Application of Active Power Filters in Distributed Energy Systems

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Abstract – **A possibility of using energy from a renewable source for supplying a system of active power filters is discussed in the present paper. The system improves both the quality of voltage obtained from the public distribution grid for supplying the local sub-network, and the power factor of the local sub-network with respect to the public distribution one. If the public-grid voltage disappears, the system provides an uninterruptible power supply for the local sub-network.**

Keywords – **Active Power Filter, Distributed Energy System, Power Quality, Power Factor, Uninterruptible Power System.**

I. Introduction

Active power filters (APF) combine the present-day achievements of the power electronics and information technologies. Their advantages with respect to the traditional passive filters as well as combining the two types of filters are discussed in [1]. A review of the abilities of various types of active power filters – shunt, series, or hybrid ones – regarding the improvement of various parameters of the quality of electric power is given in [2]. The development of the power electronics provides new opportunities for applying power electronic converters to systems with distributed generation of electric power by using renewable energy sources [3], [4]. Normally, the energy from the renewable source is transformed into electrical energy which can be transferred to the public grid.

A photovoltaic system for distributed generation of electrical energy by using a bidirectional converter is described in [5]. Special attention is paid to increasing the power factor K_P.

A non-traditional possibility of using the energy from a photovoltaic generator, which, having been transformed into DC power, is used for supplying a system of Shunt and Series APF's, is described in the present paper. The system improves both the quality of the public-grid voltage for supplying a local sub-network, and the power factor K_P of the local sub-network with respect to the public distribution one. In addition to that, when the public-grid voltage disappears, the system is able to provide an uninterruptible power supply for the local sub-network. The system structure is presented in Part II. Structural diagrams for the realization of APF control systems are described in Part III. Results from experimental investigations of the filters are given in Part IV.

II. Description of the System

The general structural diagram of connecting the system of active power filters is shown in Fig. 1. In their traditional use as Unified Power Quality Conditioner (UPQC), the intermediate DC voltage U_{DC} is obtained through transformation from the AC grid. In such a way, the active power consumed by the grid is increased at the expense of the power dissipated in the system of the two active power filters. As it can be seen in Fig. 1, in this case a photovoltaic generator is used for obtaining the intermediate DC voltage U_{DC}. The energy is transformed by a DC/DC Converter and stored in an accumulator battery. Controlling the DC/DC

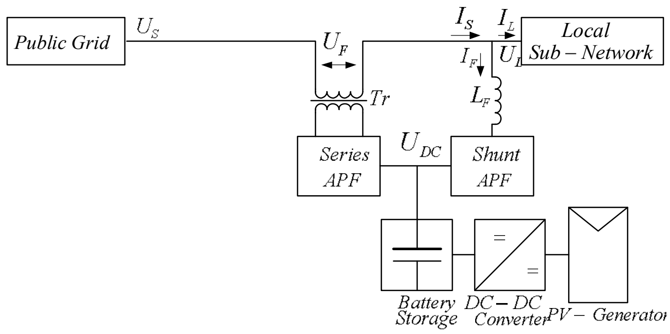

Fig. 1. General structural diagram.

Converter may be performed through a system for Maximum Power Point Tracking (MPPT) for the photovoltaic generator, at an optimal regime of charging the accumulator battery depending on its type. The energy may be also stored in another element intended for that purpose – for instance, a supercapacitor. In such a way, the system of APF's does not

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consume any active power from the AC grid, its supply being provided by the renewable energy source.

The functions of the two active power filters are as follows:

- for a Series APF – its control system is synchronized with the voltage of the public distribution grid, it tracks continuously the instantaneous values of the local sub-network voltage U_L, and compares them to those of a reference sinusoid of fixed value [6]. Switching over the filter devices is performed in such a way that at any time the voltage U_F complements the instantaneous values of the voltage U_S from the public distribution grid to those of the reference sinusoidal voltage. As a result, stabilization of the value of the local sub-network voltage U_L is achieved for a change in the value of the public-grid voltage. In addition, distortions in the waveform of that voltage depending on the power devices used and the algorithm of control system realization are compensated for. It is also possible to compensate for short-duration overvoltages or dips in the curve of the public-grid voltage. This is the main function of the Series APF. In addition to that, it is possible to perform one more function – realization of supply to the local sub-network if the public-grid voltage has disappeared. In such a case the connection to the the public distribution grid can be interrupted by means of a circuit breaker, and the winding of transformer Tr for connection to the public grid can be switched over to supplying the local sub-network. Here again, the control system follows the reference sinusoid, but in this case the filter generates the entire voltage, and not only the complementary voltage to the sinusoidal waveform as it was in the first case described.

- for a Shunt APF – its control system tracks the instantaneous values of the current I_L consumed by the local sub-network. It controls the power devices in such a manner that at any time the filter current I_F complements the current of the local sub-network in such a way that the current I_S being consumed from the public distribution grid is of sinusoidal waveform and in phase with the voltage U_L [7]. As a result, the Shunt APF compensates for the reactive power Q of the local sub-network and eliminates the higher harmonics of its current, i. e. it compensates for the distortion power D as well. This allows maintaining the value of power factor K_P close to 1. In case of disappearance of the voltage of the public distribution grid and if supplying of the local sub-network is conducted by the Series APF, the operation of the Shunt APF is disabled as it would consume additional active power from the storage element. It should be noted that due to the power circuit configuration of the Shunt APF it is possible that it also provides the power supplying of the local sub-network. At the same time, the connection to the public distribution grid should be interrupted, without switching over the transformer Tr. In this case, the operation of the Series APF is disabled, and the system for controlling the Shunt APF performs the control of its devices for synthesizing a sinusoidal voltage to the local sub-network, for instance, in accordance with any of the known methods used in voltage inverters.

A particular case of before described UPQC and combining active filters with renewable energy sources is discussed in [8]. Here a Multifunctional PV-Inverter System with a battery storage is presented which mainly feeds in PV-energy but can additionally be used for Power Quality Improvement of sensitive loads in the local sub-network including an uninterruptable power supply, or for compensation harmonic currents of local loads against the public grid. This system is mainly designed for industrial customers. A prototype system in the range of 100 kVA, developed by ISET and SMA Solar Technology AG, is tested at the moment at a real industrial side. First results are expected within this year. Further information can be found at [9].

III. Control Systems of APF's

The block diagram for realization of the system for controlling the Series APF is presented in Fig. 2. The instantaneous values of the public-grid voltage U_S are tracked by the Voltage Transducer 1 (VTr1). In such a way, it is possible to achieve continuous synchronization of the control system with respect to that voltage.

Using a low pass filter (LPF), the first harmonic is separated from the output voltage of VTr1 and its value is stabilized. This approach allows building up the reference sinusoid for the local sub-network voltage U_L. Its instantaneous values are tracked by means of the VTr2 and compared with those of the reference sinusoid. The comparison result obtained with the help of a hysteresis comparator (C) is used for controlling the transistor drivers for the bridge circuit of the Series APF [6].

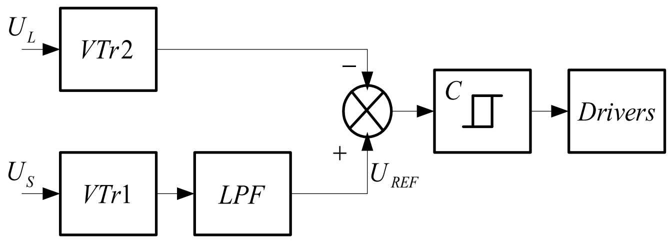

Fig. 2. Control system of the Series APF

A block diagram for the realization of the system for controlling the Shunt APF is shown in Fig. 3. The method of “the equivalent sinusoid” is applied [7]. The instantaneous values of the local sub-network voltage U_L and the current I_L, consumed by said grid, are tracked by means of the VTr1 and Current Transducer 1 (CTr1). The voltage period T is also measured. The values obtained are used for calculate the consumed active power P and the effective value of voltage U. Based on the latter results, it becomes possible to calculate the amplitude I_M of “the equivalent sinusoid" for the current I_S from the public distribution grid. This sinusoid is generated synchronously and in phase with the voltage U_L. Its instantaneous values are compared with the instantaneous values of the current I_S which is tracked by means of the CTr2. The comparison result obtained with the help of a hysteresis comparator (C) is used for controlling the transistor drivers for the bridge circuit of the Shunt APF.

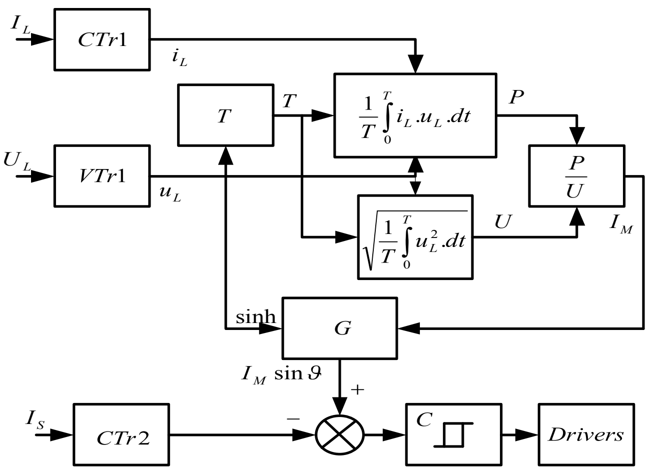

Fig. 3.Control system of the Shunt APF

IV. Investigation of APF's

A laboratory model of a single-phase system of active power filters realized with bridge circuits using transistors MP 75 – 12A3 is investigated. The value of the intermediate DC voltage U_{DC} is equal to 360 V, and that of inductance L_F is equal to 2.5 mH. The power of transformer Tr is 700 VA, which enables the Series APF to compensate for changes in the value of the input voltage (from the public distribution grid) within ± 15 % around 230 V at power for the local sub-network up to 5 kVA. The output voltage (for the local sub-network) is maintained equal to 230 V ±2%, irrespective of the character of the load. At the same time, the Series APF allows compensating the non-sinusoidal character of the input voltage up to 15 %. In the range up to 5 kVA, the Shunt APF maintains a power factor K_P higher than 0.98, irrespective of the character of the load. The systems for controlling the filters are realized on the basis of digital signal processors (DSP) TMS320LF2407. Investigations show efficient performance of the system of APF's for various linear or non-linear loads. Oscillograms characterizing the performance of a Series APF for a non-linear load are shown in Figs. 4 and 5. It is possible to observe the improvement of the voltage waveform around its maximal value.

Oscillograms characterizing the performance of a Shunt APF, for a non-linear load again, are shown in Figs. 7 and 8. The harmonic composition of the current without and with a Shunt APF is presented in Figs. 8 and 9.

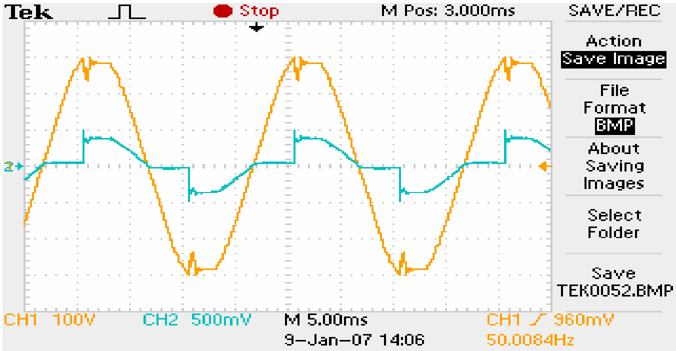

Fig. 4. Voltage for the non-linear local consumer (CH1) and current of the consumer (CH2) without a Series APF.

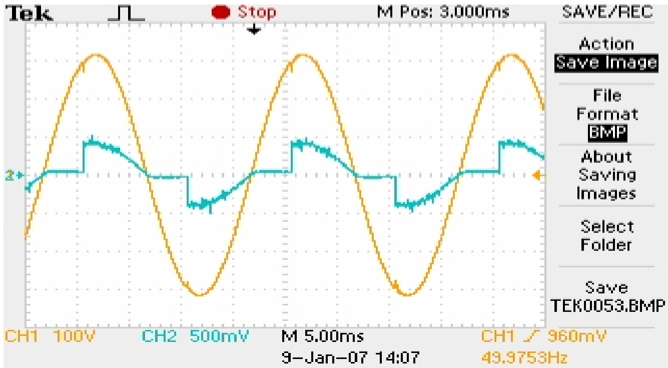

Fig. 5. Voltage for the non-linear local consumer (CH1) and current of the consumer (CH2) with a Series APF.

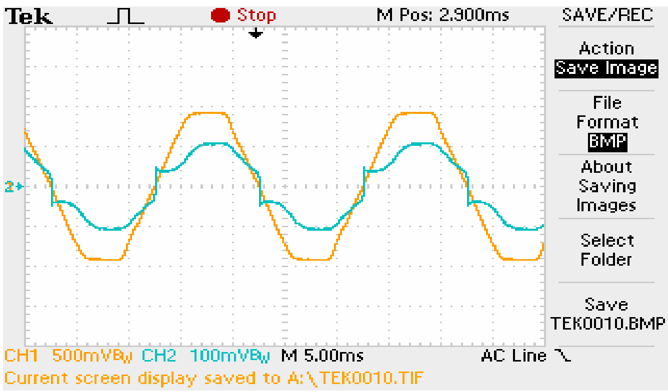

Fig. 6. Voltage of the public grid (CH1) and current of the non-linear local consumer (CH2) without a Shunt APF

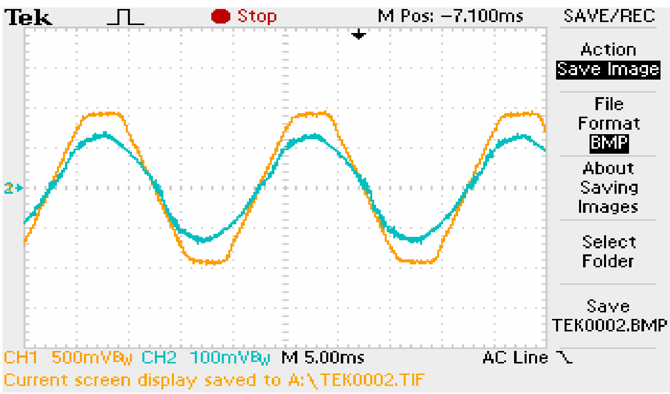

Fig. 7. Voltage of the public grid (CH1) and current of the non-linear local consumer (CH2) with a Shunt APF

As it can be seen from the comparison between Fig. 8 and Fig. 9, the Total Harmonic Distortion (THD) is diminished

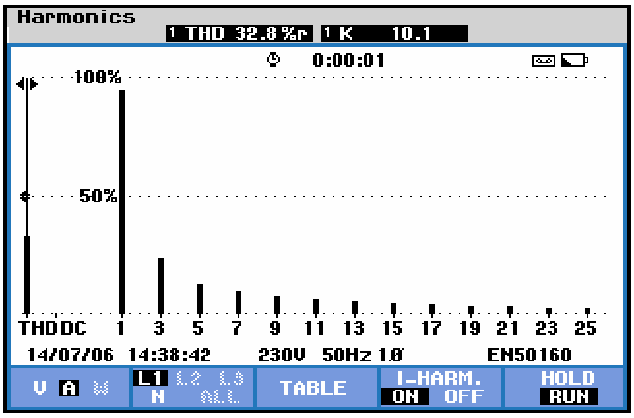

Fig. 8. Harmonic composition of the current without a Shunt APF.

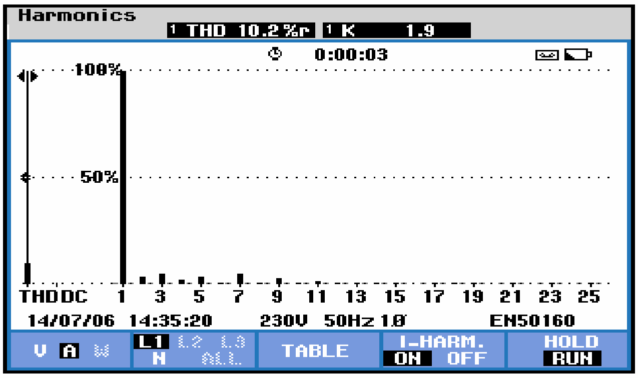

Fig. 9. Harmonic composition of the current with a Shunt APF

from 32.8 % for operation without a Shunt APF to 10.2 % after connecting the filter. In this case, an index for correcting the waveform of consumed current towards the sinusoid one is the so called crest factor (K), which has diminished from 10.1 to 1.9 after connecting a Shunt APF.

An increase in the total power factor K_P from 0.93 to 0.99 is found out after connecting a Shunt APF.

The investigations presented demonstrate the efficient performance of APF's, the power circuits of which are controlled by the control systems described in Part III. They may be successfully applied also for a three-phase variant of the system. In case of unbalance the following functions of APF's are possible as well:

- for the Series APF – equalizing the voltage values in the three phases of the local sub-network for different phase-voltage values in the public distribution grid.

- for the Shunt APF – equalizing the values of currents I_S in the three phases of the public distribution grid for a power factor close to 1, even for different values and waveforms of currents I_L in the local sub-network.

The proposed connection of the system of APF's may be also applied when using another renewable energy source with appropriate transformation for obtaining the intermediate DC voltage U_{DC}.

V. Conclusion

Using a renewable energy source in order to obtain an intermediate DC voltage supplying a system of Shunt and Series APF's is described in the present paper. The system of APF's is used for improvement the quality of the voltage supply of a local sub-network, as well as for correcting the power factor K_P of the local sub-network with respect to the public distribution grid. The system of APF's may be used as an uninterruptible power supply for the local sub-network as well. Two options for attaining that objective are presented – through the use of either a Series APF, or a Shunt APF. An advantage of said arrangement consists in the fact that no additional active power is consumed from the public distribution grid for covering losses in the two APF's, this power being supplied by the renewable energy source.

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