An Analysis to Improve Voltage Stability in Smart Grids by Regulating Active Power in Intelligent Buildings

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Abstract—**This paper describes an approach to minimize the uneven effect of voltage and power in smart buildings and on electrical networks. The idea is to analyze and improve the voltage variation in intelligent buildings and in electrical networks. In a second step, the actual power consumption and power reserves of selected Smart Homes is calculated and regulated by a control application using Next Generation Network technology. In the last step, stationary storages for improving the stability of the smart systems are discussed and evaluated. The analysis is performed by considering multiple scenarios in smart power grids. We consider intelligent buildings (Smart Homes) based on Next Generation Network components. These components are applied as a communication and integration platform between the smart phones of the Smart Home owners and the building control system, as well as the energy supplier of the smart power grid. The Session Initiation Protocol and the Presence Service are used to build a performant and scalable system based on open source software. The Smart Home appliances are based on the KNX bus, a secure and trustful architecture by which the user can remotely monitor and control his house or facility from anywhere in the world.**

Keywords-Energy Management; Home Automation; Smart Power Grid; Next Generation Network; Presence Service.

I. INTRODUCTION

The work at hand is an extended version of our paper “Stability Improvement Solution of the Smart Power Grid by an Analysis of Voltage Variation in Intelligent Buildings” [1].

Intelligent power grids form the core of the future power supply. As a part of smart cities, smart buildings, home area networks (HAN) are composed of devices that communicate with each other, can communicate data to utilities (or other energy service providers) and can respond to signals sent by these remote entities. An overarching vision of the Smart Grid holds that providing consumers with information about their energy usage will support an array of electricity pricing models and enable customers to better control their use of electricity. Smart thermostats, smart meters, real-time dynamic pricing and next-day energy information feedback to electricity users play an important role in this intelligent energy management infrastructure. Every part of our energy environment will be connected to each other and may be controlled from central points with the given rights, to exchange both energy and information. The actual intelligence is supplied by the IT-supported structure and control tactics, especially to match fluctuating Smart Grids, which are supposed to guarantee stable power supplies within the European Norms. For the stability of a Smart Grid system, there are two main criteria: First, the power generation has to match the demand at any time and has to hold a reserve (e.g., battery storage) for immediate outages. Second, the grid has to provide sufficient capacities for voltage stabilization at every point in time. According to our particular status, all countries need to simplify the smart cities and adjust their parameters in order to fit their own features.

A. *Purpose and Relevance*

The purpose and contribution of this paper is to investigate various issues regarding voltage and power instabilities of Next Generation Network (NGN) based smart building systems from uncertain energy sources, and to suggest solutions based on exemplary calculations.

Our previous work presented a novel approach for a performant, scalable, secure and trustworthy interaction between intelligent homes, control managers and energy suppliers of the smart grid [1]. Our work also described energy management mechanisms by load balancing tactics that include manual and automated control of equipment in smart homes, using NGN technologies based on the Session Initiation Protocol (SIP) and its Presence Service. Based on these ideas, a near-real-time push solution has been implemented, using the IP Multimedia Subsystem (IMS) to remotely monitor and control Home Automation systems via mobile devices with open source software [2][3].

According to the latest report by GTM Research, the U.S. home energy management market is forecasted to be worth more than USD 4 billion by 2017 [4]. This forecast shows the business opportunities and relevance of our proposed ideas for home control and energy management services. According to this source, the sectors with the largest potential for saving energy are buildings and mobility.

B. *Structure of the paper*

Following this introduction, Section II shows related work for the suitability of our previous idea to implement a control solution based on NGN technology. In Section III, the instability problem and two important use cases are presented. The overall system design is described in Section IV. The calculation for the first solution is discussed and evaluated in Sections V and VI. Section VII gives power and energy consumption statistics for the second solution. The components used to analyze the solution are presented in Section VIII. Section IX gives an outlook on future work and concludes the paper.

II. RELATED WORK

Many companies and institutions are working on solutions for energy efficient management of buildings. But only a few of them are working on a complete solution that relies exclusively on open standards. Most of the systems focus on the inside- or outside-systems of the building. Many control and automation system devices are usually installed at the low-voltage part of the grid. They have more capabilities in controlling electrical energy consumption of consumers [5][6][7][8]. In our previous work, we presented the idea to connect the technology of NGN to Smart Homes The next step is to use SIP with all its benefits as the main communication protocol and connect it to a KNX bus system. The general architecture is depicted in Figure 1.

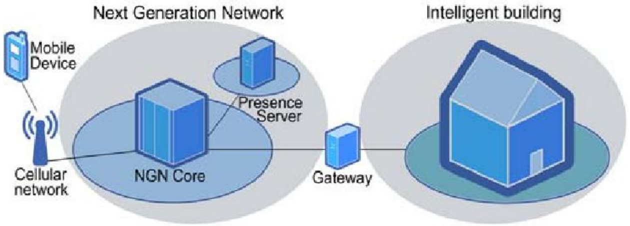

Figure 1. General architecture.

The NGN infrastructure that has been prototypically set up at our project consists of an IP Multimedia Subsystem (IMS) in its center. The IMS is a control architecture based on SIP, designed by the wireless standards body 3rd Generation Partnership Project (3GPP). It aims to standardize access to different networks. The core functionality of the IMS is to operate and manage multimedia sessions of various types in NGN infrastructures, ranging from simple telephone calls to multi-participant video conferencing and many more applications. Therefore, all communication is based on the Internet Protocol (IP).

An important functionality of the IMS is the Presence Service. This service was originally specified to manage and track the online status of all connected multimedia units. The basic idea in our project was to use the Presence Service to store the status of sensors and actors of Smart Homes instead. Advantageous about this idea is that the effort for setup and implementation of our demonstrator system is reduced, since most of the major functionality maps quite simply from IMS to home automation. Also, means to enable secure communication are already included or may be added at a relatively limited expense.

This idea enables to represent different home automation appliances as users to the outside world. Each appliance can set its own current status, or the status can be monitored by the central instance. Thus, it is possible to register a mobile device at the SIP network, and in this way at the Presence Service. The status information of the different home automation appliances can also be viewed on mobile devices, such as smart phones.

The IMS is connected via a gateway to a KNX bus system. The gateway translates control messages from SIP to KNX, and vice versa. The KNX bus installation is connected to different types of actors and sensors. Actors are appliances that perform different actions, for example switching lights on or off. They provide their activity status and are able to receive telegrams from physical switches. Sensors are appliances that can detect different conditions, e.g., temperature or brightness. They are capable of sending KNX messages (so-called KNX telegrams) to specific actors or software tools.

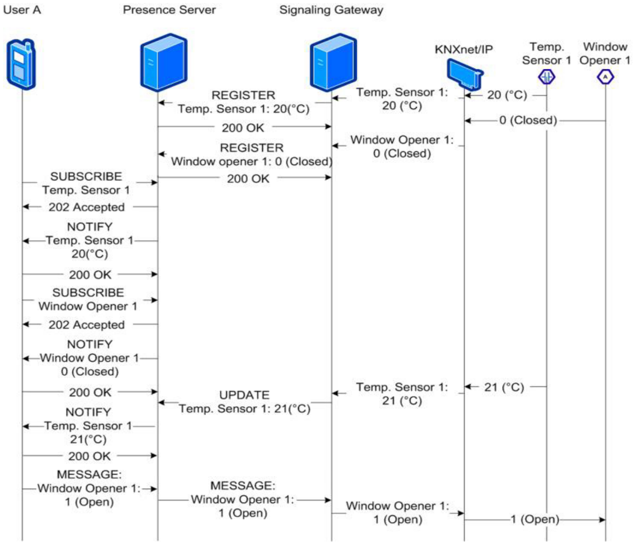

Figure 2. Signal flow in system.

The signaling gateway is the main part of this concept and has been prototypically implemented. The signaling gateway is used to control the whole infrastructure that is connected to it. It also provides various interfaces to the outside world, for example, for the connection of mobile devices, on which the smart grid management component runs that is part of the ideas described in the paper at hand.

This software service connects the KNX bus to the IMS network, as mentioned. Figure 2 shows a typical signal flow in the system. The sensors and actors on the right are connected through a KNXnet/IP device to the signaling gateway. The signaling gateway is connected to the presence server. User A (which may be any kind of IP enabled device) is connected to the Presence Server. The SIP protocol is used to communicate between the participants as shown. At first, the participants are set up using the REGISTER command. To transfer status messages and to store and manage the status data at the Presence Service, SUBSCRIBE, NOTIFY and UPDATE messages are used.

Using a KNXnet/IP connector device, KNX telegrams are transferred to an IP network. The telegrams are packed into the payload of UDP packets and are sent over the network. Thus, one function of the signaling gateway is to receive these IP packets sent by the KNXnet/IP device. Furthermore, the information contained in the telegram has to be extracted. The telegram may consist of sensor values or other status messages of different home automation appliances. The KNXnet/IP device is also able to receive IP packets from the IP network and to send the containing telegram to the KNX bus. Thus, in order to control appliances that are associated with the bus installation, the signaling gateway has to have the ability to generate KNX telegrams (see Figure 3).

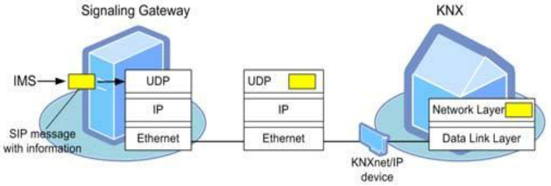

Figure 3. Basic System Architecture.

A. System security

It is necessary to ensure a secure connection to the mobile device, a secure authentication for the user and a generally secured environment that is up to current standards. The original KNX standard, which historically dates back to a predecessor from the 1980s, did not offer sufficiently secure communication environments. Here, our security approach is introduced that secures the end-to-end network communication of the system. For all connections, SIP Security (SIPS) is used, applying Transport Layer Security (TLS) and the Secure Real-Time Transport Protocol (SRTP). SRTP is used for securing Voice and Video-Data connections. TLS is used for exchanging signaling messages (e.g., for authentication and registration). TLS is a hybrid encryption protocol for secure data connections over the Internet. In the OSI reference model, TLS acts at the transport layer. Within SIPS, TLS takes care of the following security tasks:

- Bidirectional authentication of communication endpoints
- Exchanging shared secrets
- Cryptographic encoding of data to be transferred
- Securing the integrity of transferred SIP messages

We measure the security of the selected approach according to the four pillars of information security [9].

- Confidentiality
- Integrity
- Availability
- Authenticity

As described above, SIPS is using the protocols TLS and SRTP for secure communication. TLS uses a high security encoding and therefore grants high confidentiality. The TCP/IP protocol ensures integrity by adding a checksum to each message. Authenticity is granted by using an authentication with credentials**.**

III. USE CASES FOR SMART ENERGY MANAGEMENT

The focus of this paper is to analyze the problem of voltage and power variation in NGN based smart homes, using our project infrastructure described above. In order to meet today's power system requirements, it is necessary to apply regulation in order to keep the voltage in the permitted voltage range for the distribution grids on the low voltage and middle voltage levels. The consumption of electrical power causes the voltage to drop at the junction point of the smart buildings, whereas an injection of power will make it rise. This overshoot-and-dip-effect increases with the power and the distance of the smart buildings to the substation. If the voltage drops or rises too much, the distribution system operator has to take countermeasures. This is because the end users' appliances and electrical devices are designed for a certain voltage range defined by European norms (EN50160:2007, [10]). The amplitude of the supply voltage is defined in this norm (see Table I). It is defined in the norms that the magnitudes of the low voltage and high voltage should be in the given range.

TABLE I. AMPLITUDE OF SUPPLY VOLTAGE

Voltage Magnitude	LV: U =230V MV: "by convention"
Voltage Magnitude Variations	LV, MV: ±10% for 95% week

A. Use case UC1: Insufficient or lack of renewable energy

In our previous work, we discussed the following use cases. In use case UC1, the power consumption in the city and the load on the distribution grid reaches its maximum level. During the same time frame, the feed-in of renewable energy is diminishing to the minimum, e.g., because of wind calm or the lack of sun radiation. Figure 4 illustrates this situation.

After further analysis of this topic, we found that in times of high load, the voltage at the terminals might fall below 0.9 p.u. (red line, equivalent to 207V), which would be a voltage magnitude violation according to the European norm. This dip effect increases with the power and the distance of the smart houses to the substation. The typical instrument to counteract this effect is the application of tap-changer transformers, because the end users appliances and electrical devices are designed for a certain voltage range, as defined by the norm. This lack of electric power shall be balanced with an optimum approach, at least partly by the intelligent buildings of the city.

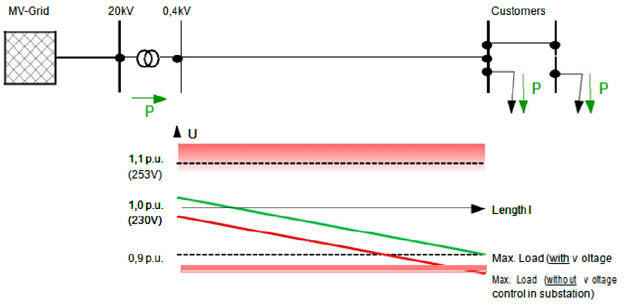

Figure 4. Maximum load scenario.

In order to do that, the lack of energy is signaled by the power providers towards the owners of intelligent buildings in the city by means of usual communication technologies.

The house owners can then react by turning off domestic appliances (e.g., white goods), set air conditioning units or heat pumps to eco-mode and deactivate charging stations for electric cars and vehicles. Therefore, the energy supply within the city could be balanced in a better way by the swarm behavior of the intelligent consumers by de-activating power loads. This is one of the core ideas of our previous and current work.

B. *Use case UC2: Surplus or excess of renewable energy*

In our previous work, we also discussed use case UC2. The power consumption and load in the city reaches its lowest level. During the same time frame, the renewable energy is fed into the power grid at maximum levels because of strong winds or strong sun radiation. Figure 5 illustrates this situation.

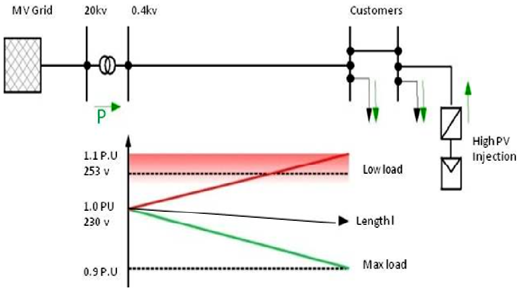

Figure 5. Low load scenario.

This is likely to occur in time periods when the injection of photo voltaic (PV) is high and the load on the net is low, typically during the morning hours. The high PV injection shown here is meant to illustrate the idea of getting more power from the grid to the consumer. An injection of power may make the voltage at the terminals rise up to 1.1 p.u. (red line, equivalent to 253V), which is also a possible voltage level violation to the European norm. This overshoot effect increases with the power and the distance of the smart houses to the substation. If the voltage rise gets too high, the distribution system operator also has to take counter measures, because the end users appliances and electrical devices are designed for a certain voltage range only (as mentioned above). Again, this surplus or excess of electric power shall be used with optimum approach by the intelligent buildings of the city. In order to do that, the surplus of energy is again signaled by the energy suppliers towards the owners of the intelligent buildings in the city. The house owners with our smart phone application can then react by turning on additional power loads such as domestic appliances (e.g., white goods, air conditioning units or heat pumps), as well as electric cars and vehicles. Also in this case, the energy supply within the city could be balanced by the swarm behavior of the intelligent consumers.

IV. CONCEPT AND OVERALL SYSTEM DESIGN

The core concept is to minimize the uneven effect of smart buildings on electrical networks and on the smart power grid by analyzing and controlling the load profile of the intelligent buildings. The use of information technology allows an improvement on the electricity's transport from the power grid, with power system stability to consumer consumption integration. The idea is to balance loads in power grids by using KNX-enabled Smart Homes and a communication infrastructure as described above. The advantages of NGN are used to build a communication platform between mobile devices and an intelligent building with a home automation solution.

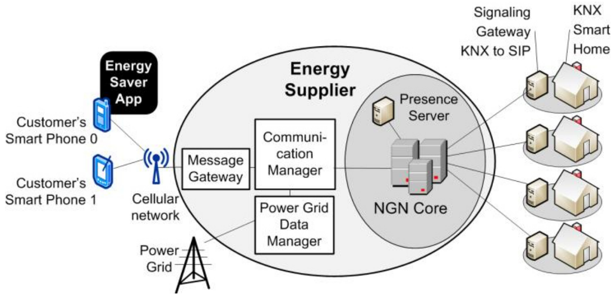

Figure 6. Control system with smart loads L9.....L20.

Figure 6 depicts the smart loads and their control system architecture. For simplicity, the loads are named L 9, 10, 19, 20. To analyze the facts related to smart homes and power networks, we used an integrated engineering tool for the power system calculations. The following features are provided by "Dig SILENT Power Factory" [11]: It has been designed as an advanced integrated and interactive software package dedicated to electrical power system and control analysis in order to achieve the main objectives of planning and operation optimization. Some of these functions are load flow, stability calculation and modal analysis. To design a distribution model of a smart home electrical network and a power grid, the following steps have been applied that include the external grid, transformers, bus-bars etc. (see Figure 7).

At first, an external grid (medium voltage) was connected to the bus-bar (B1). The specific bus-bar was connected to a transformer (step-down), the parameters being 120/20 kV. The low-voltage side was connected to the bus-bar (B2). At the high-voltage end of Transformers T1...T3 line, one end was connected to B3 and the other end to the consumer (load), the line-line voltage being 400V and 230V line-ground.

There is a total of 12 smart houses and 23 "normal" houses, loads being 1.14 kW each, with a power factor of 0.95 to bus-bar B3. The transmission line of B3 is 5 km in length. The resistance value for each kilometer of B3 is 0.2215 Ohm, with a reactance of 0.037 Ohm, which are standard values. When voltage is applied to the transmission line of (B3), due to different loads, the voltage in the simulation sags from 400V to 343V. The voltage of 343V does not comply with the norms: According to these, there may be a ±10% voltage magnitude variation of the reference voltage.

The distribution grid model consists of five transmission lines, three transformers 0.4 kV, four photo voltaic generators (PV cell) and one motor (battery). Every load at the consumer end could be "1 to n" number of customers. Three transmission lines are connected to one bus-bar, which is connected to one transformer (20/0.4 kV). The other two transmission lines are connected to a separate bus-bar, which is connected to another transformer (20/0.4 kV).

Now, there are mainly two tasks: Energy balancing and operational control. Both tasks are closely linked, since the power that is generated at different places and times in the grid must be evacuated and transported. According to the German Energy Industry Act, the power from internal Renewable Energy Sources (RES) generators must be evacuated [12]. For a further coverage of 30% RES, contracts for RES outside the grid have been made. However, forecast and reality do not always match, neither on the generation nor on the load side [13].

V. EVALUATION AND ANALYSIS OF OUTPUT PLOTS

The scenario being displayed in Figure 8 shows the high load connection. It shows a voltage dip after each smart load.

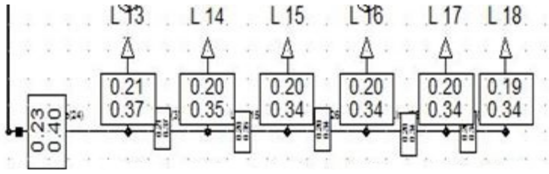

Figure 8. Transmission line with max load smart homes.

In Figure 9, the scenario being displayed is high load. On the X-axis the distance in kilometers is displayed, the Y-axis shows the voltage (unit: p.u.).

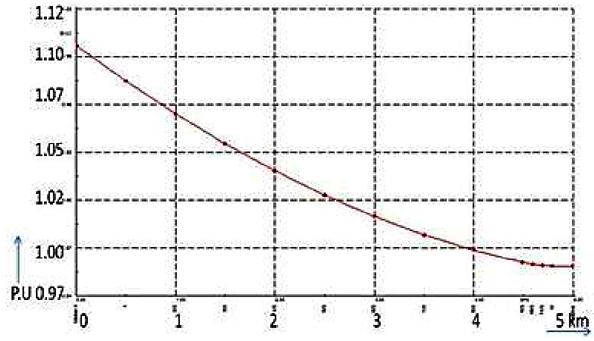

Figure 9. Voltage drop across supply line, high load at terminals.

Let us assume that the voltage has dropped from 1 p.u. to 0.97 p.u., which is equivalent to 207V at the end of the line. The graph shows that when high smart loads are connected to a transmission line, there will be a voltage drop

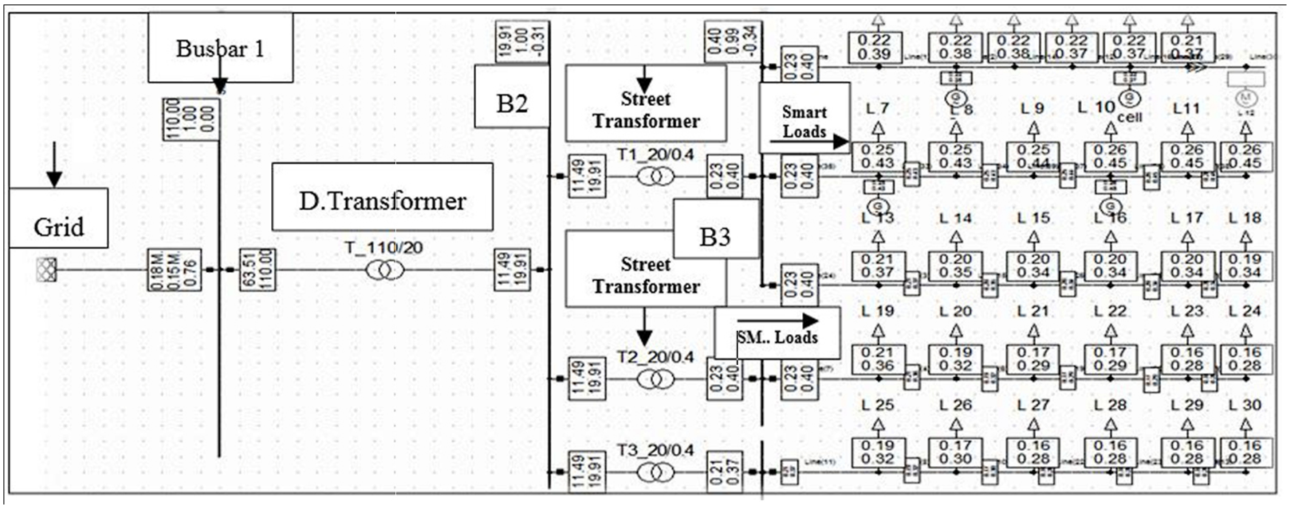

Figure 7. Transmission from grid to consumer end.

at the consumer end, so that the effect is increasing when the distance to substation increases. Line-to-line and line-to-phase voltages are drastically reduced. Here, the voltage variations are also violating the norms, since the voltage should be within the 10% range. Usually, tap-changer transformers are used by distribution system operators as the typical instrument to counteract this effect. The technique is to choose another tap winding so that the voltage in the substation increases, which also affects the terminal voltage. However, they can only be operated in a load-free state, which is a great disadvantage. If the voltage is supplied by the grid, the feed-in of renewable energy is diminishing to the minimum and the consumer is in the high load state, the voltage at the transmission line is decreased. This has to be improved to a standard that complies with the norms. Electrical appliances may be damaged if the voltage levels are not kept within the specified range. The electrical appliances at households cannot bear such decreases in voltage. More current will be drawn by the appliances, causing higher expenses and affecting the efficiency of these appliances.

In the following, a scenario for high PV injection is described (Figure 10). Each load is connected to bus-bar B3 (0.4 kV). Every alternate load is connected via a generator to smart houses.

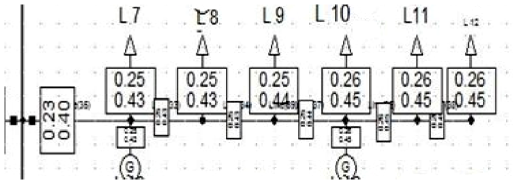

Figure 10. Transmission line with smart homes delivering excess power.

In Figure 11, the scenario being displayed is a high integration of in-feed electrical power by a high PV injection. On the X-axis the distance in kilometers is displayed, the Y-axis shows the voltage (unit: p.u.).

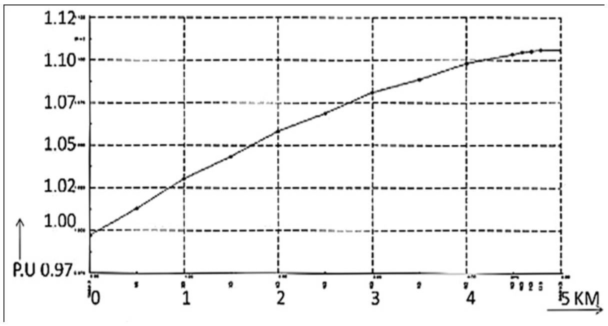

Figure 11. High photo voltaic generation violates voltage criteria.

Figure 11 shows the results of our simulation when the voltage goes up from 1.0 p.u. to 1.10 p.u. (equivalent to 253V) at the end of the line. Due to the power injection by the generators (PV panels) on the specific loads, which are connected to that generator, the effect will be distributed and the voltage is increased after every kilometer. Because of this injection of power, the transmission line voltage went high. The system voltage shows an overshoot from the normal range, therefore violating the norms, when excess power is available. In this scenario, balancing should be applied. Here, the PV generators are replaced with asynchronous generators just to implement the idea. The active power of each generator is 4.5 kW, the reactive power is 0 MVAr, and the consumer is considered as normal households. Now the voltage is supplied by the grid, and the generator injection is applied with the consumer having a lower load. The voltage at the transmission line increases (overshoots), and now it has to be lowered to the standard given by the norms. The electrical appliances at the households cannot bear such an increase of voltage. Damage could be caused to the appliances and also affect the efficiency of these appliances.

VI. CALCULATION AND EVALUATION

The purpose of the calculations given in this section is to find the actual power that is needed to minimize the uneven effect of our smart houses, in order that an optimal control and balancing technique can be applied.

Voltages with U=230V are used as a reference. Concerning the given voltage magnitude variations, the admissible voltage range for the LV consumer is 207V < ULV < 253V. The terminal voltage is subject to the line impedance R, X and the apparent power, as shown in Figure 12.

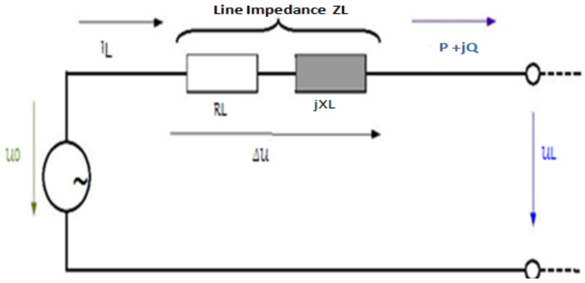

Figure 12. Equivalent circuit of supply line with line impedance.

Figure 12 shows the equivalent circuit of a supply line with the voltage U0 at the substation, and UL at the junction point of the load. The apparent power S = P + jQ is injected and flows towards the junction point. The voltage ΔU drops across the line impedance ZL = RL + jXL and can be defined as [14]:

$$U = U_0 - U_l = I \cdot R_l \cdot jX_l \qquad (1)$$

Figure 13 shows the voltage across a supply line in the low voltage grid. The flow of the active power P is directed from the MV-grid downwards through the MV/LV transformer, over a stub line, towards the customers. In the following, a calculation of different scenarios (high/low load, high/low PV injection) is presented.

Figure 13. Single line distribution.

Apparent power: $S = P + (j \cdot Q)$ (2)

Let Q = 0, then S = P. Number of smart loads = 12.

P/Customer at any specific time = $1.14\ kW \cdot 12 = 13.68\ kW$

Voltage at load: $U_a = U_0 \pm U_K$ (3)

Difference voltage = U_k

The voltage at the customer end is in question: U_a =?

Supply Voltage: U_0 = 230V (Line-Earth),

P [W] = U [V] · I [A]

Current: I = $\frac{P}{V}$ = 13.68 kW / 230 V (4)

I = 59.4 A

The change in voltage is: $U_k = I \cdot Z_k$ (5)

$U_k = I_k \cdot Z_k$

$Z_k = R_k + (j \cdot X_k)$

Resistance = 0.207 Ω / km,
Reactance X_k = 0.0804 Ω/km, Distance = 5 km.

$$Z_k = \sqrt{0.5748} = 0.758155 \cdot 5 = 3.79\,\Omega \quad (6)$$

$$U_k = I_k \cdot Z_k = 59.4 \cdot 3.79 = 225.17\,V \quad (7)$$

Calculations of specific power:

$$U_k = I_k \cdot U = I \cdot Z_k$$

$$U_a = U_0 \pm U_k = 230V - 225.17\,V = 4.83\,V$$

$$P\ specific = 4.83 \cdot 59.4 = 286.9\,W \quad (8)$$

This power is needed to stabilize the transmission line (Figure 14).

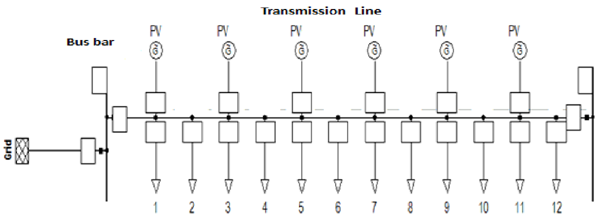

Figure 14. Unloaded transmission line.

Now, the excessive and deficit of power is calculated:

$$U_a = U_0 \pm U_k = 230\ V - 205\ V = 25\ V$$

$$P = 1.485\ kW \quad (9)$$

$$U_a = U_0 \pm U_k = 230\ V - 253\ V = -23\ V$$

$$P = -1.366\ kW \quad (10)$$

The important results for the first solution are:

- Equation (9) indicates the power needed to be fed into the system in order to balance the uneven effect of voltage caused due to a high load at the consumer end.
- Equation (10) indicates the power value needed to be taken out of the system in order to balance the uneven effect of voltage caused due to low load and surplus power at the consumer end.
- Equations (9) and (10) also indicate that if the storage battery system of same power capacity is added to the system, it will balance the load profile in both cases, charging when surplus energy is available and discharging when energy is less than the required limit.

Figure 15 contains loads, PV generators and a battery system, which defines the balanced load profile. Low load and high load scenarios are balanced with regulating the power by integration of battery storage systems.

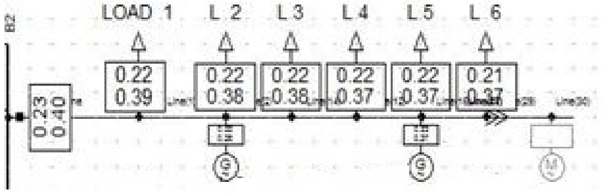

Figure 15. Stabilized voltage scenario.

In Figure 16, the scenario being displayed is balanced power. Again, on the X-axis the distance in kilometers is displayed, the Y-axis shows the voltage (unit: p.u.).

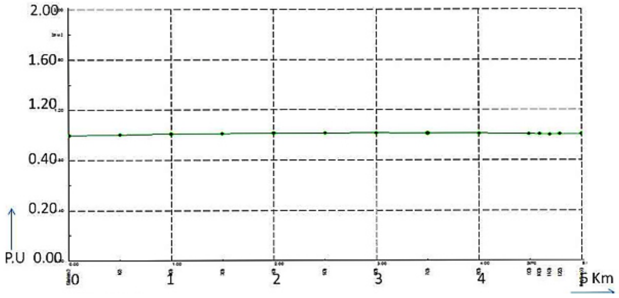

Figure 16. Stabilized voltage scenario.

The above graph indicates the balanced voltage values with high load and high in-feed from PV generators with an integration of battery systems.

VII. POWER AND ENERGY CONSUMPTION, SECOND SOLUTION

In this section, we will discuss some power consumption statistics in detail and find out how our NGN based network can minimize the problem. We will discuss two use cases here. The power usage data will be collected in dynamic power environment, which varies with the utilization.

A. Residential environment

For instance, we look at a two person living room apartment. Before we start with the power and energy consumption analysis, we must have a rough idea about the consumption of power and energy among the individuals in the residential environment. The full system power consumption is divided into two components: Static or constant power, which is independent of system activity, and dynamic power, which varies with the utilization [15]. The data that we have collected leads us to come up with a synopsis of power and energy used among the two persons at peak hours (see Figure 17).

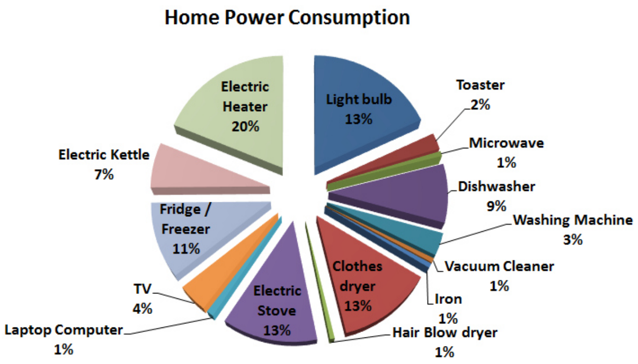

Figure 17. Power and energy consumption in residential environment.

The above power consumption statistical graph is for a high-load residential environment, where an excessive number of appliances is in use by the residents. So, for the simplification of our calculation, we will use the ideal case as given in Table II. In this table, the values are depending on the variable time.

It can be constant and variable according to the different profile of the individuals. It also depends on the type and number of appliances that are being used at certain points in time. Power consumption per day for pure resistive loads (from the above figure and calculation):

- Light bulb, heaters, smart devices = 1550 W
- Energy per day for same loads = 5.4 kWh
- Energy per month for same loads=162 kWh

TABLE II. POWER CONSUMPTION OF DIFFERENT APPLIANCES

Items	Quantity	Power consumption (W)	Operational time (h)	Energy (kWh)
Light bulb	4	40	6	0.96
Electric Stove	1	1500	1	1.5
Electric Heater	1	1500	2	3.0
Fridge /Freezer	1	100	24	2.4
TV	1	80	1	0.08
Washing Machine	1	200	1	0.2
Cloth dryer	1	2000	0.5	1.0
Smart Devices	6	10	24	1.44

It should be kept in mind that these values are taken in a normal two person ideal residential environment. These values vary with different profiles and different household appliances. This example of normal households is given to illustrate the idea of analyzing how load profiling is taking part to regulate the power system networks in different levels [16].

Now we discuss the given example in more detail. We take a specific time interval between (5pm to 10pm) when all of the house appliances are in operating mode, meaning that the house residents are using most of the appliances at this specific time. So, this will be about load calculation in peak hours. At the same time, our Smart Home communication infrastructure is providing the information to the house owner by a graphical user interface panel, installed at the same premises. Alternatively, the information is passed through our smart phone android application to the user. The house owner will have the possibility to minimize or regulate the power consumption profile by switching off the high power rating device or appliance.

An example for a random user: If he turns off a specific appliance, for instance a heater, at peak hours - how much effect will be observed after this specific action? Let us assume that he is reducing the load by 20% at peak hours. Similarly, if ten users are using the same control technique for their smart homes, they are reducing a considerable amount of load, which obviously sends a positive effect to the energy suppliers. The energy supply within the city could be balanced in a better way by the swarm behavior of the intelligent consumers by de-activating power loads.

The active power per customer taken in the above calculation is for simulation and to analyze the effect of power and voltage variation in electricity networks. Now again, we will use the ideal case values as above and analyze the effect of our control action on our power and energy statistics.

In the calculations, power reduction and energy differences in the defined time is given.

$$Power\ reduction\ Total - Spec\ = 5{,}430 - 1{,}550 \\ = 3{,}880\ W$$

$$Energy\ difference\ in\ 0.3h = 1{,}550\ W \cdot 0.3h \\ = 0.46\ kWh$$

$$Energy\ difference\ for\ 5\ appliances =\ 2.3\ kWh$$

$$Energy\ difference\ per\ day\ =\ 10.58 - 2.3\ kWh \\ = 8.28\ kWh$$

In the same manner, the same control technique of our smart KNX architecture affects different environments [17]. Now, we will take another use case for power consumption statistics.

B. *Office in a business environment*

Now follows a power consumption analysis of an office in a business environment, taking into account the broad spectrum of workflows of the office environment and including different appliances in the office. To deal with power consumption, the components used in the business office system should be known that are responsible for the consumption of power. Also, the recourses that are been used in the same scenario should be taken into account. All these power measurements are taken in real time. To overcome the repetition of the measuring part, we came up with estimated data and the calculation of power consumption.

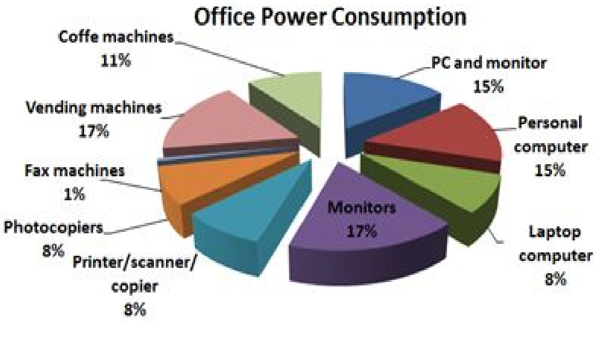

Figure 18. Power and energy consumption in a business environment.

This provides us with the parameters we want to observe. This approach also focuses on benchmarking the computer system in order to achieve an overall overview of the energy consumed by the computer system in the office. So, in the end we have the infrastructure of the power consumption used in the business environment in a real-time scenario [18].

For the simplification of our calculation, we will use the ideal case as given in Table III. In this table, the values depend on the variable of time. It can be constant and variable according to the different profile of individuals.

TABLE III. POWER CONSUMPTION OF DIFFERENT OFFICE APPLIANCES

Items	**Peak rating**	**No of Items**	**Time (h)**	**Power (W)**	**Energy (KWh)**
PC and monitor	300	30	7	63000	63
Laptop computer	100	10	4	4000	4
Monitors	200	5	8	8000	8
Printer/scanner/ copier	50	5	4	1000	1
Fax machines	130	10	0.3	390	0.39
Vending machines	3000	2	8	48000	48
Coffee machines	1000	1	5	5000	5

Power consumption per day for specific loads (from the above figure and calculation):

- Coffee machine = 1 kW
- Energy per day for same load = 5 kWh
- Energy per month for same load = 150 kWh

It should be kept in mind that these values are taken in a normal, "ideal" office environment. These values vary with different profiles and different equipment or appliances. The given example of normal loads again illustrates the idea to analyze how load profiling is taking part to regulate the power system networks in different levels.

Now we discuss the given example in more detail. Again, we look at a specific time interval (between 5pm to 10pm) when all of the office equipment or appliances are in operating mode. This means that the office workers use most of the devices at this specific time, leading to a load calculation for peak hours. At the same time, our KNX-enabled office [19] communication infrastructure is providing the information for the office energy operator by a graphical user interface panel, installed at the same premises, or the information is passed through our smart phone application. The operator will have the possibility to minimize or regulate the power consumption profile by turning off the high power rating device or appliance. Example: A specific appliance, for instance a coffee machine, is used for 3 hours instead of 5 hours, at peak load. How much effect will be observed after this specific action? Let us assume there will be a reduction of the load by 11% (see Figure 13) at peak hours. Similarly, if ten users are using the same control technique for a "smart" office, they are reducing the load by a considerable amount, which obviously sends a positive effect to the energy suppliers of the city. This could be balanced in a better way by the swarm behavior of the intelligent consumers by de-activating power loads. The active power per customer taken in the above calculation is used for simulation and analyzing the effect of power and voltage variation in the electricity networks. Again, we will use the ideal case values as above and analyze the effect of our control action on our power and energy statistic [20].

$$Energy\ difference\ in\ 2h = 1000\ W \cdot 2h = 2\ kWh$$

$$Energy\ difference\ for\ 5\ appliances = 10\ kWh$$

$$Energy\ difference\ per\ day = 129.39 - 10\ kWh = 119.39kWh$$

VIII. COMPONENTS

The following section introduces the components that are needed for the proposed analysis and calculation. The following parts of the Power Factory workspace are visible.

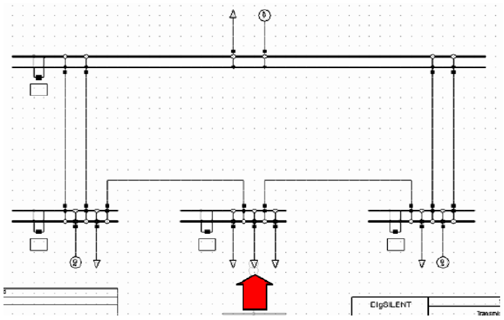

Figure 19. Transmission grid, single line diagram.

The distribution grid (see Figure 19) is fed by an external grid element. The transmission grid has a load element in the middle that represents the distribution grid, as depicted in Figure 20 by the red arrow. In order to connect the two grids, we have to remove the external net object in the distribution grid, and the middle load element in the transmission grid.

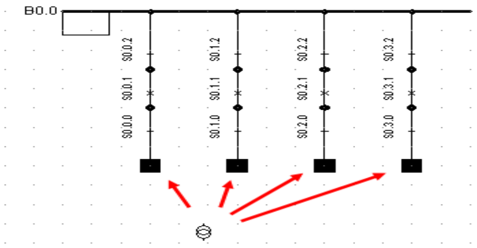

Figure 20. Transformer connected to the single busbar system.

To create a 110/33 kV transformer and to connect the 110 kV double busbar system with the 33 kV busbar, the terminals (busbars) of the substations are to be connected with two winding transformers. To draw the first transformer, the upper terminal at the position is suggested by the background pattern. The transformer is now connected to the terminal at that position. The middle terminal makes the second connection (see Figures 20 and 21).

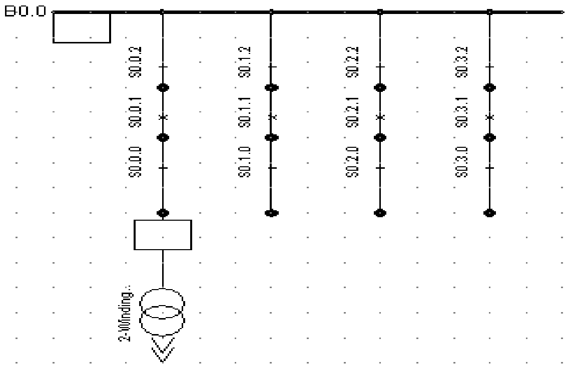

Figure 21. Two winding transformer connection.

A load flow calculation may be started from the main menu of Power Factory. For the intended load flow calculation, the following options need to be set: Calculation Method = AC Load Flow, balanced, positive sequence. All other options on the basic options page need to be disabled. The load flow calculation is not executed to resolve the error. One should first find the element for which the error was reported. With the Power Factory output window, the error can be corrected and the load flow calculated again.

Then, the calculation shows that the load flow solving algorithm has found one area (separated area) in the whole system and chosen the external grid element as a reference element. The single line graphic in Figure 21 shows the results of the load flow in the result boxes.

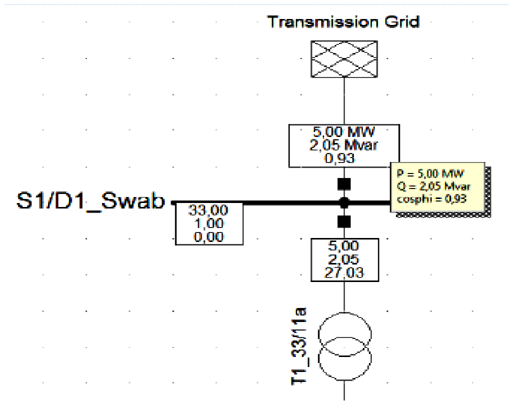

Figure 22. Results of the load flow calculation.

IX. FUTURE WORK AND CONCLUSION

We are concluding this work by stating that our smart home KNX control architecture solution is secure and trustworthy for the solution of current challenges in the field of optimal smart grids. Capable of energy efficient management for intelligent buildings, our simulation provides the important values, which estimate the values of power that can balance the uneven effect of voltage in both cases. An interesting alternative is the integration of battery backup systems. Already a proven technology for uninterrupted power supply (UPS) units, they become increasingly interesting for applications in power systems. They cannot only be used for energy balancing purposes, but can also serve as primary and secondary control reserves.

Actually, this concept is not new: A battery-based system was built in Germany for voltage and frequency stabilization for the supply of the island network used in West Berlin in 1986. The 17 MW plant was to going through an entire charge and discharge cycle twice per day [21]. Keeping in view that if emerging renewable energy sources act as separate generation, they cannot balance the existing energy demand. It is necessary that RES will be integrated in the existing power grid.

Our results evaluate the following important conclusions: In case of high loads and a lack of power, and in case of excessive power and low loads, we have to manage a certain amount of power that can balance the effect. This could be done by reducing or raising the load with our load management and control solution.

In the power statistics (Section VII), the collected data will help us to create a power model, as the power model would be the most efficient and effective way to replicate the workload on the different users in the business environment dealing with real time data. Advancements are required in the existing power management systems.

The software being used for simulation purposes in this work is a limited version, in which only small networks can be analyzed. For future work, voltage variations are to be looked upon with specific actual loads as presented in Section VII at larger scales. This will be done with an extended version of the software, allowing to simulate a whole city as a grid model [22]. The number of transmission lines will be increased as well as the number of parameters for the distribution grid. Thus, we will have the knowledge to give an intelligent idea within this remarkable field of study.

ACKNOWLEDGMENT

This work has been performed within the project "Smart Home Control" at Hochschule Darmstadt (University of Applied Sciences). The authors would like to acknowledge the support of the Energy Lab at the University for giving access to the Dig Silent software and Albrecht JUNG GmbH & Co. KG for their contribution of KNX actors, sensors and other KNX home automation devices and kind support.

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