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New approach for power profile determination of remote controlled electrical consumers

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ABSTRACT

Optimal use of electrical energy and efficiency of the consumption are the two most important questions in today's industrial energy management. Suppliers buy energy from power plants and transmit it to the customers. Power consumed is the input for the end users, thus the supplier has no real impact on it. The supplier is subject to the stochastic changes in energy utilization and has limited possibilities to control power consumption; nevertheless, the supplier has an interest in keeping this power level as smooth as possible. One of the suppliers' compensation tools is the integration of remote-controlled heating equipment, such as electrical boilers and heaters that can be switched on by the supplier in low tariff periods. The aim of this project was to develop reliable methods for more efficient utilization of a *centralized ripple control system* (CRCS), through controlled storage and water heaters. This paper summarizes the results of the research on optimization of power consumption by CRCS.

1. Introduction

During the transmission and transformation process of electrical energy, suppliers purchase electrical energy in the optimal time schedule. The energy demand and instantaneous power consumption depend on the number of consumers and their usual (or unusual) usage practices. Due to this, stochastic energy changes greatly affect the work and costs of power suppliers.

Suppliers have limited possibilities to direct the customer's consumption, but one of the most effective tools is the making difference of the kW h price in different time periods. However, not all customers take the cheapest energy into account and use own electrical equipment in cheaper time periods. The power companies are interested in providing high quality electrical energy [1,2] on the one hand, and on the other hand they have to work according to suitable economic conditions [3], e.g. to make the highest possible profits [4,5]. This paper deals with control of storage and water heaters, nevertheless, as is widely known, suppliers can also control community street lighting [6] and civil defense alarms through CRC.

The type, power input and number of communal (user-applied) machines in the electrical network show continuously fluctuating stochastic changes appearing as stochastic characteristics in the energy consumption. The suppliers have to define in advance the expected power consumption every 15 min [7] to the plants. Therefore, the daily energy consumption should be defined by an empirical power load curve. If the resultant of the actual determined user consumption curve differs from the estimated power (according to power scheduling) then the suppliers have to pay higher charges to the power plants. Therefore, suppliers aim to minimize unplanned changes in power and also try to direct a considerable part of the consumption. The only tool the power suppliers have, in order to manipulate and control the power load, is the strict tariff schedule (for industrial consumers) and switching heating equipment under certain conditions using remote control, like *centralized ripple control* (CRC).

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Accordingly, power suppliers are able to manipulate the load profile by CRC very quickly to satisfy the specified power (load) schedule [8,9].

2. Basic considerations for CRC

The problem with CRC is the difficulty of exact computation and determination of the switched power level. Users have special habits in their usage and they have different needs in the daytime or nighttime, morning or evening, on weekdays or weekends, and in the summertime and wintertime. Therefore, certain parts of the controlled customer equipment do not regularly switch to the on state after a turn-on command, or the time periods for remaining switched on are different, depending on the actual customer's needs. In addition, heating equipment has a very wide range of operational parameters and characteristics: some types will not start immediately on command, but have a delay of several seconds or several minutes, and therefore some boilers remain in the off state for a while after a turn-on command. Some parts of equipment may be temporary or continuously disconnected from the network, others were simply heated up in a previous heating term and not used, and therefore they will be kept turned off by their own thermostats [10]. Also, there are huge differences in consumer needs depending on the geographical placement and socio-economic environment of the actual place. Due to these considerations the "*built-in controlled power*" (the constant maximal heating power of an electrical network) is not equal to the switched-on heating power of boilers. The difference between these two power levels depends on the actual place and the current time, day of the week and season.

Besides the problems described above, there is no policy of encouraging consumers to inform the suppliers of equipment changes (e.g. when old equipment is disconnected, new equipment different from the previous power is installed, etc.). Therefore, power suppliers in most cases do not have accurate and up-to-date information on heating load and do not register CRC units and the power of them on the customer side, although this would provide the possibility for more accurate power estimation. These effects accumulate at the transformer station level as well as at regional level.

What are the supplier's possibilities in such a situation? How can more information be acquired about the electrical network? How the power fluctuation caused by CRC can be analyzed? Which methods are necessary to determine the heating power profiles for more efficient demand-side management and for providing continuous hot water supply (to users) by optimized timeprograms? [11] Answers are given in this study.

3. General description of CRCS

The *audio-frequency* (AF) signal is controlled by one-way signal transmitting. In general, the CRCS consists of 6 elements (see Fig. 1). AF messages (a series of pulses, about 60 s long) are generated by the central computer at each transformer station (in different geographical regions) and have to be coupled and filtered before the signal will be modulated to the 3-phase high voltage network. Suppliers use different carrier frequency for CRC switching (e.g. 183.33 Hz; 213.66 Hz; 283.33 Hz; 383.33 Hz) where the amplitude of generated AF signal is between 1% and 2% of mains voltage. AF messages are received by customer equipment, thus boiler heating starts or stops.

One message should consist of minimum three elements: start pulse, address and switching command. The structure of these three parts can differ in number of pulses, pulse length or number of controlled consumption groups. For example in North-Hungary start pulse lasts about 4 s, address includes 10 pulses and CRC units are controlled by 20 command pairs (ON and OFF) to control 10 different heating groups.

We suppose that level of the switched heating power is unknown by the supplier which is the usual case. The effects of AF messages is difficult to prognose on the network, thus, one of the main problems for the supplier is the lack of feedback on the switched power, e.g., how many boilers were used on customer side (heating energy consumption $\approx$ hot-water consumption). Thence, repeated long-term (1-week) measurements of each transformer station in different seasons are required for information collection. However, development of new methods was necessary to study each power change caused by CRC, including recognition of CRC signals and computation of heating power changes. A specialized recognition model is worked out in order to analyze CRC-caused (CRC-triggered) power changes. An on-line universal module recognizing the various AF messages in real time and analyzing the power changes of different suppliers is realized by our research team.

4. Developed simulation applications

Three simulation applications were developed to support the final diagnostic system.

In the first step a reliable and fast method for AF signal recognition in the voltage signal was required. According to the carrier frequency of the AF signal, the optimal size of FFT-window (*Fast Fourier Transform*) can be determined [12]. Our initial studies showed that reliable determination of AF pulses is the key element of the research, as this will provide reliable determination of heating power (for each boiler cluster). As is well known, the frequency of the AF signal must not be a multiple of mains frequency (50 Hz or 60 Hz depending on network) in order to avoid spectral distortion of the main voltage. In addition, the CRC effects can be analyzed only if correct FFT is performed on both the mains and AF signals, therefore both the mains frequency (f_{mains}) and AF carrier (f_{carrier}) have to be the whole multiple of the fundamental frequency (f_0). The fundamental frequency of the spectra (f_0) is the reciprocal of the analyzed time window (T_{analyzed}), which depends on two parameters: the sampling rate (f_{sampling}) and the number of samples (n) as follows:

$$f_0 = \frac{1}{T_{\text{analyzed}}} = \frac{f_{\text{sampling}}}{n} \tag{1}$$