Electrical Complex of Combined Power Supply on the Base of Renewables and Hybrid Correction Device

Boris N. Abramovich, Yuriy A. Sychev
Saint-Petersburg Mining University
Saint-Petersburg, Russia
sychev_ya@spmi.ru

Veronika B. Prokhorova
Saint-Petersburg State University of Aerospace Instrumentation
Saint-Petersburg, Russia
vb@vu.spb.ru

***Abstract*—The main topic of presented article is the effective application of alternative and renewable energy sources with demanded level of power quality and electromagnetic compatibility. This decision is especially actual in conditions of industrial enterprises with continuous mode of technological process and responsible consumers. The configuration of electrical complex of combined power supply on the base of renewables and hybrid correction device is developed and proved in this article. Also the control algorithm of proposed electrical complex functioning is developed. The main functions of hybrid correction device, which is included in proposed electrical complex structure, are determined. The mathematical model of proposed electrical complex is developed. The results of mathematical modeling and computer simulation show the satisfactory level of power quality and electromagnetic compatibility in conditions of application of developed electrical complex.**

I. Introduction

The main trend in developing and designing of modern power supply systems of industrial enterprises of different areas is the complex application of local alternative and renewable sources in the framework of distributed generation [1]. This decision is conditioned by the presence of responsible power consumers, which define the continuity and stability of technological process in industrial enterprises. For example in conditions of oil production enterprises such consumers are submersible motors of centrifugal pumps [2] and in conditions of cable production enterprises such consumers are the installations of isolation preparing for cross-linked polymer cables [2]. According to the results of theoretical and experimental researches for such installations the permissible duration of voltage dip and power supply interruption is less than 0.15 s [3].

Distributed generation systems may function in two main modes: in autonomous mode without presence of conventional centralized power supply system and in parallel mode with presence of conventional centralized power supply system. In one's turn any distributed generation system may contain one or more alternative and renewable power sources [4]. In case of parallel functioning of distributed generation system with centralized electrical network or combined working of few alternative and renewable energy sources in one local power supply system there is the problem of effective synchronization of parallel working of generators of different types [5], [6].

Also the power quality rising and electromagnetic compatibility ensuring problem is important and actual in case of centralized and distributed power supply systems. In the first case there is a great number of power converters, which are included in variable speed drive systems of technological installations [7]. In the second case the electrical complexes of wind-diesel installations, solar stations and micro turbine installations, which work on the following oil gas, contain power converters for concordance of voltage and current parameters with required values of connected load, which also may include power converters [8].

Thus the problem of developing of electrical complexes on the base of centralized and distributed energy sources for uninterruptable power supply for responsible consumers and ensuring power quality and electromagnetic compatibility level is quite actual in any industrial area [9].

II. The existing technologies

Nowadays there is a number of technical devices and decisions, which allow to provide the uninterruptable power supply mode, the required level of power quality and electromagnetic compatibility. Let's consider the most significant and perspective devices and decisions.

The application of STATCOM device or parallel active filter with wind power station for improvement of power quality level [10], [11] is suitable and effective only in case of weak power systems with large internal impedance, which work mainly in isolated mode without presence of centralized power supply.

The application of series active filter as controllable voltage source for concordance of voltage levels of centralized and distributed power supply systems [12] is effective applicable only for one load or for small group of loads of similar types and functioning mode. Also the installation of series active filter may reduce the reliability level of whole power supply system in case of filter failure.

The application of hybrid parallel active filter in the mode of uninterruptable power supply is suitable only in case of digital computer loads [13], which are very sensitive to voltage distortions, dips and deviations.

Also all mentioned decisions are not able to provide the required level of synchronization between different generators of different alternative and renewable sources in parallel functioning mode. Besides it's necessary to take into account the opportunity of co-generation and three-generation modes of micro turbine installations, which work on the following oil gas. In such case there are two generators in micro turbine installation: first is the main generator, second is the auxiliary generator, which works on gas exhaust energy [6].

III. THE PROPOSED DECISION

According to the results of theoretical and experimental researches it was detected that in conditions of presence of the responsible technological consumers, which are territorially dispersed, without centralized power supply it is reasonable to use distributed generation systems on the base of combined functioning of wind-diesel installations, solar stations and micro turbine installations, which work on the following oil gas [14]. Also in such generation systems the micro turbine installations may work in co-generation and three-generation modes for improvement of energy usage efficiency [15].

For the mentioned conditions the electrical complex of combined power supply on the base of renewables and hybrid correction device was designed, which structure is presented on the Fig.1.

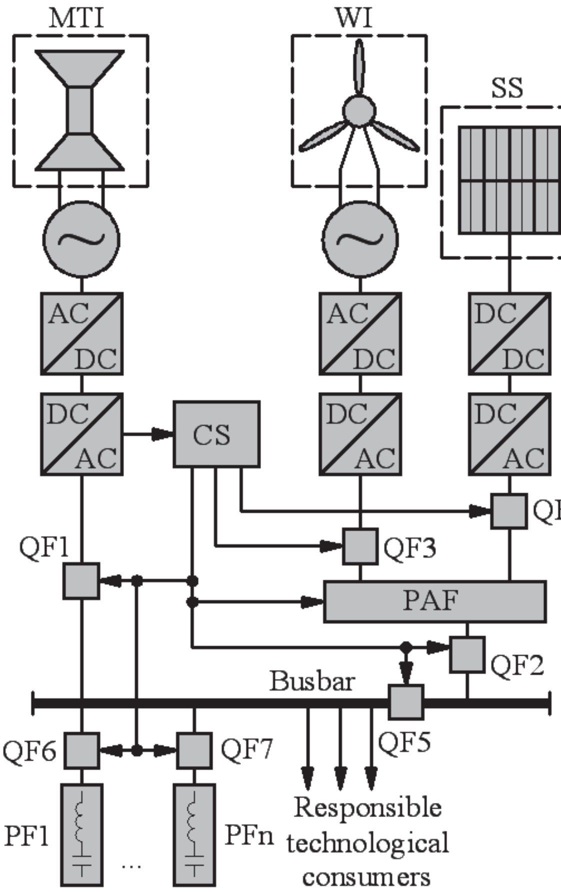

Fig. 1. The structure of proposed electrical complex

On the Fig.1: MTI – mircro turbine installation, which works on the following oil gas, WI – wind installation, SS – solar station, CS – control system, PAF – parallel active filter, PF1…PFn – passive filters, QF1-QF7 – circuit breakers. The structure on the Fig.1 presents the case of isolated functioning without centralized power supply system, but it can be supplemented to this structure.

Let's consider the functioning principle of this system. The group of responsible consumers is fed from common busbar, which has two input circuit breakers QF1 and QF2. The main power supply input is provided by the MTI through QF1, QF2 is the bypass power supply from WI and SS. MTI, WI and SS are equipped by power converters AC/DC and DC/DC for current and voltage levels concordance with values, required by consumers. QF5 provides the automatic reserve input in case of MTI breakdown and in case of combined power supply from MTI, WI and SS. Hybrid correction device according to the structure, presented on the Fig.1, consists of PAF and set of passive filters PF1…PFn.

There are two main functions, which are provided by the mentioned hybrid correction device. The first function is the ensuring of synchronization of parallel functioning of MTI, WI and SS. The second function is the improvement of power quality and electromagnetic compatibility level during power supply of responsible technological consumers. The first function is realized by means of PAF application in the structure of proposed electrical complex. The second function is realized by means of usage PF, which quantity is determined by the harmonic spectrum of nonlinear load in content of responsible consumers.

The basic structure of PAF consists of three main parts: power part, storage element and control system. The power part includes voltage source inverter on the basis of IGBT elements and output passive filter, which may includes resistors, inductances and capacitors. The control system includes voltage and current primary sensors and microprocessor or programmable controller, realizing the demanded functioning algorithm. The capacitor plays the role of storage element, which is connected in direct current side of voltage source inverter [16], [17].

The PF are implemented on the base of resonance filters, which are tuned for elimination of character harmonics, which orders are 5^{th}, 7^{th}, 11^{th}, 13^{th} and so on. According to the harmonic spectrum of nonlinear load, when only one harmonic may give the main contribution to the total harmonic distortion factor, it is reasonable to use one PF, which is tuned to elimination of that harmonic. Also the PF quantity may be changed according to the variations of harmonic spectrum.

The control and monitoring of structure, functioning modes and key parameters of the proposed electrical complex are provided by CS.

The structure, presented on the Fig.1, can be changed in case of parallel functioning of renewables with centralized power supply system. In such mode the reference signal for synchronization process is the centralized power supply voltage. In case of isolated work of proposed electrical complex without centralized power supply the reference signal is the output voltage of MTI, because the last one has the largest rated power in comparison with WI and SS as a rule. That's why MTI or centralized power supply system can be considered as the main source in proposed electrical complex.

IV. The Control System of Proposed Electrical Complex

The structure of control system of proposed electrical complex of combined power supply is presented on the Fig.2.

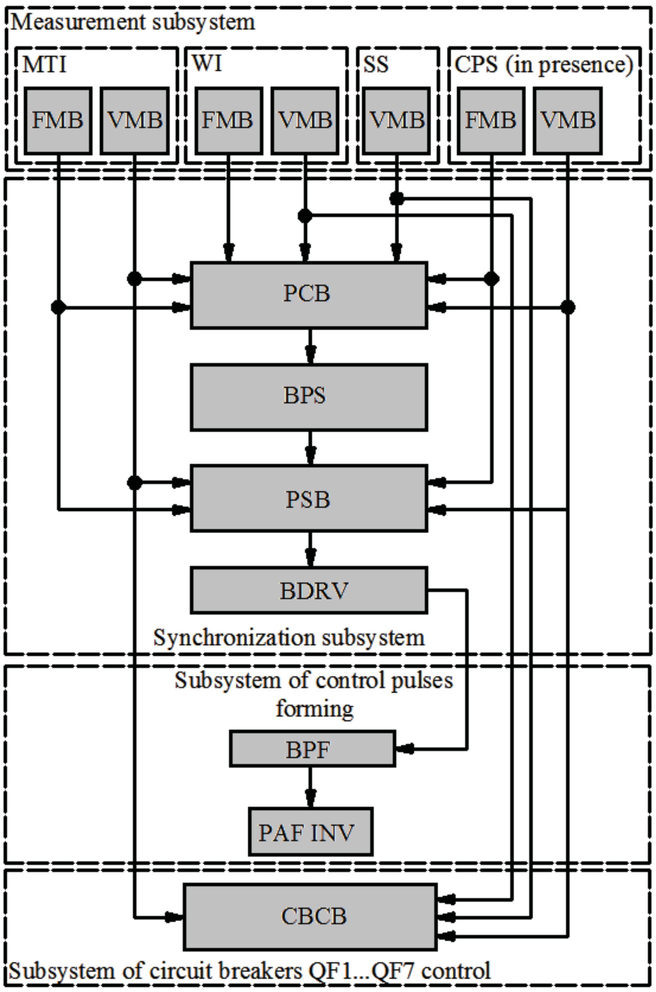

Fig. 2. The structure of control system of proposed electrical complex

On the Fig.2: FMB – frequency measurement block, VMB – voltage measurement block, PCB – phase conversion block, BPS – block of phase separation, BDRV – block of determination of reference values, PSB – phase synchronization block, BPF – block of pulses forming, PAF INV – voltage source inverter of PAF, CBCB – control blocks of circuit breakers QF1…QF7, according to the structure on the Fig.1.

The presented structure includes four main subsystems: measurement subsystem, synchronization subsystem, subsystem of control pulses forming and subsystem of circuit breakers QF1…QF7 control.

The measurement subsystem includes voltage and frequency sensors for determination of current values of voltage and frequency on the output of each power source. The information from these sensors is necessary for two main aims: appropriate synchronization of parallel functioning of several power sources and detection of failures on the output of each source for operative change of the proposed electrical complex structure by means of circuit breakers QF1…QF7. The accuracy level of these sensors must be in the range of 0.5-1 % for ensuring the proper mode of synchronization.

PCB provides the conversion of measured phase or linear (phase-to-phase) voltages on the output of sources according to the following equations [18], [19]:

$$U_\alpha = (2\cdot U_{ab} + U_{bc})/3;\; U_\beta = U_{bc}/\sqrt{3}. \quad (1)$$

$$U_\alpha = \frac{2}{3}\left[U_a - 0{,}5(U_b + U_c)\right];\; U_\beta = (U_b - U_c)/\sqrt{3}. \quad (2)$$

In equations (1) and (2) U_a, U_b, U_c – root-mean-square values of phase voltages on the output of power source (MTI, WI, SS, CPS), U_{ab}, U_{bc} – root-mean-square values of linear voltages on the output of same power sources. Also in some cases it is reasonable to use *dq* phase conversions, which allow to separate active and reactive components of voltage, current and power for effective compensation of reactive power [20], [21].

BPS ensures separation of the reference phase θ for pure sinusoidal voltage generation according to the following equations:

$$\cos\theta = U_\alpha / U_{sm};\; \sin\theta = U_\beta / U_{sm};\; U_{sm} = \sqrt{U_\alpha^2 + U_\beta^2}. \quad (3)$$

PSB provides phase synchronization between different power sources during their parallel functioning for combined power supply. Such synchronization is realized by means of phase locked loop (PLL) system, which structure may differ from typical according to the application area. In conditions of electrical complexes it is reasonable to apply the structure, which presented on the Fig.3, in case of phase conversions usage [22].

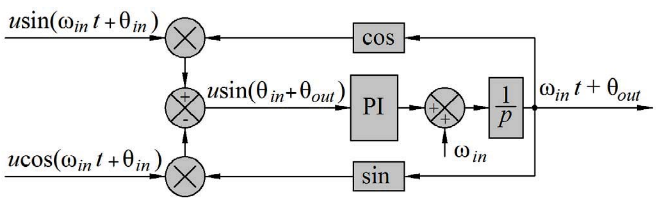

Fig. 3. The structure of PLL system for phase synchronization

On the Fig.3: ω_{in}, θ_{in} – power source input frequency and phase correspondingly, ω_{in}, θ_{in} – output frequency and phase correspondingly, PI – PI regulator, $1/p$ – integrator, sin, cos – trigonometric functions, $u\sin(\omega_{in}t+\theta_{in})$ and $u\cos(\omega_{in}t+\theta_{in})$ – orthogonal components of input phase or linear voltage in αβ or *dq* reference frame [23].

BDRV provides determination of reference values of voltage and frequency. There are two main cases: the absence and the presence of CPS. In the first case the reference values determine in the output of MTI as the most powerful source, in the second case the reference values determine in the output of CPS. After phase synchronization by means of PSB and determination of reference values, using BDRV, the reference signals of voltages are defined according to the following equations [24]:

$$U_{ref\alpha} = U_{ref}\cos\theta_{out};\ U_{ref\beta} = U_{ref}\sin\theta_{out}, \tag{4}$$

$$\begin{aligned} &U_{refa} = U_{ref\alpha};U_{refb} = (\sqrt{3}\cdot U_{ref\beta} - U_{ref\alpha})/2; \\ &U_{refc} = (-\sqrt{3}\cdot U_{ref\beta} - U_{ref\alpha})/2. \end{aligned} \tag{5}$$

In equations (4) and (5): U_{ref} – the reference value of voltage, determined on the output of MTI or CPS, θ_{out} – the voltage phase on the output of PLL system, presented on the Fig.3.

BPF is realized on the base of hysteresis regulators with controllable width of hysteresis zone for improvement of pulse forming mode. The hysteresis zone width is measured in units of controllable value and in our case can be regulated in the range of 1 to 10 Volts. The generated control pulses are entered to the drivers of control system of PAF voltage source inverter. The PAF inverter generates synchronized voltage in parallel mode with MTI or CPS for ensuring of uninterruptable power supply mode of responsible technological consumers [25].

CBCB provides the operative control of circuit breakers QF1…QF7 state in case of proposed electrical complex structure changing.

V. THE FUNCTIONING ALGORITHM OF PROPOSED ELECTRICAL COMPLEX

The structure of the functioning algorithm of proposed electrical complex of combined power supply is presented on the Fig.4.

According to the presented algorithm first of all it is necessary to start the main power source. In case of CPS presence such operation is not required. In case, when MTI is the main power source, few minutes are required for starting turbine and generator. After starting and going out of MTI on the steady state it is necessary to measure of the key parameters of generated power on the output of MTI DC/AC converter, namely voltage level and frequency. The obtained measured values are the reference quantities for the following synchronization procedure [26].

Further the responsible consumers are fed from MTI by means of switching on circuit breaker QF1.

After it the measurement of power consumption parameters of the responsible consumers is provided, including rated active and reactive power measurement, rated current of each consumer.

According to the results of measurement the demanded quantity of power sources is determined.

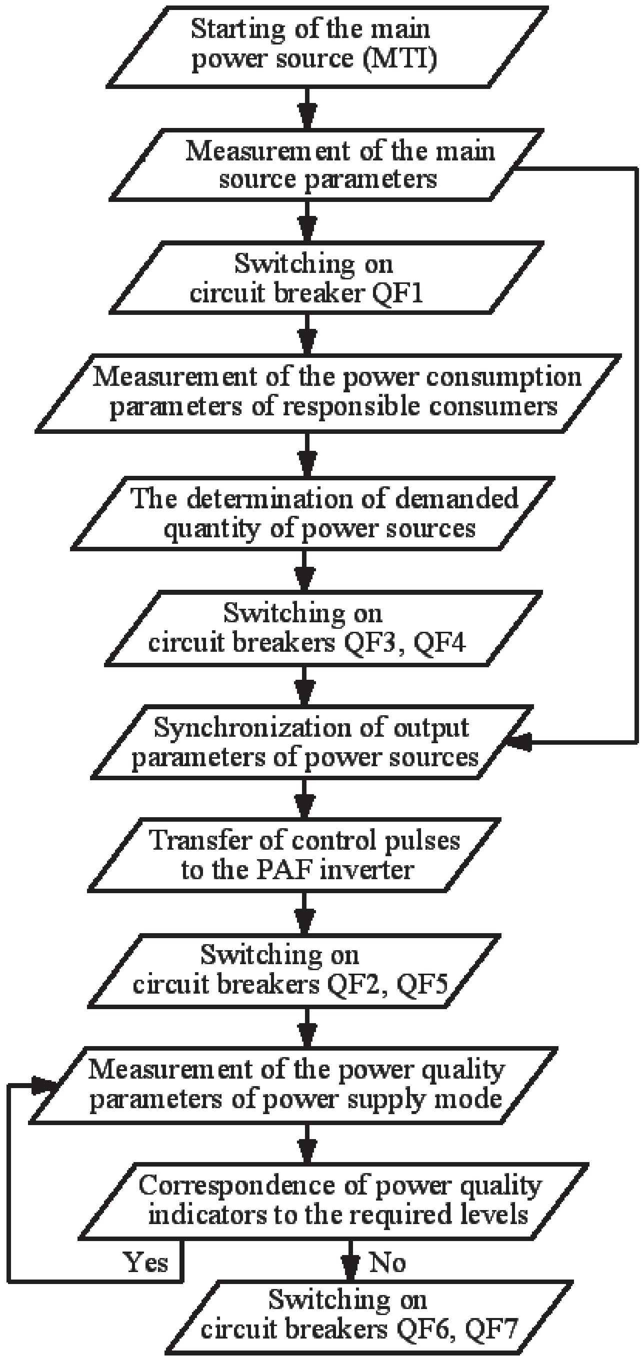

Fig. 4. The structure of functioning algorithm of proposed electrical complex

Among the whole group of responsible consumers there are several parts of consumers of different rated power, different functioning mode, which defines the character of power consumption. Such character should be taken into account when selection of power sources quantity and types. For example the responsible consumers of technological automation, low power electric drives of technological valves, which work several times per year, can be fed from SS. More powerful consumers can be fed from MTI or WI. Also in emergency cases for proper finishing of responsible technological process without damage for people and equipment, the energy, stored in super-capacitors, should be used. The charging mode of super-capacitors is defined by control system of AC/DC converters of MTI, WI and SS.

The next stage is switching on of circuit breakers QF3, QF4 for comparison of reference values of voltage and frequency on the output of MTI DC/AC converter with current output values of voltage and frequency on the output of WI and SS DC/AC converters.

According to the results of comparison the signals of task for output voltage and frequency for DC/AC converters of WI and SS are formed. These signals are transformed to control pulses for PAF inverter by means of pulse former on the base of BPF.

Further it is necessary to switch on the circuit breakers QF2 and QF5 for power supply of responsible consumers. The function of circuit breaker QF5 is to separate of responsible consumers according to criterion of rated power, functioning mode according to technological process, level of technological responsibility. In some cases one part of powerful responsible consumers can be separately supplied from MTI and another part of low-power consumers, which are very sensitive to any disturbance in power supply system and have the highest level of technological responsibility, can be connected to SS and WI. For example powerful nonlinear responsible consumers can negatively influence to power supply mode of digital control system for technological process in case of parallel functioning of MTI, WI and SS. Therefore sometimes it is necessary to separate some groups of responsible consumers when selection of power supply source among MTI, WI and SS [27].

The next stage is the measurement of power quality indicators. For ensuring of stable power supply mode the following power quality indicators should de measured:

- Voltage and current total harmonic distortion factor.
- Voltage and current individual harmonic distortion factor.
- Voltage dips and deviations level.

On the base of measurement results the number of filters PF1…PFn must be selected and for power quality improvement.

The correspondence of measured indicators to the required levels is checked according to the demands of Russian GOST 32144-2013 and International standard IEEE 1459-2010 in power quality and electromagnetic compatibility area. According to the GOST 32144-2013 the voltage total harmonic distortion factor must be less than 8 % in conditions of low voltage networks. The level of voltage dips and deviations must not exceed ±10 % of rated phase voltage value. The individual harmonic distortion factor is set for each harmonic component. In conditions of industrial power supply systems with intensive spread of variable speed drive systems, as the man kind of nonlinear load, the main contribution to the total voltage and current harmonic spectrum is brought by character harmonics with numbers 5, 7, 11, 13 and so on. For voltage harmonics of such numbers the GOST 32144-2013 determines the following levels of the individual harmonic distortion factor: for 5^{th} – 6 %, for 7^{th} – 5 %, for 11^{th} – 3.5 %, for 13^{th} – 3 %.

In case of harmonic elimination necessity the circuit breakers QF6, QF7 must be switched on. The quantity of filters PF and corresponding circuit breakers are defined by harmonic spectrum of nonlinear load of responsible consumers.

The hardware implementation of the proposed control system and algorithm can be realized by means of existing microcontrollers and microprocessors. Also in case of territorially dispersion of responsible consumers and presence of several proposed electrical complexes, the whole information about power quality level in each group of consumers from control system of each complex can be collected in cloud storage by means of wireless technologies for further analysis and processing. From this point of view the proposed control system can be easily integrated in any complex control and monitoring system.

VI. Simulation results

For evaluation of efficiency of proposed electrical complex of combined power supply the mathematical model of such complex with nonlinear load as responsible consumer, PAF and two PF, which are tuned to eliminate 5 and 7 harmonic, is developed in MATLAB Simulink software. In this model the power supply source is presented by means of MTI and WI. The parameters of power supply sources and nonlinear load are selected according to the results of experimental researches, which were carried out in conditions of oil production enterprises. These parameters are suitable also for other industrial areas, where nonlinear load has wide spread in form of power converters of variable speed drive systems. The control system of electrical complex is realized on the base of proposed structure and algorithm.

The results of mathematical modeling are shown on the Fig.5, 6. and in the Table I.

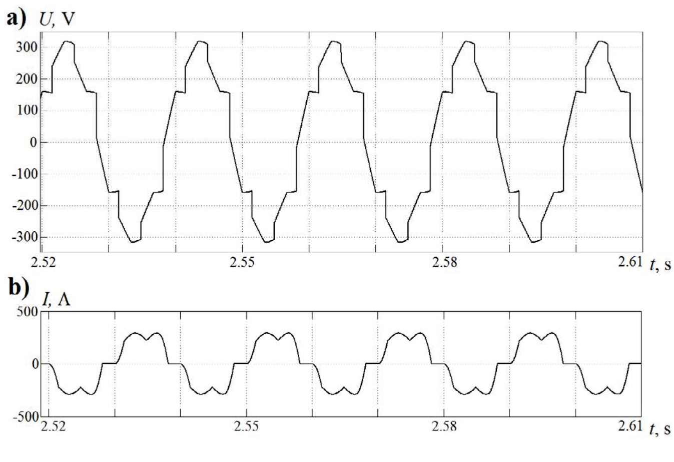

Fig. 5. The network voltage (a) and total consumption current (b) waveforms, obtained during mathematical modeling without PF connection

The waveforms of network voltage and current without PF connection show the satisfactory synchronization mode without any oscillations, which may appear in case of poor synchronization mode.

TABLE I. THE RESULTS OF MATHEMATICAL MODELING

Quantity	Value
Voltage total harmonic distortion factor, % (without PF)	16.09
Voltage total harmonic distortion factor, % (with PF)	1.43
Current total harmonic distortion factor, % (without PF)	22.99
Current total harmonic distortion factor, % (with PF)	0.43
Voltage individual 5th harmonic distortion factor, % (without PF)	13.85
Voltage individual 7th harmonic distortion factor, % (without PF)	8.75
Current individual 5th harmonic distortion factor, % (without PF)	21.32
Current individual 7th harmonic distortion factor, % (without PF)	11.41
Voltage individual 5th harmonic distortion factor, % (with PF)	0.08
Voltage individual 7th harmonic distortion factor, % (with PF)	0.02
Current individual 5th harmonic distortion factor, % (with PF)	0.13
Current individual 7th harmonic distortion factor, % (with PF)	0.02
Network voltage deviation, % (without PF)	2.49
Network voltage deviation, % (with PF)	1.18

In the Table I the values of voltage and current total harmonic distortion factors before and after connection of two PF, which are tuned to eliminate 5th and 7th harmonics, are presented. Similarly the the values of voltage and current individual harmonic distortion factors for 5th and 7th harmonics are also presented for such modes.

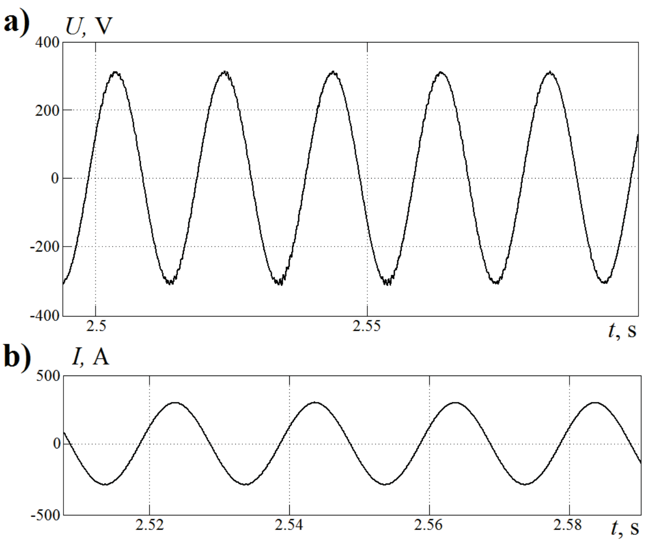

Fig. 6. The network voltage (a) and total consumption current (b) waveforms, obtained during mathematical modeling with PF connection

The obtained results show the compliance of mentioned values for voltage with GOST 32144-2013. The current factors are decreased significantly after PF connection, but such factors are not regulated by GOST 32144-2013. Also the level of voltage deviations also decreases in mode of PF connection.

The waveforms of network voltage and current with PF connection also show the satisfactory harmonicity level.

Therefore the hybrid correction device, including PAF and PF, in structure of proposed electrical complex ensures in satisfactory level two main functions: synchronization of parallel working of several renewable power sources during combined power supply of responsible consumers and power quality improvement.

VII. DISCUSSION

The proposed technical decision is based on the existing well-known physical and electrical effects, but the new main feature of this decision is the opportunity of effective synchronization of parallel working of several renewable sources, which have different origin. Also there is an opportunity to improve the efficiency of micro turbine installation functioning by means of co-generation and three-generation modes. Besides the main existing application of hybrid correction systems is the harmonic elimination, but in the presented decision such system is used for synchronization of parallel working of several power sources. The application area of the proposed decision is both conventional power systems and smart grids.

VIII. CONCLUSION

The electrical complex of combined power supply on the base of renewables and hybrid correction device is proposed. The electrical complex allows to ensure the uninterruptable mode of power supply of the responsible technological consumers. The proposed electrical complex is realized on the base of micro-turbine installation, wind installation and solar station. The hybrid correction device, which is included in the structure of proposed electrical complex and consists of active and passive filters, ensures the synchronization of parallel functioning of several renewables in the mode of combined power supply.

The proposed control system and algorithm for electrical complex is intended for operative changing structure of power supply system, power quality control and monitoring.

The results of mathematical modeling prove the satisfactory performance level of the proposed electrical complex of combined power supply.

ACKNOWLEDGMENT

The presented results were obtained as a part of scientific researches according to the contract № 13.707.2014/K within the scope of the State task "The competitiveness level improvement of mineral resources enterprises due to decreasing of energy component in whole price of products by means of distributed generation with combined application of alternative and renewable power sources and super-capacitors", grant № SP-671.2015.1 "The energy efficient system of power quality improvement in conditions of microgrids with distributed generation on the base of alternative and renewable power sources", the contract № 13.3746.2017 within the scope of the State task "The designing on the base of systematic and logic probability evaluations of rational and economically proved structure of centralized, autonomous and combined power supply systems with high reliability and stability level with usage of alternative and renewable power sources for uninterrupted power supply of enterprises with continuous technological cycle".

REFERENCES

[1] A. Sumper, A. Bagini, *Electrical energy efficiency: technologies and applications*. New York: Wiley, 2012.

[2] B.N. Abramovich, Y.U.A. Sychev, D.A. Ustinov, A.Y.A. Shkljarskiy, "The methods of voltage dips and distortion compensation in electrical networks of oil production enterprises", *Neftyanoe khozyaystvo - Oil Industry*, vol. 8, Aug. 2014, pp. 110-112.

[3] B.N. Abramovich, D.A. Ustinov, V.E. Poljakov, "Dynamic stability of operating modes electrocentrifugal pumps installations", *Neftyanoe khozyaystvo - Oil Industry*, vol. 9, Sep. 2010, pp. 104-106.

[4] T.A. Short, *Distribution reliability and power quality*. Taylor & Francis Group, LLC, 2006.

[5] P. Tenti, A. Costabeber, P. Mattavelli, "Improving power quality and distribution efficiency in micro-grids by cooperative control of switching power interfaces", *in Proc. of 2010 International Power Electronics Conference (IPEC-Sapporo 2010). Sapporo (Japan)*, Jun. 2010, pp 472-479.

[6] R.H. Lasseter, "Smart distribution: coupled microgrids", *in Proc. of Consortium for Electric Reliability Technology Solutions (CERTS)*, Jan. 2011, pp. 1-8.

[7] B.N. Abramovich, Yu.A. Sychev, V.A. Burchevskly, A.A.Vyrva, R.A. Ulbaev, V.V. Polishuk, "The shunt active filters implementation for power quality increasing in electrical networks of Priobskoye deposit", *Neftyanoe khozyaystvo - Oil Industry*, vol. 6, Jun. 2011, pp. 130-132.

[8] V. Khadkikar, R.K. Varma, R. Seethapathy, A. Chandra, H. Zeineldin, "Impact of distributed generation penetration on grid current harmonics considering non-linear loads", *in Proc. of the 3rd IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, 25-28 Jun. 2012, pp. 608 – 614.

[9] A. Bose, "Smart transmission grid applications and their supporting infrastructure", *in Proc. of the Consortium for Electric Reliability Technology Solutions (CERTS)*, Oct.2008, pp. 1-18.

[10] M. Ranjbar, M. A. Masoumand A. Jalilian, "Comparison of compensation strategies for shunt active power filter control in unbalanced three-phase four-wire systems", *in Proc. of the 22nd Canadian Conference on Electrical and Computer Engineering (CCECE'09)*, May 2009, pp. 1061-1066.

[11] Z. Shu, Y. Guo, J. Lian, "Steady-state and dynamic study of active power filter with efficient FPGA-based control algorithm", *IEEE Trans. on Industrial Electronics*, vol. 55, Apr. 2008, issue 4, pp. 1527-1536.

[12] S.P. Litran, P. Salmeron, J. Prieto Alejandro Perez, "Control strategy for an interface to improve the power quality at the connection of AC microgrids", *in Proc. of the International Conference on Renewable Energies and Power Quality (ICREPQ'14) Cordoba (Spain)*, vol.12, Apr. 2014, pp. 27-33.

[13] R. Rajasree, S. Premalatha, M.A. Bhaskar, V. Meenatchi, "A New Control Scheme for Unified Power Quality Conditioner (UPQC)", *in Proc. of the 3rd International Conference on Electronics Computer Technology (ICECT)*, Apr. 2011, pp. 54 – 58.

[14] B.N. Abramovich, Yu.A. Sychev, D.A. Ustinov, "Intelligent active-adaptive power system of industrial enterprises", *in Proc. of the 12th Conference of Open Innovation Association FRUCT and Seminar on e-Travel*, Nov. 2012, pp. 197-203.

[15] S. Horowitz, A. Phadke, B. Renz, "The Future of Power Transmission", *IEEE Power and Energy*, vol.8, no.2, Mar./Apr. 2010, pp. 34-40.

[16] R.S. Herrera, P. Salmeron, H. Kim, "Instantaneous reactive power theory applied to active power filter compensation: different approaches, assessment, and experimental results", *IEEE Trans. on Industrial Electronics*, vol. 55, issue 1, Jan. 2008, pp. 184-196.

[17] L.F.C. Monteiro1, J. L. Afonso, J. G. Pinto, E. H. Watanabe, M. Aredes, H. Akagi, "Compensation algorithms based on the p-q and CPC theories for switching compensators in micro-grids", *in Proc. of the 10th Brazilian Power Electronics Conference*, vol. 1149, Sep./Oct. 2009, pp. 32-40.

[18] L.S. Czarnecki, "On some misinterpretations of the instantaneous reactive power p-q theory", *IEEE Trans. Power Electronics*, vol. 19, no. 3, 2004, pp. 828-836.

[19] H.K. Morales Paredes, A. Costabeber, P. Tenti, "Application of conservative power theory to cooperative control of distributed compensators in smart grids", *in Proc. of the 10th International School on Nonsinusoidal Currents and Compensation*, Jun. 2010, pp 126-132.

[20] R. Klempka, "Distributed system for power quality improvement", *Electrical Power Quality and Utilisation, Journal*, vol. XIV, no. 2, Feb. 2008, pp. 53-68.

[21] M. Popescu, A. Bitoleanu, M. Dobriceanu, "On the current decomposition based on instantaneous apparent power vector", *in Proc. of the Tenth IASTED International Conference on Power and Energy Systems*, 16-18 Apr. 2008, pp. 120-125.

[22] J. Li, Z. Chen, Z. Shen, P. Mattavelli, J. Liu, D. Boroyevich, "An adaptive dead-time control scheme for high-switching-frequency dual-active-bridge converter", *in Proc. of Applied Power Electronics Conference and Exposition Annual IEEE Conference - APEC*, 5-9 Feb. 2012, pp 1355 – 1361.

[23] A. Patrascu, M. Popescu, "Comparative active current calculation by p-q and CPC theories", *Annals of the University of Craiova, Electrical Engineering series*, vol. 35, 2011, pp. 25-30.

[24] F. de Leon, J. Cohen, "Discussion of instantaneous reactive power theory and power properties of three-phase systems", *IEEE Trans. Power Delivery*, vol. 23, no. 3, Jul. 2008, pp. 1693-1694.

[25] B.N. Abramovich, Yu.A. Sychev, A.S. Mingazov, V.V. Polishuk, "On the elimination of voltage and current harmonics created by uninterruptible power supply", *Neftyanoe khozyaystvo - Oil Industry*, vol. 10, Oct. 2013, pp. 126-127.

[26] L. S. Czarnecki, "Closure on "Instantaneous reactive power - theory and power properties of three-phase systems", *IEEE Trans. Power Delivery*, vol. 23, no. 3, Jul. 2008, pp. 1695-1696.

[27] A. A. Belsky, A. N. Skamyin, E. V. Iakovleva, "Configuration of a standalone hybrid wind-diesel photoelectric unit for guaranteed power supply for mineral resource industry facilities", *International Journal of Applied Engineering Research*, vol. 1(11), Jan. 2016, pp. 233-238.