SYNTHETIC THREE-PHASE LOAD PROFILES

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ABSTRACT

Since common domestic load profiles do not consider unbalanced loading, mismatches may occur when comparing simulation results and measured values from real operation of low voltage distribution grids.
In this paper, the modification of a method for the generation of individual stochastic load profiles is proposed, to gain synthetic three-phase load profiles which take account of unbalance. By regarding the individual consumption behaviour of domestic homes, these profiles may be applied for the examination of small low voltage distribution grids or single strings.

INTRODUCTION

Common examinations of three-phase power systems concerning voltage drop and rise, overload of equipment and line or transformer losses assume balanced load or balanced generation.
In low voltage distribution grids, however, primarily single-phase devices are connected. Although electricians are urged to arrange the individual circuits equally to the phases when erecting indoor installations, the stochastic operation of ordinary domestic devices – especially of devices with high power consumption like washing machines, tumble dryers, dishwashers or electric kitchen equipment – leads to an unbalanced three-phase power system. Even superposition of load profiles of all customers within a grid area is not sufficient for balancing. Hence, unbalanced loading can be observed principally in these grids.
As a consequence, measured values of low voltage distribution grids show a mismatch between simulation with balanced load and real grid operation. Particularly higher losses than calculated can be observed.
To allow a more realistic simulation of these grids, individual three-phase power profiles for each domestic customer are needed. This paper presents a method for the generation of load profiles which comply with these requirements.

SYNTHETIC LOAD PROFILES FOR DOMESTIC CUSTOMERS

For the examination of unbalanced three-phase power systems, synthetic electrical power profiles for all three phases are needed. Common domestic load profiles as in [1] - [3] characterize the average active power consumption based on a high amount of customers within one year. Individual load peaks of devices with high power are not considered. Hence, the impacts of the individual behaviour of each domestic home in a grid area are completely neglected. This becomes especially obvious when examining a small low voltage distribution grid or just a single string. So their application for this purpose is limited. Furthermore, unbalanced load and the need of reactive power [4] are not taken into account as these profiles represent the total active power consumption.
A method for the generation of stochastic synthetic load profiles for the consumption of electrical energy in domestic homes is described in [5]. Each house connection within a grid area receives its individual load profile generated by the use of stochastic methods. The superposition of a multiplicity of these profiles corresponds to the known average power consumption profiles in [1]. Moreover, this method takes account of reactive power by applying individual power factors for different devices.
The stochastic synthetic load profiles created with this method describe the individual total power consumption of each customer in a grid area for all three phases together. To receive individual load profiles for each phase, this method was modified. The considered load classes, devices, their operation schedules and the consideration of their single-phase design are described in the following sections.

STOCHASTIC THREE-PHASE LOAD PROFILES

The stochastic load profile model in considers three load classes which include typical devices found in domestic homes. **Table 1** shows the assignment of these devices to the classes base load, medium power and high power which are defined in the following sections [5].

Table 1. Classification of consumer devices

Class	Devices
Base load	refrigerator, freezer, circulation pump in heating installations, stand-by consumers, low power devices
Medium power	electric lightning, consumer electronics
High power	electric cooker and oven, dishwasher, washing machines, tumble dryer

As the profiles represent 15-minute average values, high rated power devices which are normally operated only for short duration like hair dryers or electric kettles are not taken into account. The profiles consider active and reactive power by allocating individual power factors to the different devices.

Weekdays and public holidays are considered as well as the time of sunrise and sunset, average temperature and light intensity. The difference in equipment of the domestic homes is also taken into account. Furthermore, it is distinguished between working and non-working households as well as between apartments and houses.

Typically, the profiles are generated for the duration of one year for a desired number of domestic homes. To take account of differences in climate, it is also possible to regard longer periods. In doing so, the particular progress of the chosen years in terms of weekdays, public holidays, temperatures and lightness conditions is considered.

The generation of a set of profiles starts with the stochastic determination of the individual equipment for each household. In this process, it is defined which of the devices in **Table 1** are present and which power consumption they possess. In a second step, the stationary devices are stochastically allocated to the phases for each house connection individually. Considering realistic conditions, some dependencies have to be regarded. These are explained in the descriptions of the load classes.

Base Load

A main characteristic of base load consumption is its independency from factors as time of day and especially the presence of inhabitants. Though its level remains well below any peak load, the base load has a major impact on the annual energy consumption of a domestic home. The base load consumption consists of power demand from standby-consumers, low power devices, circulation pumps of heating systems as well as freezing- and refrigerating units.

If further differentiated, the standby-consumption arises from devices as telephones, clock radios, home entertainment systems etc. Its proportion is generated stochastically for each domestic home. It varies between 30 W and 130 W in a working household and 40 W and 160 W in a family household, respectively. A power factor of $\cos \varphi = 0.9$ is presumed for these consumers.

The effect of circulation pumps of heating systems is calculated for an average daytime temperature of 12 °C, with the underlying presumption of an operating time from 6 am to 23 pm due to overnight shutdown. This operation time is shifted randomly for four quarters of an hour for each domestic home to avoid unrealistic load steps caused by simultaneous turning-on and -off. For the circulation pumps a power input of 100 W at a power factor of $\cos \varphi = 0.85$ is assumed. The circulation pump is allocated stochastically to one phase.

Although the power consumption of cooling and refrigerating units is irregular and non-permanent, it is reckoned as base load. For such devices time interval operation and a power factor of $\cos \varphi = 0.85$ is estimated, the exact power input of each device is again generated stochastically. For refrigerators two quarters of an hour with constant power input alternate with three quarters of an hour standby operation. The power input lies between 90 W and 140 W. The interval cycles of freezers are timed as two quarters of an hour with constant power input and four quarters of an hour standby. For both devices a phase is assigned stochastically.

Because of the fixed operation intervals of freezing- and refrigeration units, exact consumer behaviour cannot be inferred from the data.

Medium Power

Consumer electronics and electric lighting compose the medium power demand of a domestic home. Despite the lower power consumption compared to high power devices, those in the medium power range also have a high impact on the total power demand of a domestic home, which is due to long and frequent operating times.

While consumer electronics stands chiefly for television it also includes the use of computers. For the use of these devices the load curve is generated by turn-on probabilities at definite time instances. A probability for the on-time at each time of a day is given for the duration of their usage. For example, the operating time after turning-on the device at 8 pm is most probably about 15 minutes (newscast), while at 8.15 pm a motion picture is the most likely event.

The most important parameters for operating times of electric lightning are the times of sunup and sunset as well as atmospheric conditions. These factors define a time frame with the necessity of electric lightning. The power spectrum ranges from 500 W for apartments to 800 W for detached houses. For each quarter of an hour interval a new electric lightning event is started with a certain probability – if lightning is required by time of day or weather conditions. The duration of an event is proportional to the probability of the chosen event. Thus, long lightning intervals take place in the evenings and shorter ones by night. The respective power requirement is generated anew for each quarter of an hour, the power factor is constantly $\cos \varphi = 0.98$.

As consumer electronics and electric lightning are typically allocated evenly within a domestic home, their load is divided equally to the three phases assuming a standard conforming indoor installation.

High Power

Due to their considerable power input and energy consumption, high power devices have a major impact on the load curve of a domestic home. Besides, these devices operate in limited time intervals, with the particular time of turning-on and -off underlying distinct daily variations. Therefore, these loads show the highest impact on stochastic characteristics of load profiles.

Typical high power loads are washing machines, laundry dryers, electric cooking devices and dishwashers. For the generation of load profiles for washing machines and cooking devices the same approach is chosen, while the operation of dishwashers and laundry dryers are treated as dependent events of washing or cooking, respectively.
The probability for the use of washing machines and cooking devices is assumed according to the type of household and day of the week. If one of these events occurs, the turn-on instant is calculated by frequency distribution. Additionally, a specific procedure is chosen from yet another frequency distribution that results in the load curve of the respective consumer for one day, beginning with the turn-on instant. The probability for the application of a certain load curve depends on the day of the week as well as on the turn-on instant.
The washing machine operates over 90 minutes with a power consumption between 250 W and 2000 W under the washing program. As the operation of a tumble dryer is associated to a washing event, its turn-on instant is timed up to six quarters of an hour after washing. It consumes a real power of constantly 1500 W with cos φ = 0.98 for a period of 1.5 hours.
The washing machine is stochastically allocated to one phase. If a tumble dryer is present, it is connected to another phase with high probability but not definitely due to lower standards of older indoor installations.
Four different cooking-events are differentiated, which probabilities p depend on the day of week. As a high portion of modern three-phase cookers use two phases for the cooking plates and one phase for the oven, its load is also unbalanced and depends on the individual cooking procedure. According to this, the power consumption for the cooking events is split up stochastically to the single phases.
The event of dishwashing is closely connected to the cooking event. Even though it follows not necessarily directly after cooking, this was presumed for the profile generation. The dishwasher - when being present in a household – starts with a random time lag up to six quarters of an hour after cooking and continues over two hours with a load between 100 W and 2000 W and a power factor between cos φ = 0.95 and cos φ = 0.98 according to the washing procedure. The phase which the dishwasher is connected to is ascertained stochastically.

ILLUSTRATION OF LOAD CURVES

The following figures exemplary show the stochastic load curves generated with the presented method. The individual load characteristic of the three phases of on exemplary house connection is given in **Figure 1** for a summer day and in **Figure 2** for a day in winter. A detailed illustration of the winter day where high load peaks are not displayed completely is presented in **Figure 3**.

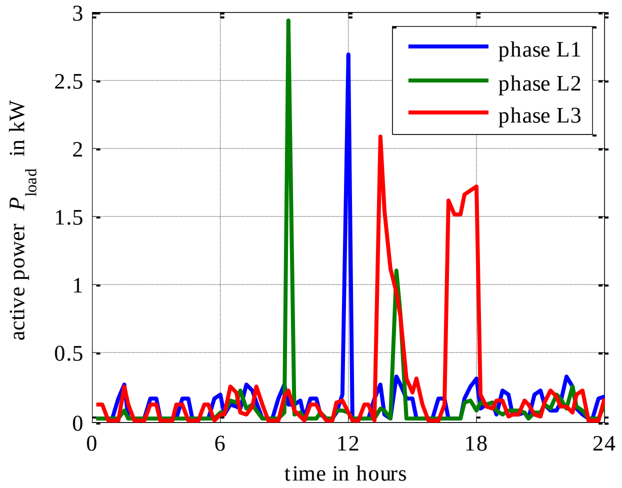

Figure 1. Stochastic three-phase load profile for an exemplary domestic home on a summer day

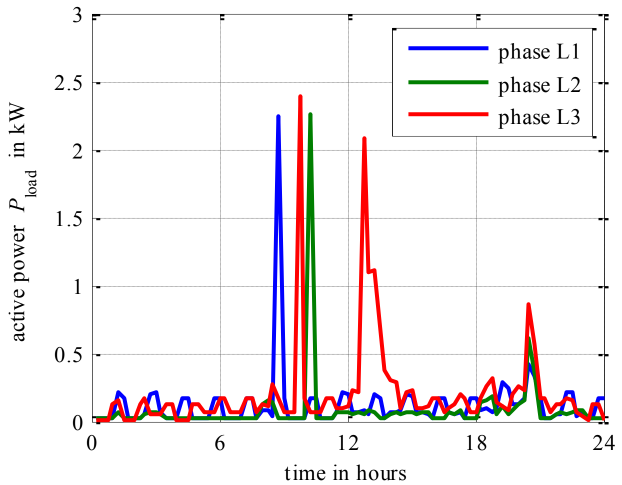

Figure 2. Stochastic three-phase load profile for an exemplary domestic home on a winter day

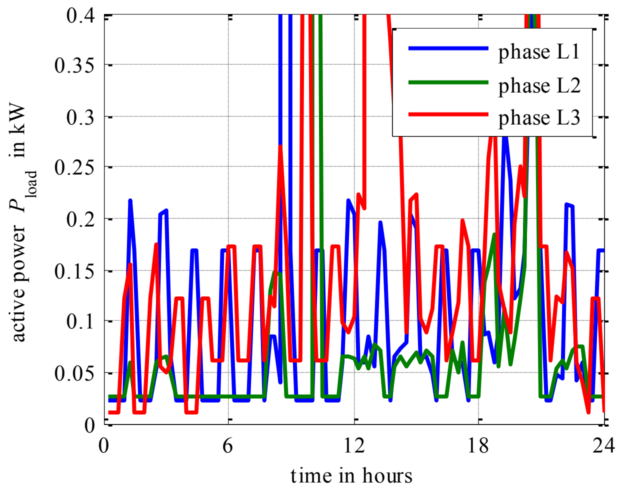

Figure 3. Detail of stochastic three-phase load profile for an exemplary domestic home on a winter day

Besides depicting the diverse loading of the three phases, **Figure 1 and 2** show the difference between summer and winter. As an example for identifying the effect of particular devices, the operation of the circulation pump can be detected in **Figure 3** during the winter day. In the night hours, its load is missing on phase L3.
As mentioned above, domestic homes within a grid area consume electric power individually, which may not be neglected for the simulation of distribution grids. **Figure 4** illustrates the individual loading at the house connection of three exemplary domestic homes using the example of phase L2.

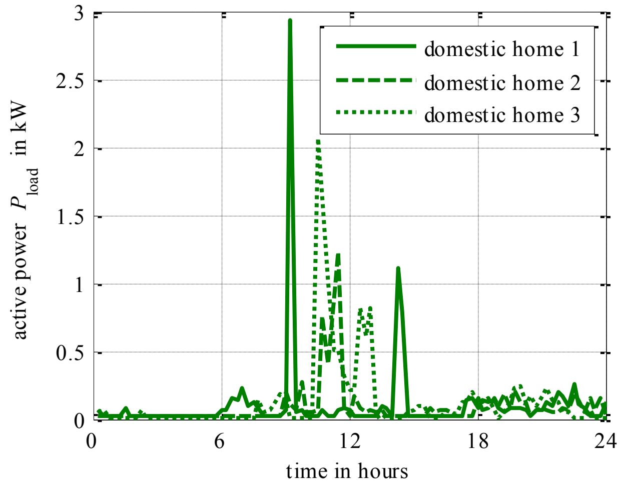

Figure 4. Stochastic load profile of phase L2 for three exemplary domestic homes on a summer day

Not only the load of the respective phases varies between the house connections. Corresponding to the requirements described above, the particular total load of each domestic home has an individual character as to be seen in **Figure 5**.

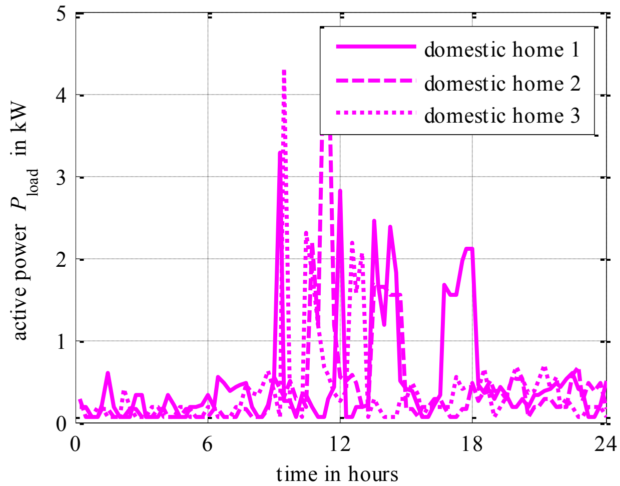

Figure 5. Total load per house connection of three exemplary domestic homes on a summer day

The comparison in **Figure 6** shows that the superposition of a multiplicity of the individual profiles (here 500) generated with the proposed method corresponds to the known average power consumption profiles for domestic homes in [1].

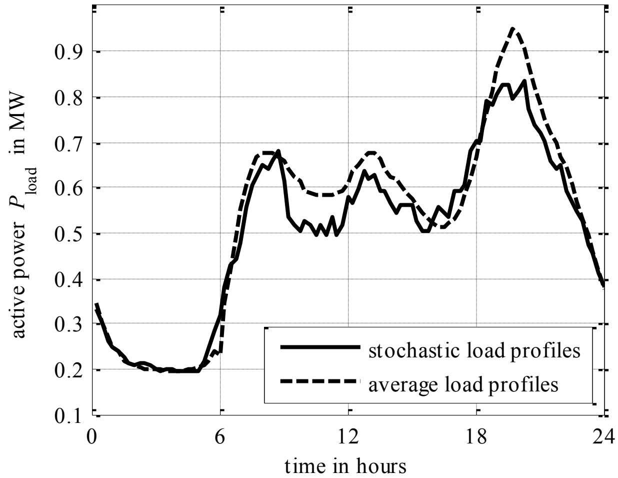

Figure 6. Superposition of 500 individual stochastic load profiles compared to the average power consumption profile for domestic home in [1] on a winter day

CONCLUSION

The stochastic load profiles generated with the presented method offer a possibility for the examination of distribution grids with unbalanced loading. The stochastic load model takes account of load peaks as well as reactive power consumption and different types of households. An individual profile is created for each house connection within the grid so that the different consumption behaviour in the domestic homes is considered. Thus, a more realistic simulation of small low voltage distribution grids or just a string of it is possible.

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