Assessment of an Impact of Power Supply Participants on Power Quality

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Abstract— **Currently, due to the global shortage of energy carriers the goal of more efficient use of the existing power sources and transmission lines is getting increasingly more important. At the same time, however, there is a known contradiction. In order to enhance the efficiency, we use advanced industrial electronics, rectifiers, frequency transducers, inverters, etc. This increases the efficiency of the technological plants, but at the same time the supply voltage suffers from an elevated level of harmonic components in the network. As is well known, nonlinear load generates harmonic components, resulting in a change of delivered power characteristics, namely indicators degrades the supplied power quality. In turn, the deterioration of the power quality leads to its overrun. In this regard, the problem of monitoring and reducing the harmonic components is relevant. Timely and accurate measurements based on data recorders vector quantities with high resolution, offers the prospect of continuous monitoring of the quality of power supply. The paper presents a system of continuous power quality monitoring. The system makes it possible to detect a source and a level of nonlinear distortions (harmonics), estimate the harmonic energy cost and control power quality parameters.**

Index Terms**-- Power quality, voltage and current harmonics, distributed monitoring of power quality, electric power systems, smart grids.**

I. INTRODUCTION

Nowadays great attention is paid to the problem of power quality. This is explained by objective reasons. Firstly, there is a trend toward an increase in highly technological equipment and sophistication of production processes, which imposes high requirements for the quality of power to be supplied. Moreover, electric energy as a subject of market relations has a commercial value. On the other hand, most of the modern loads are nonlinear and their number is increasing. The nonlinear load generates harmonics, which leads to the distortion of voltage and current waveforms, changes in the characteristics of supplied power, and requires an increase in the power of system by the value spent on these distortions [1-4].

Depending on the point of connection and a share of power consumed, such a load affects negatively the operation of electrical equipment.

It is obvious that the decrease in power quality indices leads to a decline in reliability of power supply, inefficient power use, and causes additional technological and economic damage for both consumers and suppliers. With a view to receive information on the power quality indices it is necessary to provide their continuous monitoring by adopting modern measurement systems, and make an analysis of the data obtained. Since the consumer power indices may not correspond to the established standards, which can be both due to consumers and suppliers, there arise the questions of distributing the responsibility between them and differentiating the cost of the electricity consumed [5,6]. Therefore, it is necessary to control harmonic distribution in various cutsets of the supply network [7-9].

Based on the analysis of harmonic distribution we can generate signals to control the operation of frequency setting circuits: regulated capacitors, reactors, passive and active filters.

We propose a system of continuous power quality monitoring which allows detection of a source and determination of a level of nonlinear distortions (harmonics), estimation of harmonic energy cost and control of quality parameters.

II. PROBLEM STATEMENT

We suggest that the available PMU infrastructures used for power system monitoring be used as the sources of primary data at different points of the network. To this end the sensors of instantaneous values of current and voltage, which come via satellite to the control center for monitoring were installed at nodal points of the system (generators, distribution substations, consumer substations). These signals can also be used to control power quality. It is necessary to install a smart meter for separate measurement of harmonic energy and fundamental frequency energy at the control centre. This meter will receive the data on current and voltage at different nodes of the system. Then these data are processed and a

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decision is made on an action through the FACTS devices on the variable (controlled) reactive components C_r and L_r.

Electric power system reminds of a living organism whose survivability can be provided by the devices intended for control of its parameters. These devices on the one hand are autonomous and on the other hand should be interrelated. For successful operation of energy system it is necessary to create a distributed system for power quality monitoring.

In this paper the monitoring of quality is limited to the monitoring of the harmonic level in the supply voltage. To this end it is necessary to measure harmonic energy flows at different cutsets of the system in the conditions which are close to the conditions of real time.

To perform this task there are the following preconditions: the existing PMU [10,11] infrastructure, namely: measurement of instantaneous values of current and voltage at different cutsets and their transfer to the control center. Traditionally, these data are used for recording vector parameters of the energy system. The authors suggest using the same primary data for the determination of the energy flows of the fundamental frequency and harmonics at different cutsets using a smart meter developed by the authors [6]. The second precondition is the existence of FACTS which makes it possible to remotely change the values of reactive components of a circuit.

III. KEY PRINCIPLES OF THE APPROACH

Theoretically, however, it is virtually impossible to develop an algorithm for the control of parameters of several reactive components. Therefore, we suggest the use of a method of successive approximations, i.e. by randomly changing one of the parameters within some small limits, for example a controlled capacitance, observe the system response. For an objective function we use a relationship between power of fundamental frequency P_1 and power of harmonics P_{HH}, which is received from the smart meter.

$$\frac{P_1}{P_{HH}} = f(x_1, x_2, x_3, \ldots x_n) \quad (1)$$

In a general case such an objective function (1) depends on many variables where x_1, $x_2, x_3 \ldots x_n$ are the values of reactive components that affect the frequency properties of a circuit, and x_1, x_2 - are variable values which can be changed remotely from the control center, and the remaining values x_3, x_4 and etc. are quasi constant, i.e. they change at a speed of a change in the operating conditions of the system. We will consider an equivalent circuit of a typical local electricity supply system (Fig.1). For simplicity we will think that there is only one harmonic, for example the third one, which is generated by both the source e_g and the nonlinear consumer e_3, and there are two variable reactive components: capacitance C_r, and inductance L_r.

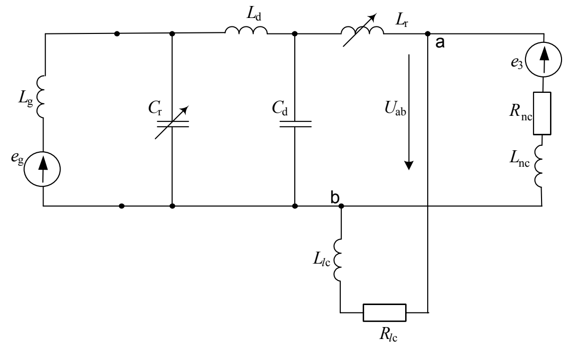

Fig.1. An equivalent circuit of the micro-network

To determine a principal possibility of automatically adjusting the variable values we will consider a special case. It is necessary to ensure the highest power quality at the connection point (ab) of a linear consumer. We will consider the inductance of generator L_g, distributed capacitance C_d, distributed inductance L_d and inductances of consumers L_{nc} and L_{lc} to be constant, and the controlled capacitance C_r, and controlled reactor inductance L_r - to be variable.

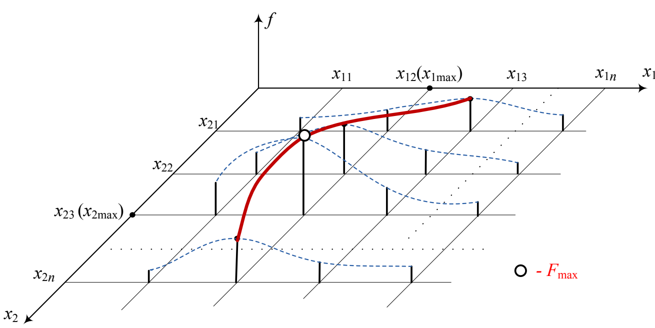

Fig.2. Determination of the maximum objective function

The procedure for determining the maximum objective function at two variable parameters of a circuit (x_1 - variable capacitance, x_2 - variable inductance) is presented in Fig.2. In the presented model we introduce the input numerical parameters of constant values x_3, x_4 etc., and the minimum values of a range of change in variables x_1, x_2. Then, we fix the first values of variable x_2 at the beginning of the established range (x_{21}), and increase variable x_1 with a constant step Δx_1, from the minimum value x_{11} to the maximum value x_{1n} of the range, where n is the total number of cutsets. At each value x_1, the ratio of the fundamental frequency power to the harmonic power at points (*ab*) (Fig.2) is calculated using the electric circuit calculation methods. We find the value $x_{\max 1}$, which corresponds to the maximum objective function (1) at given value x_{21}. The obtained values $x_{\max 1}$, x_{21} and the values of the objective function $f_{\max 1}$ are entered into the memory of logic device.

Then, we increase variable x_2 with an increment Δx_2 and obtain:

$$x_{21} + \Delta x_2 = x_{22}.$$

Repeat again the operation of change in x_1 in the entire range and find $x_{1\max 2}$ at value x_{22}. Similar to the first case, we determine $f_{\max 2}$. This process is continued unless variable x_2 reaches the upper limit of the range of its change $x_2 = x_{2n}$ and, correspondingly, $f_{\max n}$ is determined. The obtained data array is processed by the logic device and the final values $x_{1\max}$, $x_{2\max}$ are determined.

Then by comparing the calculated local maxima of the objective function $f_{\max 1}$ - $f_{\max n}$, we determine the largest of them $F_{\max}$, being the maximum of the objective function (1) (Fig. 2).

The values $f_{\max 1}$ - $f_{\max n}$ are transferred to the logic device which generates the output signal controlling the actuators. These devices in turn change the values of x_1 and x_2.

In order to determine the maximum of the objective function, the authors propose the scheme shown in Fig .3.

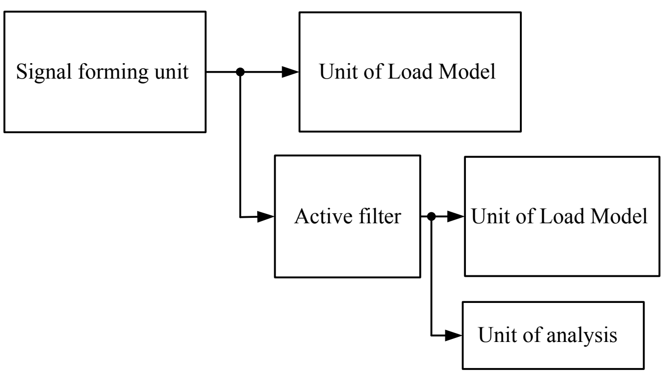

Fig. 3. Flow-chart of the realization of the maximum objective function

This structure may be implemented in any computer system or systems of simulation of power facilities.

Polyharmonic signal forming unit allows to obtain the spectral composition of the input signal within the tested range.

Unit of load model simulates the parameters of the substitution scheme for real loads. The active filter unit allows a wide range to change the inductive and capacitive components according to a given algorithm for studying the behavior of the simulation model of the power system.

The analysis unit is based on the implementation of the mathematical algorithm for Fast Fourier transform, which makes it possible to calculate the active components of the total powers for each harmonic separately. And also calculate the active component of the power of fundamental harmonic. all calculations are based on the objective function (1).

The implementation of this functional scheme by computing means allows you to obtain the recommended parameters of active filters in named units.

This was a preliminary determination of the optimum values of variables, as we did not consider many influencing factors, for example, not all harmonics, harmonic sources, etc. were considered.

IV. Technical Implementation

When this method is technically implemented for determining the true values of variables x_1 and x_2, the above procedure should be performed by really changing the parameters. Relation (1) is fixed by the smart meter intended for separate measurement of harmonic energy and fundamental frequency energy, which makes it possible to determine the maximum values of the objective function $F_{\max}$ and the values of local maxima $f_{\max 1}$ - $f_{\max n}$. Accordingly, the actuators change the values of variables x_1 and x_2.

In order to provide the required power quality (the harmonic magnitude at the substation terminal) in the specified limits, the value of the objective function (1) should be lower than the specified value ε.

$$\frac{P_1}{P_{HH}} \geq \varepsilon \qquad (2)$$

According to the European standard BS EN 50160:2010 the admissible harmonic level in the MV networks does not exceed 0.08 against the fundamental frequency, i.e. the relation should be:

$$\frac{P_1}{P_{HH}} \geq \frac{1}{0,08} = 12,5$$

Figure 4 presents the structural scheme of the supply voltage quality control based on searching for the maximum of the objective function (1). The value of $F_{\max}$ corresponds to the minimum harmonic value in the supply voltage at the connection points. The scheme shows controlled components x_1 and x_2: capacitance C_r and inductance L_r, whose values are varied by using FACTS.

The analogue signals of instantaneous values of current i and voltage u, at the substation terminal from the current and voltage sensors arrive at the PMU which transfers these values through the GPS satellite to the control center at the smart meter suggested by the authors [6]. The smart meter measures total energy and separately energies of fundamental frequency and harmonics multiple of the fundamental frequency. In the meter the energy is converted to power and at its outlet we obtain separately the signals proportional to P_1 and P_{HH}. The signals arrive at the digital divider inlet. From the digital divider outlet, the relation P_1 / P_{HH}, being the objective function (1), comes to the logic device.

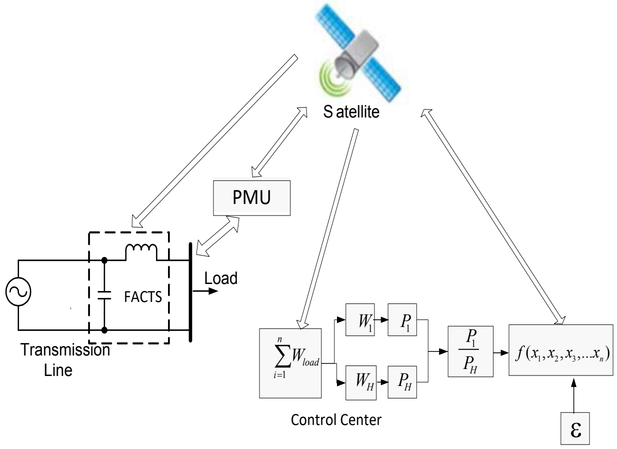

Fig.4. Scheme of supply voltage quality control.

After the procedure of changing the values of variables x_1 and x_2 the logic device determines the maximum value of the objective function $F_{\max}$ and the values of variables x_1 and x_2, corresponding to this maximum. Herewith the logic device generates the control signal of FACTS elements, which in turn change the values of variables x_1 and x_2 up to their optimal value.

The algorithm of searching for the objective function extremum is presented in Fig. 5.

The value of P_1/P_{HH} is compared with the specified value ε against the condition (2). If this condition is satisfied, the power quality corresponds to the specified requirements and further correction is not needed. If the condition is not satisfied, the control signal from the logic device is supplied to FACTS through the GPS satellite to control variable parameters $x_1(L)$ and $x_2(C)$ in accordance with the earlier described procedure of successive approximations. Note that it is more reasonable to perform a rough adjustment with the help of $x_1(L)$, and a more accurate adjustment - by using $x_2(C)$. Value 3ε is taken as a threshold for the rough or accurate adjustment.

In particular, the reactive parameters are controlled by the static synchronous compensators (STATCOM) [12,13]. The STATCOM is capable of controlling the output current in the whole range of capacitive and inductive current irrespective of voltage level of the AC system.

As compared to other devices, for example, to the static VAR compensator, the STATCOM has the following advantages [14]:

- Possibility of both inductive and capacitive behaviors;
- Reduction in the area occupied, since there is no need to use bulky capacitor banks and reactors for static VAR compensators;
- Availability of a large dynamic control band;
- High speed and better performances during transients;
- Insensitivity to harmonic resonances in the system, etc.

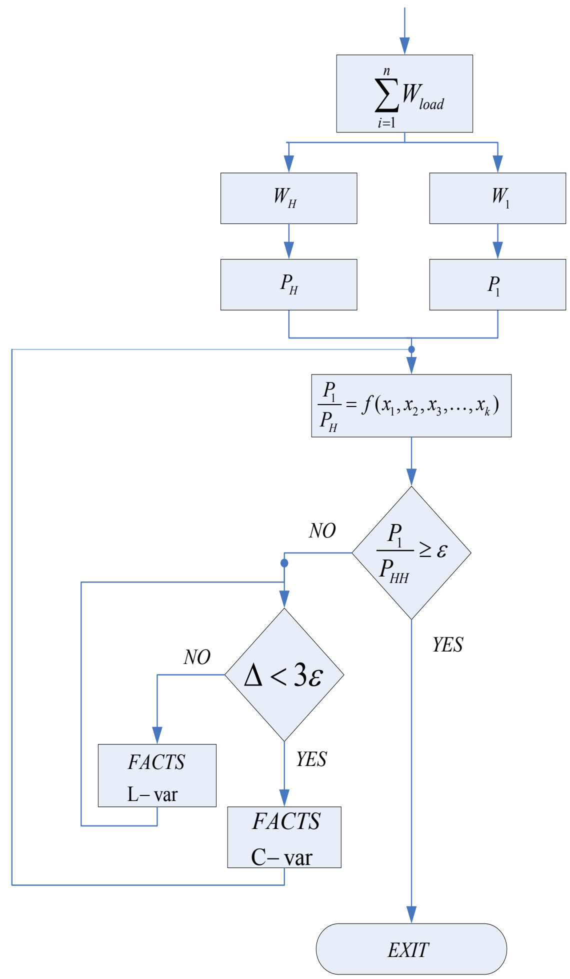

Fig.5. Algorithm of searching for the objective function extremum

Since the monitoring system operates in real time, the mode of possible minimum harmonic at the connection points is continuously maintained. The described technique can be extended to more branched schemes. For this purpose it will be necessary to install a multiplexor before the meter to optimize frequency modes at many connection points.

The described procedure is performed on-line and thus the power supply system is continuously adjusted to the mode close to the optimal one from the view point of the harmonic content in the supply voltage at the selected connection points.

V. CONCLUSIONS

The content of the level of harmonics in the supply voltage has a significant effect on the efficiency of the use of electrical energy. To ensure continuous monitoring of the level of harmonics in different sections of the power system, the authors propose a distributed monitoring system of power quality. The system allows in real time to determine the direction and levels of harmonics in the supply voltage by using a smart meter developed by the authors and separately estimate the cost of energy distortions (harmonics) and fundamental frequency energy. An imitation model for determining the level of harmonics of the power system has been developed. The implementation of this functional scheme by computing means allows you to obtain the recommended parameters of active filters in named units. Transmission of information about the instantaneous values of current and voltage from the system is carried out by the PMU infrastructure. A technique for determining the optimum values of the regulated reactances to reduce the level of harmonics using FACTS devices was developed.

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