up all over the world in recent years, with outputs ranging from a few kilowatts (in the case of residential photovoltaic systems) to a few megawatts (in the case of large photovoltaic and wind generators).

Integrating them into the system has resulted in a seismic shift in the whole electrical power infrastructure [22]. Unfortunately, there are a number of obstacles on the ground that are exacerbated by the current power grid's ageing infrastructure, including its unreliability, poor power quality, exorbitant and growing costs, and low levels of consumer satisfaction. Essential components of the power grid include distributed generators, power transformers, and distribution feeders. Due to its increasing complexity, huge number of geographically scattered producers, and side effects created by the unpredictable nature and high penetration of renewable energy systems (RES), it is becoming increasingly vulnerable, requiring extensive security methods [23].

The existing power grid is a centralised system, with electricity flowing in just one way, from power plants to consumer locations, via transmission and distribution lines. As a result, remote terminations (i.e. loads) are almost or completely passive, while intelligence is centralised and only partially distributed to substations. Reliability, flexibility, efficiency, economy, and security in power supply and consumption would all be possible because to the new systems' embedded intelligence, which would be greater and more broadly dispersed in local electricity generation.

Author in [24] first proposed EONs, research into optical networking has expanded into uncharted territory. Static and dynamic RSA were both the subject of multiple research [25]. In [26], we see experimental evidence of the effectiveness of scalable networking algorithms and adaptive spectrum control and management techniques. The impairing effects of fibre have been described using a closed-form relation in [27], which introduces a quality of transmission aware RSA. Modeling the operation of EONs from both the node and network levels is the focus of [12]. In [28] explored EON as a way to dynamically handle both traditional and high-burst traffic across data centres. We base our ILP formulation on the work by [29], who originally presented static many cast RWA and proposed an ILP formulation. Also, in order to reduce the time needed to fulfil several cast requests, they developed two heuristic approaches. Notably, this many cast RWA formulation is not applicable to EONs because to the fundamental differences between EONs and typical WDM networks. Energy optimization in EON is a topic that has been studied in [30] for conventional building design (i.e, unicast routing). In order to reduce the amount of spectrum that is used, an ILP formulation for static EON planning was presented in [19]. And then they brought out a heuristic approach using the genetic algorithm. Assuming elements with both brown and green power supply, [20]-[23] examine the impact on GHG emissions from WDM-based networks' energy efficiency. The authors in [31] suggested ILP formulations for RWA in a network with dual sources, green and brown sources. A approach for decreasing greenhouse gas emissions through routing has been presented in [21] for use in cloud computing networks that include data centres powered by renewable energy. The overall GHG emission is affected by the light-tree selection of many cast RWA heuristic approach, which has been studied in [22]. In many ways, the foundation of our many casts RSA heuristic method is similar to that of the many cast RWA technique published in [22]. For EONs, however, the many cast RWA described in [22] needs some tweaks in order to achieve the necessary modulation level and SA. In [32], several routing and resource allocation algorithms are explored to examine their effects on GHG emission in data centres with either a green or brown power supply. To our knowledge, this is the first study to investigate energy-efficient many casts routing, modulation level, and SA issues in a cloud computing environment based on EON. In order to account for the lack of information on demand and generation profiles and asymmetry, the few studies that have examined the effect of dispersed energy resources on LV networks (e.g. [5]) have used simplistic assumptions.

This is the first-time synchronized measurement data and a three phase/four wire representation have been used to model and simulate a low voltage distribution network. Thus, there has been no study of the consequences of EV and PV or other asymmetric load or feed based on actual grounding values or measurable data.

Historically, proprietary or otherwise non-standard communication protocols were used in Smart Metering deployments. However, various proposals [16] to standardise and guarantee connectivity among Smart Meter devices have been suggested recently. Data transfer for metre reading, tariff, and load management are just a few examples that may be cited from the International Electrotechnical Commission (IEC) 62056-58 and IEC 62056-62 [6, 7]. Smart metering apps like AMIs (Advanced Metering Infrastructures), DERs (Demand Response), and HEMSs (Home Energy Management Systems) may more easily share their respective infrastructures thanks to the standardizations [11]. In addition, it has enabled the incorporation of pervasive communication technologies into Smart Metering Infrastructures, which boosts power system visibility and optimal control for supervisory control and automation systems. In [13], a mechanism is shown that makes use of smart metering infrastructure based on GSM technology in order to monitor and automate the electric distribution system. Two-way communication is used to verify the developed model's capabilities in remote supply control, outage management, and automatic power shutoff in the event of a malfunction. Modern smart metres are proposed for application in research on power quality, load monitoring, and active power factor adjustment [14, 15]. Both consumers and utilities stand to gain from the load-characterization approaches presented in the articles, which could lead to higher power quality. They also suggest the significance of investigating passive power sources. In [33], the ADE7758 integrated circuit (IC) is recommended for use with an ATmega 16 microcontroller to monitor supply parameters, issue over voltage and over current alerts, and create bills instantaneously as part of an advanced metering infrastructure. Numerous studies have looked into how AMI may help reduce costs by cutting down on labour in the areas of energy billing, prepaid metering, and remote connection and disconnection of supply. [34] [18] [19]. Since enabling smart grid operations over flawed, heterogeneous general-purpose networks is a main goal of the SmartC2Net project [20], adaptability of network QoS and information access settings has been the subject of substantial research. [21] While [35] investigated a framework for information quality-based LV grid monitoring and its application to power quality control, [23] discussed the use of network QoS for dependable adaptive Smart Grid control, elaborating on the impact of imperfect network conditions on smart grid controllers and how to mitigate this using Quality of Service (QoS) data. Focusing on Smart Metering infrastructures that allow for network-level change of the data collection mechanism, this research presents an adaptive data aggregation methodology for monitoring the electrical grid. In contrast to this type of study, the Smart Energy Systems Laboratory at AAU [24] use a real-time hardware-in-the-loop technology to validate the outcomes of experimental field studies. The majority of Denmark's smart metres are only being used for metre reading at sluggish update rates, thus this work would contribute most if it explored the possibility of employing smart metres to enable distribution grid monitoring through the use of adaptive data gathering systems.

4. DEFINITION OF CRITICAL NODES

A. ***Static critical nodes:*** In a medium-voltage network, [7] the following factors are taken into account while choosing a statical critical node that will be controlled by a voltage-regulating algorithm:

$$\forall t\ U(t, N_{Simulation}) \quad \{t|0 < t < 1\, year\} \tag{1}$$

$$N_i \in CN, \exists\, u_i = \begin{cases} \max\{u_1, u_2, \dots, u_n\} \\ \min\{u_1, u_2, \dots, u_n\} \end{cases} \tag{2}$$

$$\forall u_i: u_1^{'} = u_2^{''}, \dots, u_3^{'''} \tag{3}$$

Where N is the set of nodes including the critical nodes CN and U is the voltage at each of those nodes.

We can describe the voltage spectrum as follows:

$$u_{Range}(t) = u_{max}(t) - u_{min}(t) \tag{4}$$

B. Dynamic critical nodes: The number of CN must be kept low so that enough communication bandwidth is available to query actual voltage measurements of important nodes from smart metres. So, we take NPSS power snapshots at our trigger timings $t_{trigger}$ and use those to dynamically assess our set of essential nodes:

$$\forall t\ U\ (t, N_{PSS})\{t|t_{trigger}\}$$

$$N_i(t_+) \in CN(t_+)$$

$$\exists u_i(t) = \begin{cases} \max\{u_1^{'}, u_1^{''}, u_1^{'''}, \dots, u_n^{'}, u_n^{''}, u_n^{'''}\} \\ \min\{u_1^{'}, u_1^{''}, u_1^{'''}, \dots, u_n^{'}, u_n^{''}, u_n^{'''}\} \end{cases}$$

$$\forall u_i(t): u_1^{'} \neq u_2^{''} \neq u_3^{'''} \tag{5}$$

And the voltage range in one phase:

$$u_{Range}^{'}(t) = u_{max}^{'}(t) - u_{min}^{'}(t) \tag{6}$$

The maximum voltage range across all phases is the biggest difference between the highest and lowest voltages across all phases:

$$\hat{u}_{Range}(t) = \max(u_i^{'}, u_i^{''}, u_i^{'''}) - \min(u_i^{'}, u_i^{''}, u_i^{'''}) \neq \max(u_{Range}^{'}, u_{Range}^{''}, u_{Range}^{'''}) \tag{7}$$

5. POWER SNAP SHOT ANALYSIS

Siemens' AMIS PLC system [15] forms the foundation of the communication system. Data concentrator (DC) plays the role of master and must begin all communication. In the AMIS PLC physical layer, transmission occurs using fast frequency hopping spread spectrum in the CENELEC A-Band from 3 kHz to 95 kHz. When transmitting a coded bit stream, it is typically divided into blocks that are then interleaved. Because of interference from the power grid, power line communications could suffer packet loss. In this way, devices that are inaccessible via direct connections might be reached via retransmissions or so-called hop layers. The communication channel can be statistically characterised by its loss probability and its delay duration, which follows a Gaussian distribution [16]. Internal registers for recording measurement values are a feature that can be added to smart metres. Different statistical metrics can be assessed by classifying power quality data throughout a 10-minute period according to factors like voltage. In [1], the potential of smart metres to analyse voltage levels statistically in order to learn more about the effects of load imbalance is highlighted. B. Setup of the System The behaviour of MV networks is well understood, while many aspects of low voltage networks, such as the effect of grounding impedance on neutral displacement, remain poorly understood. It has already been established that the interconnection assessment of distributed generation is based on worst-case scenarios. Power snap shot analysis (PSSA) using smart metres, as detailed in [17] and [18], has been created and implemented as a first step toward more appropriate analysis. The fundamental concept is to have a moment in time measurement of all network voltages and currents in order to verify the related network models. Then, physical factors like the surrounding environment can be investigated. During the 900-second window in which snapshots are taken, the maximum or minimum value of a characteristic (such as voltage, current, or imbalance) will cause a snapshot to be taken. While the 'time series' mode can take continuous measurements over the course of several minutes (usually 60 seconds) without the requirement for trigger conditions, the 'campaign' mode takes snapshots at multiple intra-day intervals to provide a good coverage over workdays and non-workdays. Large amounts of information, such as those produced by snapshot campaigns and time series, are automatically ingested into a database. By comparing the simulated voltages with the measured voltages, the network model is validated. The simulated voltages are the output of a process in which active and reactive power measurements serve as inputs. The simulation setting for investigating low voltage networks has been introduced in [19]. The loads in the network detail model are mapped to the collected data. Power Factory, a piece of software used to simulate power systems, is used to do a power flow, with the resulting voltages compared to the actual voltage measurements. To achieve model validity and approximation of the data, the error is minimised by adjusting a number of parameters (such as grounding impedances).

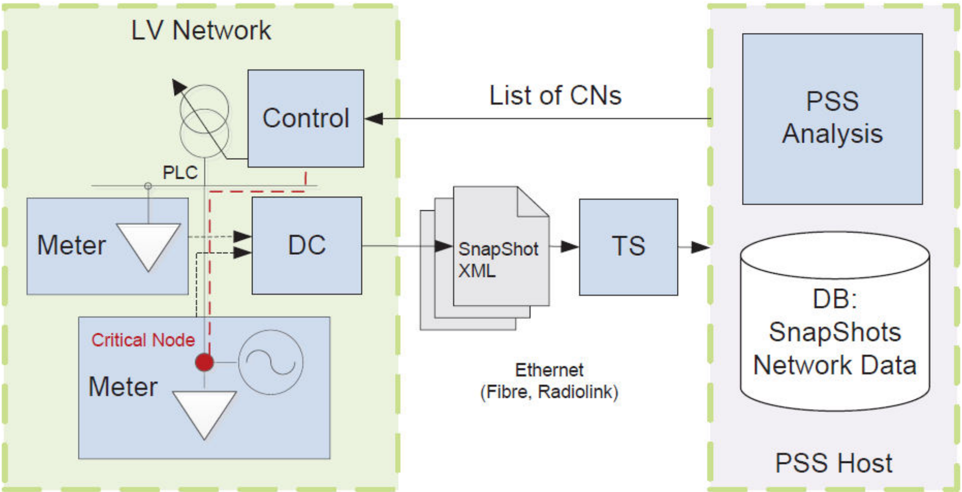

Figure 2. Overview of the Power Snap Shot Analysis (PSSA) for locating voltage-control essential nodes.

Power snapshot data may also be used to characterise LV networks by, for instance, calculating the equivalent sum-impedance, which is a measure of the network's electrical resistance ([20]). For low voltage on-load tap changers and distributed generation, the power snap shot analysis (PSSA) and controller are shown schematically in Figure 2. The number of snapshots of a measurement interval requested by a data concentrator (DC) increases in proportion to the time it takes for the DC to seek and receive data from the participating metres over the PLC communication channel. As soon as all metre readings are in, the transaction server (TS) will transfer the snapshot file to the PSS Host for incorporation into the database. By just polling the most critical nodes, bandwidth may be saved and cycle time can be reduced, as decided by the controller's analysis of the received snapshot. The whole identifying process should take between 30 and 60 minutes round trip. An example of a 60 second power snapshot series (= 60 PSS) for the feeder shown in Figure 1 is shown in Figure 3, which displays the lowest, mean, and maximum voltage per phase along with their respective frequencies. The largest voltage difference between any two phases at any instant in time is the maximum range. You can see the active and reactive powers, phase by phase and as a whole, in Figure 4.

6. RESULTS AND DISCUSSION

The meter at the far end of the feeders should always have the lowest voltages. However, not only are the metres with the maximum number of minimum voltage occurrences different; certain minimum voltages also occur halfway through the feeder or at another feeder branch.

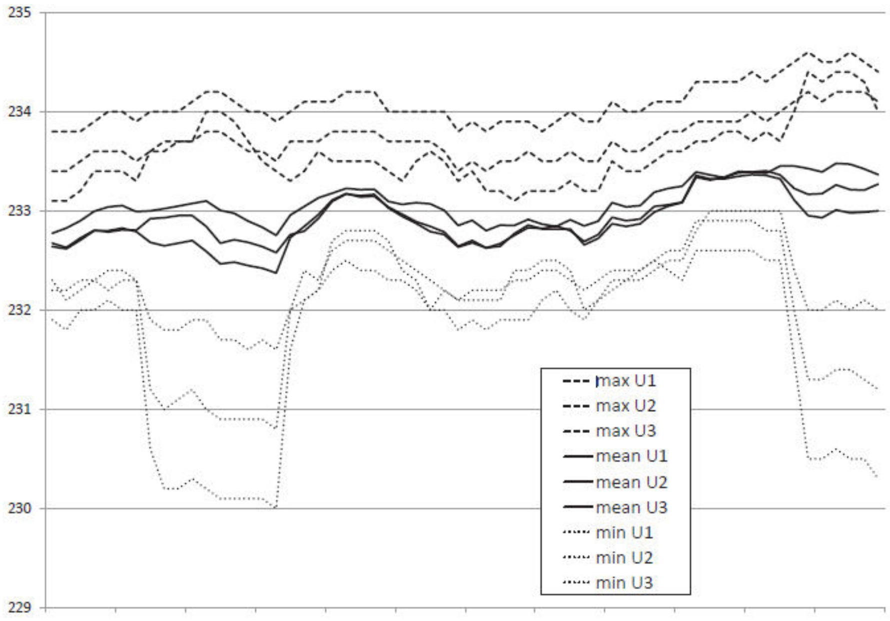

Figure 3. Minimum, average, and maximum voltages per phase for the illustrative time period.

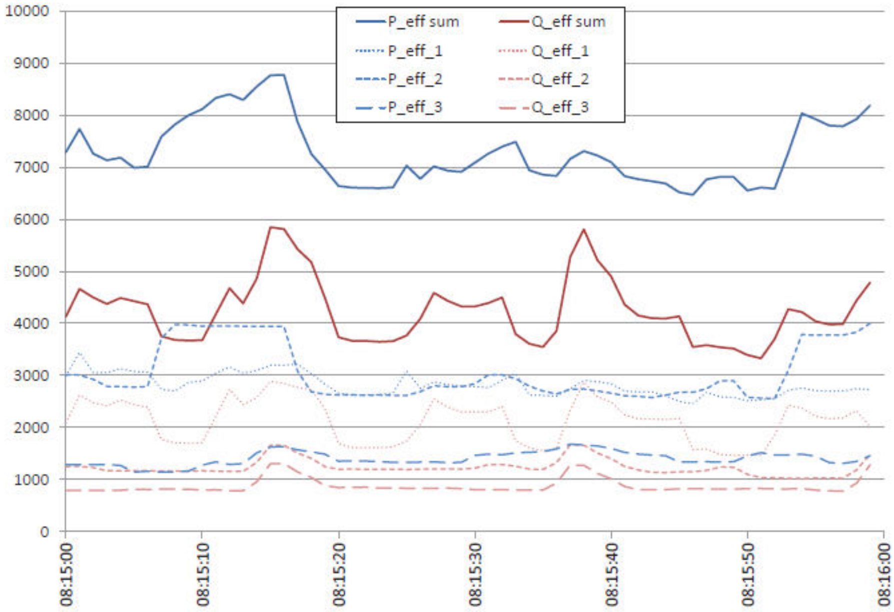

Figure 4. l. Power output (P_{eff}) and power input (Q_{eff}) for the phase and total for the illustrative time period

Figure 6(a) reveals the nodes in the beginning of the feeder (e.g., 3013604) to have the highest voltages; however, the second period in Figure 6(b) demonstrates similarly high occurrences of maximum voltages in nodes in the middle of the feeder (e.g., 3013614). This is because some phases may increase while others decrease as a result of phase disequilibrium and neutral point shifting. If dispersed generation (such as photovoltaic) causes a rise in voltage on a single phase, the voltage on the outer phases will fall (this is not the case in this example.).

7. CONCLUSION

Smart metres are capable of providing information on the circumstances of the grid that are necessary, such as the voltages that are needed for voltage controllers in low voltage networks. A PLC-based smart metre network would take too long to reach all of the potentially vulnerable points where voltages may be violated. A static evaluation may be inaccurate since the load and generation situation and its influence on the voltage range per phase or maximum voltage range in the grid are always altering.

Figure 5(a) shows the number of minimum voltage occurrences per meter over the interval of 60 seconds (= 60 PSS). Compared to the interval of 900 seconds (= 900 PSS) in Figure 5(b) the difference is clearly visible. Not only the meters with the highest number of minimum voltage occurrences are different – one would expect the meters at the far end of the feeders to have always the lowest voltages (e.g. 3013638 or 3013639) – also a share of minimum voltages occur midway in the feeder (e.g. 3013614) or at another branch of the feeder (e.g. 3013347)

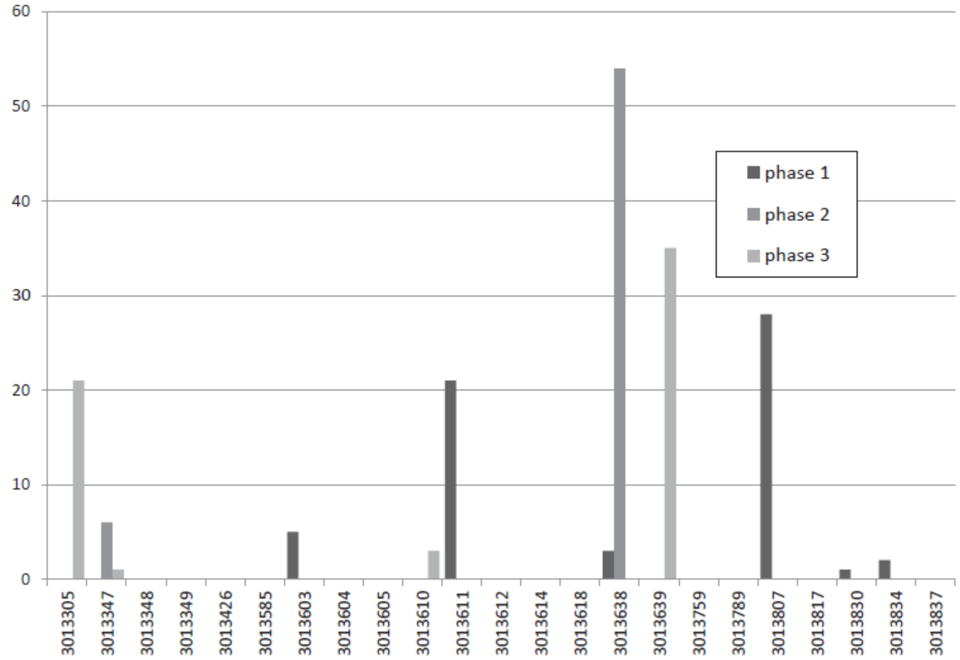

Figure 5. Number of minimum voltages per meter (a). 60 power snap shots interval

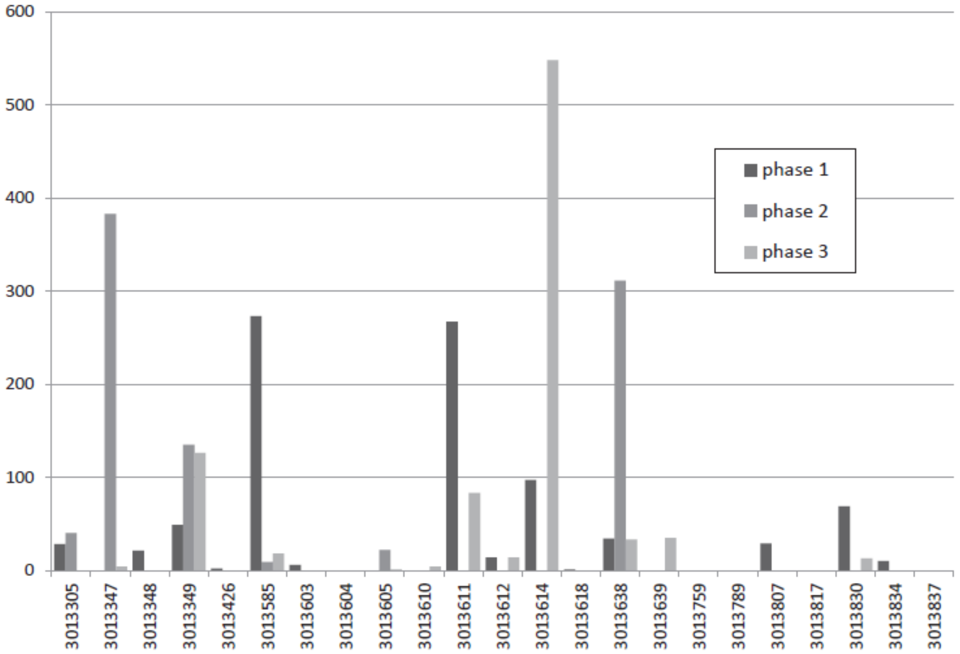

Figure 5 (b). 900 power snap shots interval

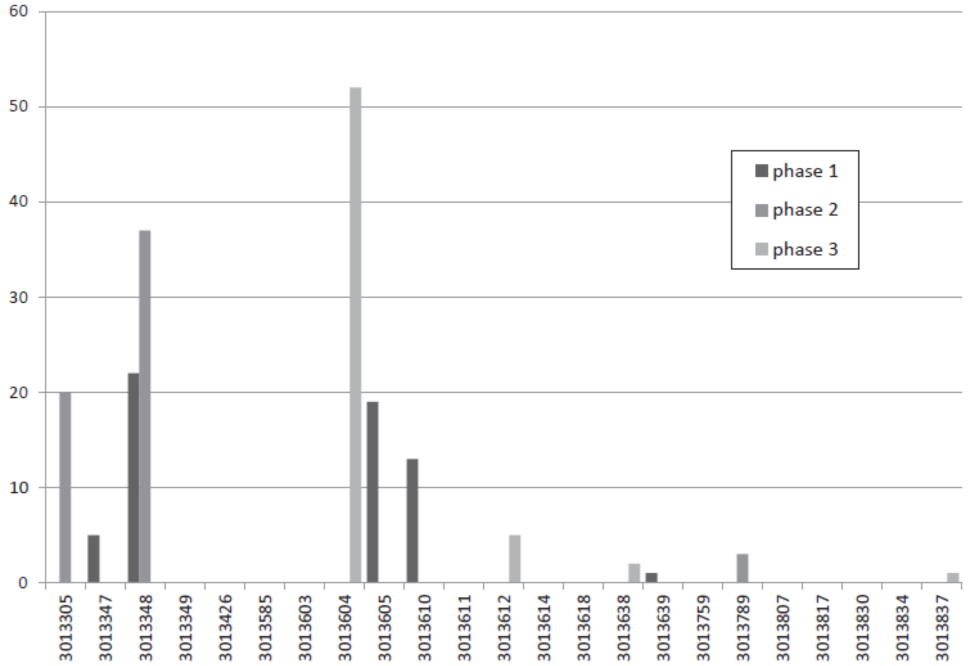

Figure 6. Number of maximum voltages per meter (a). 60 power snap shots interval

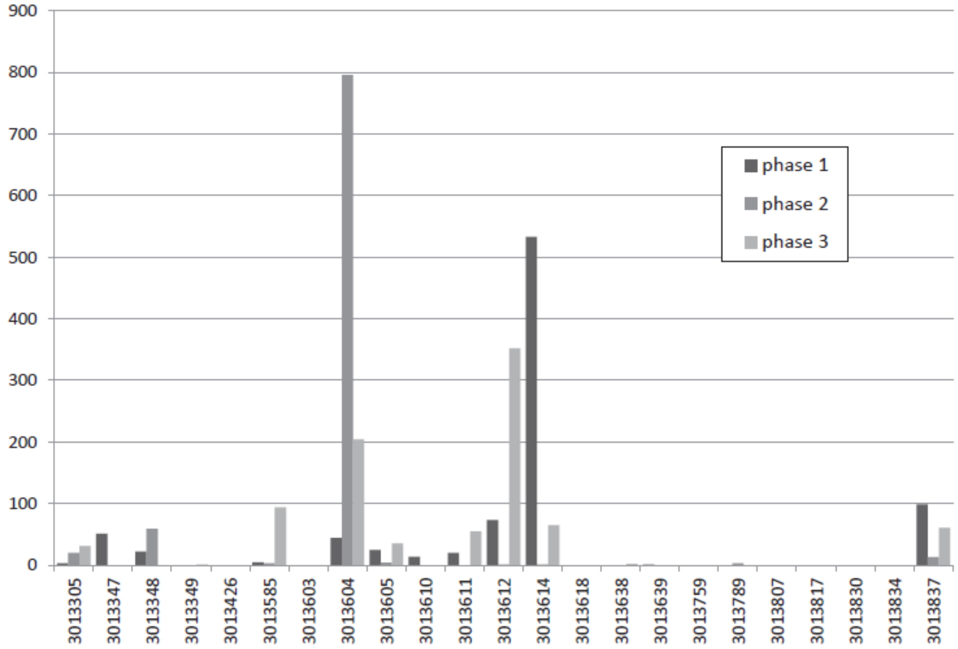

Figure 6(b). 900 power snap shots interval

The voltage level on the grid can be monitored and determined with the use of power snapshot analysis. This doesn't have to be done immediately, but it can be done quickly enough to cover or detect emerging voltage issues. Analysing data in this way can help with smart control in low voltage networks by, for example, altering the set point of local controls to balance phases (in the case of three-phase inverters) while they are operating or being planned for (in the case of single-phase inverters). The decision of whether or not to switch phases on complete feeder branches can also be based on the findings of the balancing condition. It has been shown that identifying vital nodes requires an investigation of dynamic change of crucial nodes and imbalance with regard to day or seasonal situation. An analysis of the consequences of using dynamically critical nodes in smart low voltage control applications is under consideration for the near future.

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