PROCEDURE AND EQUIPMENT FOR ELECTRIC ENERGY DISTRIBUTION RESULTING IN ENERGY SAVING AND NETWORK POLLUTION REDUCTION

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Abstract. Up to our days AC networks provide the energy distribution for industrial and domestic consumers. Electronic consumers of increasing number require DC voltage. The network pollution is considerably growing due to the significant number of line voltage rectifiers. The perspective reform of DC voltage energy distribution can solve this problem in the long-run. The suggested solution has many further technical and economic advantages.

Keywords: Distribution Of Electrical Energy, Power Factor Correction, And Energy Conversion.

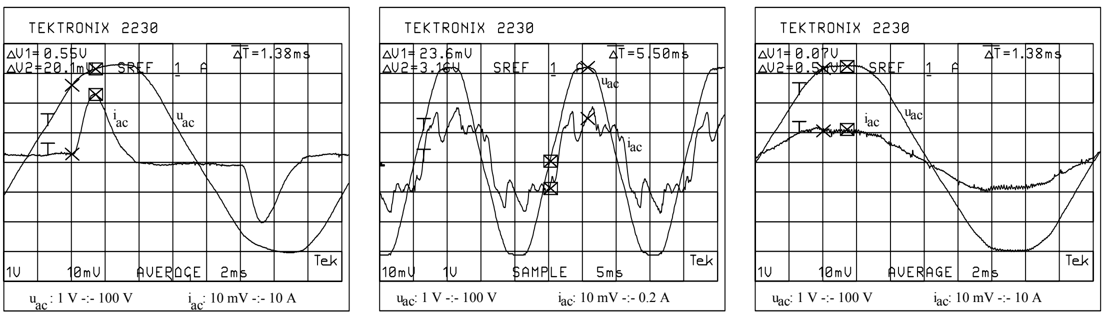
1. INTRODUCTION

At present, industrial and domestic electric energy is utilised by applying power electronic appliances. All of them contain some kind of electronic energy converters. These equipment and apparatus, disregarding direct frequency changers, require filtered DC current or voltage produced from the AC line. The controlled quantity of electricity will be produced from the intermediate DC voltage or current, by using further energy converters. In the interest of decreasing the size of electronic equipment, high-frequency (20-100 kHz) energy converters are used. By this, the outer dimension of transformers and chokes will be significantly smaller. Consequently, the first energy conversion step - when using electronic equipment supplied by AC lines of 3x400/230 V, 50/60 Hz - is the rectification of the AC line voltage and to store DC energy in some kind of temporary energy storage set. The actual utilisation of electric energy for energy conversion is done by applying DC/DC or DC/AC converters or inverters operating from the intermediate DC voltage.

The one- and three-phase variant of traditional rectifiers in discontinuous conduction mode operates as „peak-rectifiers" in most cases, because energy supply to puffer condensers occurs at the peak value of AC voltage in the form of impulse-like current. Fig. 1.a. shows the current and line voltage in an oscillogram exposure of an electronic welding equipment. The diode rectifiers of continuous operation mode provided by LC filters produce square-wave form current with full upper harmonics. Regarding the fundamental harmonic only, the phase factor will be almost 1, i.e. $\cos\varphi = 1$, but the power factor is smaller than 1 [1]. It follows from the above that the pollution of AC line is originated from the traditional rectifiers of electronic equipment [2].

2. THE PROBLEM

In the interest of reducing the network pollution, more and more international standards were initiated. Inserting „network-friendly" rectifiers, so-called pre-converters with PFC circuits (Power Factor Correction) solve the problem but it means a significant cost increase. The effect of pre-converters is that consumers act as pure resistive load to the network, i.e. the network pollution from the consumers cannot get into the line.



a. b. c.

Fig. 1. Characteristic current input of the network-polluting and network-friendly consumers

To save energy, furthermore, improve the quality of the line and to reduce network pollution, numerous solutions were introduced in electric energy transmission and distribution. First of all, in the interest of saving energy, High Voltage Direct Current (HVDC) energy transmission has been applied for long-distance energy transportation on the level of several hundred kV, see in [3]. Nowadays, many publications deal with Medium Voltage Direct Current (MVDC) electric energy transmission on the level of some kV, related to the energy supply of a city or an industrial plant, see in [4]. The development of power electronics has made all the above possible: the rectifiers produce DC voltage for DC energy transmission and the inverters produce three-phase voltage of 50/60 Hz. Consequently, the further energy distribution is realised by AC line for industrial and domestic consumers.

Analysing the problem from the viewpoint of energy utilisation, it can be stated that the local AC line distribution of 3x400/230 V, 50/60 Hz, despite its indisputable benefits, has numerous disadvantages in the era of up-to-date energy converters. They are as follows:

- the dimension and weight of transformers for voltage matching are significant at normal line frequency;
- the most significant network pollution occurs at the rectification of AC line voltage with traditional equipment, the phase and power factors are smaller than 1, the harmonic content increases, the voltage distortion is high;
- excess energy loss occurs directly at the rectification, and last but not least, the reactive power compensation results in an extra cost and loss indirectly, furthermore, the upper harmonics in the line may cause EMI and RFI disturbances (see the current and line voltage in an oscillogram exposure in Fig. 1.b of a fluorescent lamp with traditional ballast and phase-correcting condenser).

It follows from the above that the reduction or ceasing of network pollution can only be achieved by using „network-friendly" converters for electronic equipment in the case of AC line energy distribution. It can be proved that this procedure results in a significant operation cost reduction and energy saving.

3. MEASURES TO REDUCE NETWORK POLLUTION

The number of electronic consumers connecting to the local network is increasing. The realisation of the „network-friendly" qualities of today's electronic consumers is extremely important. The development trend refers to well defined consumer's sphere, all of them having „network-friendly" rectifiers [5], [6]. This requires an extra cost for consumers but the equipment provides resistive load to the line, see the current and line voltage in an oscillogram exposure in Fig. 1.c. Due to high-frequency operation mode, the „network-friendly" rectifiers may contain filter circuit elements of low weight and small dimension. The produced intermediate DC voltage can be used directly, or supplied to further energy converters. The consumer acts as a pure resistive load to the line so the system denomination of „network-friendly" is correct in every aspect.

Separate „network-friendly" arrangements do not result in general and economic solutions for handling the above problem sphere even if they have been developed based on unified principles and procedures. The pre-converters built-in all electronic consumers require an extra cost, furthermore, increase the weight and outer dimension of the equipment. Setting-in the pre-converter in some equipment is not always possible or brings about a special difficulty because of lack of place.

It seems to be a more economical solution of long-range if larger local objects (office buildings, working shops, small factories, dwelling houses, medical and educational institutes, etc.) have only one, common one-phase and/or three-phase „network-friendly" rectifier. All consumers requiring DC or AC network will be supplied from the DC line of the common pre-converter. DC consumers will be supplied from controlled DC/DC converters, while AC consumers from DC/AC inverters. Consumers requiring 3x400/230 V, 50/60 Hz may be connected to DC/AC inverters or the AC line directly, as well. The AC line feed may be suitable for heating equipment or uncontrolled AC appliances but a lot of equipment built-in recently can also be operated from the DC line. Room light by DC supplied fluorescent lamps is a good example accordingly (30 % energy saving compared to the traditional fluorescent lamps supply, DC wiring with good filtering capability, blinking-free operation), see [7], [8].

4. PROPOSAL FOR ENERGY DISTRIBUTION SYSTEM

The most important point of the suggested solution is that the reduction of the line pollution and significant energy saving at the local objects of energy consumers can be achieved by the new and unusual reform of local energy distribution. If energy distribution within the local object is solved only one, common, central „network-friendly" rectifier, this central rectifier provides a „de-coupling wall" between the line and consumers, see Fig. 2. In this case the reactive power from the line will be equal to zero and the line current will be of pure resistive character. The separate „network-friendly" rectifiers built-in energy converters would be unnecessary which results in a cost reduction of equipment. Besides the above, a lot of other possibilities come up, namely:

- using an accumulator set on the DC output for temporary energy storage, safety energy supply would automatically be solved for a shorter or longer period, ensuring the supply for emergency light and computers in work;
- the system would be appropriate for connecting other energy sources to the inner DC line,
- if the central „network-friendly" rectifier is appropriate for two-direction energy flow, the energy at braking can be recuperated to the AC line;

- inside the „de-coupling wall" traditional line transformers are applied if necessary.

The solution proposed by us is similar to the MVDC distribution. For the one-phase case, a similar arrangement has been developed and realised for DC and AC supply sources operated from accumulator plant on field see in [9]. The long-range realisation of LVDC (Low Voltage Direct Current) energy distribution on the level of 400-600 V may be carried out step-by step. The first step is the elaboration of a demonstrative reference system. A system like this may give an excellent possibility for demonstrating its preferable advantages, e.g. energy saving, the reduction of the cost and unfavourable network reaction, etc.

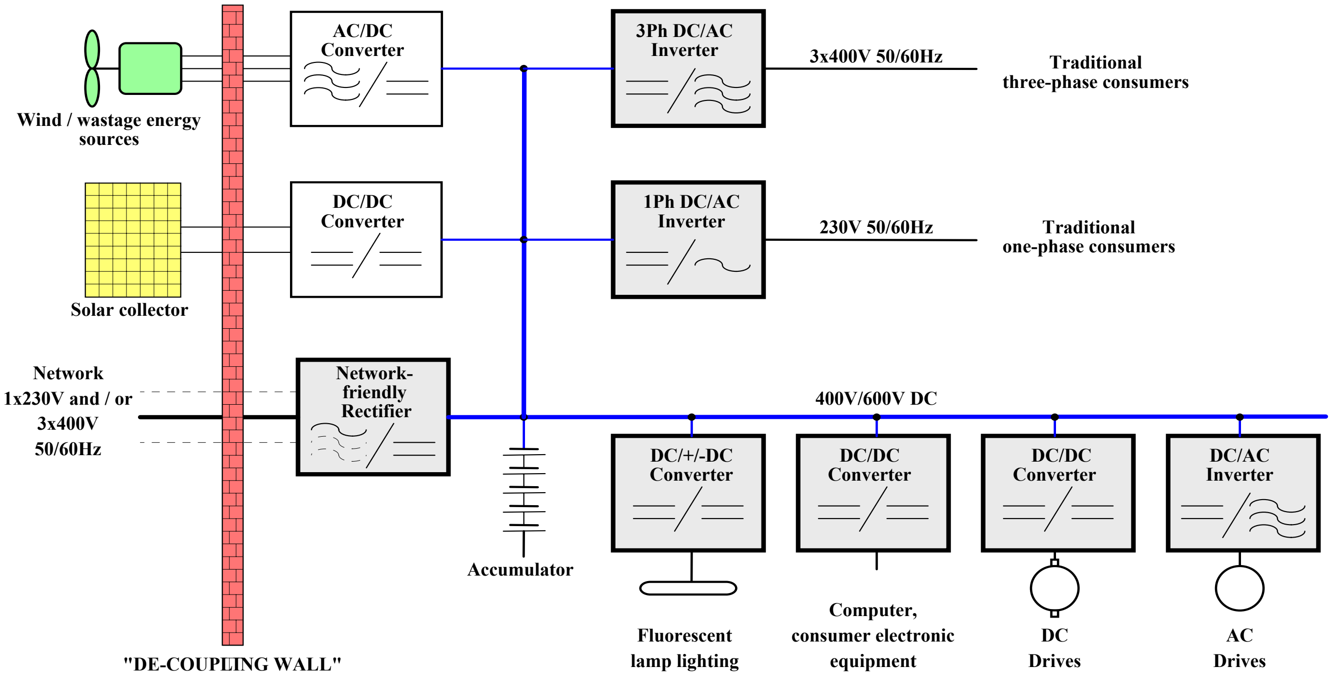


Fig. 2. Example for DC energy distribution among the local objects connected to the DC line

5. ENERGY CONVERTERS OF DC ENERGY DISTRIBUTION SYSTEM

Demonstrating the realisation of the proposed system, we give a brief account of the available means of power electronics. They are continually developing and can well be applied to the units of the block scheme in Fig. 2.

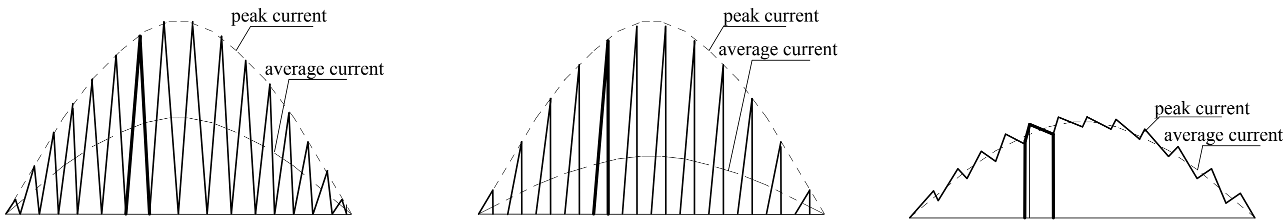
5.1. One-phase „network-friendly" rectifiers providing unidirectional energy flow

The input current of a „network-friendly" rectifier providing unidirectional energy flow corresponds to the average value of high-frequency current impulses. Depending on the operation mode, the form of current impulses may vary according to:

- triangle high-frequency changes between the zero and peak value of the sinusoidal envelope curve, see Figures 3.a. and 3.b.;
- continuous trapezoidal changes around the sinusoidal envelope curve in a well-defined interval, see Fig. 3.c.

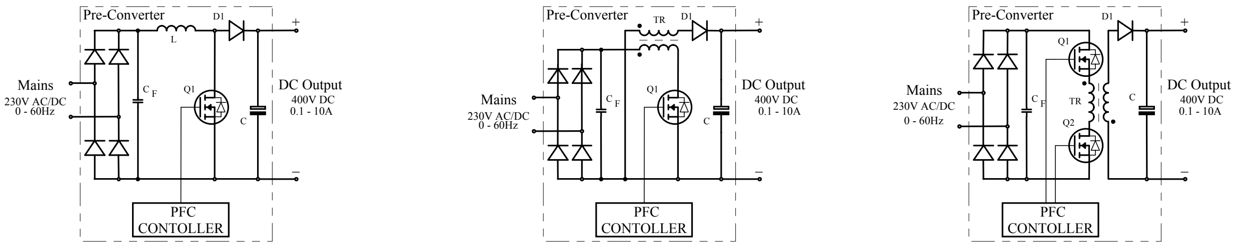
This is why the average value of input current is of sinusoidal form and the input current is in phase with line voltage, consequently, it gives pure resistive load to the network. In the latter case the energy transfer to the output is continuous, see Fig. 3.c. Fig. 3.a. shows the limit case of the continuous and discontinuous conduction modes, while Fig.3. b. shows a discontinuous conduction mode. The amplitude of the sine-wave average value of current impulses has to correspond to the actual load if the output voltage, independently of the load and line voltage, should be constant [10], [11], [12]. A proper filter impedes the effect of high-frequency current components on the line. The filtering conditions are most favourable in the case of procedure according to Fig. 3.c., but the control circuits are more complicated and the transient features are more disadvantageous than those of procedures according to Fig. 3.a. or Fig. 3.b.

The power electronic circuits applied to one-phase rectifiers providing unidirectional energy flow belong to the well-known backward converter family. Their most widespread variants are BOOST converters (Fig. 4.a.), FLYBACK converters (Fig. 4.b.), and BUCK-BOOST converters (Fig. 4.c.). The first does not allow galvanic de-coupling and its output voltage is always higher than its input voltage. The two latter converters make transformer coupling possible, therefore, they provide galvanic de-coupling and are applicable to provide output voltage of any value. All of them are used as converters in resonant or coupled condenser operation modes, as well.



a. b. c.

Fig. 3. Characteristic variants of operation of a „network-friendly” rectifier

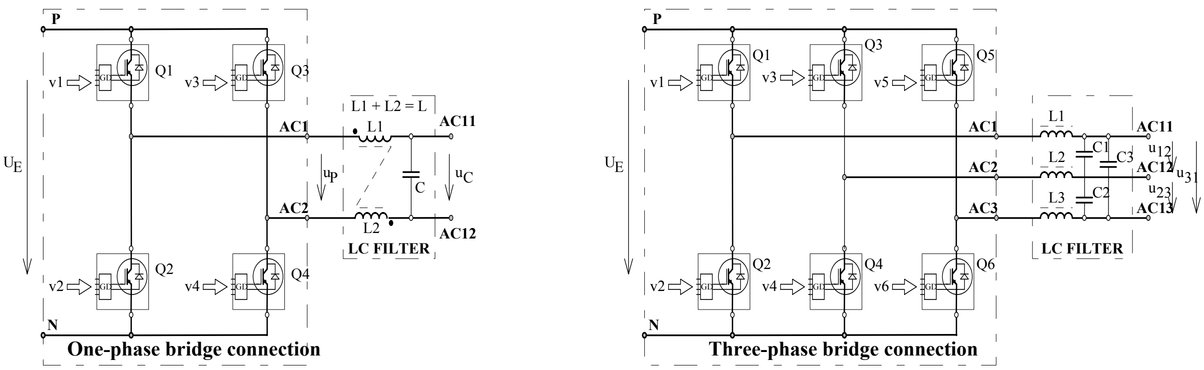


a. b. c.

Fig. 4. Block scheme of a „network-friendly” pre-converter in BOOST, FLYBACK and BUCK-BOOST arrangements

Applying the procedure according to Fig. 3.a. or b., current of triangle form flows in the inductance, its peak value is on the envelope curve of the sinusoidal wave. Applying the procedure according to Fig. 3.c., the PFC controller preserves the degree of deviation of current instantaneous value from the current reference signal, which is in phase of line voltage. The controller switches the power semiconductors on and off within a well-defined limit value. The low frequency component of current impulses, i.e. the fundamental harmonic, is of sinusoidal character and is in phase of line voltage in all the three cases. Condenser C_F separates the high-frequency current component only, therefore, current of sinusoidal wave flows on the terminals of the input rectifier. On the terminals of the condenser C, i.e. on the output terminals filtered and stabilised DC voltage will appear.

The „network-friendly” rectifiers like BOOST, FLYBACK and BUCK-BOOST converters are very effective and low-cost circuits from the viewpoint of current fundamental harmonic loading the line. The fundamental harmonic of sine-wave current derives from the average value of the high-frequency, triangle-form current versus time areas, but the current peaks may be double (Fig. 3.a.) or higher (Fig. 3.b.) than the instantaneous value of mean current. It is necessary to prevent the presence of high-frequency current peaks on the line. This is provided by the filter condenser C_F, its inner resistance and inductance have to be low, its capacitance must have a value, that the waveform of full-wave rectified line voltage should be unfiltered on the terminals of condenser C_F at small load, as well.



a. b.

Fig. 5. Multifunctional energy converters of one- and three-phase bridge connection

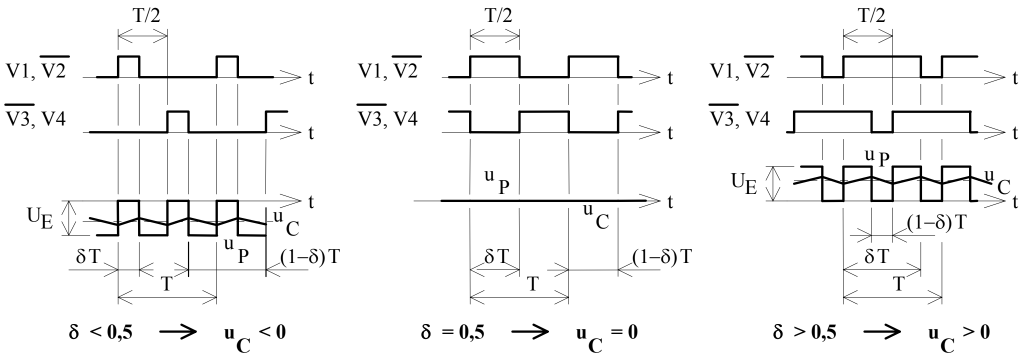


Fig. 6. Characteristic wave-forms of one-phase bridge connection in alternative control method (v1 - v4 are PWM control signals, u_P, respectively u_C is voltage of the power circuit)

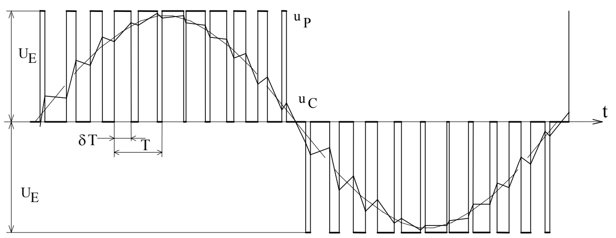


Fig. 7. Producing sine-wave form by PWM controlled bridge connection

Fig. 6. shows the wave-forms of PWM controlled signals and output voltage u_P, u_C in the case of three characteristic values of control signal δ (δ<0.5. δ=0.5 and δ>0.5). The whole range of variation δ is 0<δ<1. The main feature of alternative control method is that the power switches in the same leg receive control commands in push-pull operation mode, without delay. The conduction of two legs is dephased by a half period in such a way that one of the controlling signals increases by δ and the other decreases by 1-δ. It can be seen that the output voltage on the terminals of filter condenser C may be of positive or negative polarity depending on control signal δ if the value of switching frequency 1/T is much higher than that of the resonance frequency of LC circuit. Due to the alternative control method, the output voltage varies between 0 and $-U_E$, furthermore, 0 and $+U_E$ with two-fold switching frequency, see Fig. 6. The average value of output voltage u_P is determined by duty cycle factor δ, more exactly, by a control signal proportional to δ, if analogue control method is applied. The loading current may flow in both directions on the output terminals AC1-AC2 if the DC source on the terminals P-N of the bridge circuit can be used in a bi-directional operation mode. If the control voltage is modulated by frequency much smaller than the switching frequency, the output voltage follows the control voltage in average value, truly to form (Fig. 7.).

For producing the mean value of voltage in bridge connection converters, a low-pass filter of an adequate cutting frequency should be inserted in between terminals AC1-AC2 and AC11-AC12, see Fig. 5. The filter is effective when it removes the voltage component of switching frequency from the output voltage in a significant degree and transmits the modulating frequency totally (Fig. 7.). Due to the high switching frequency, this requirement can be easily satisfied and the outer dimension of the filter is fairly small [9].

The diversified control possibility and the four-quadrant operation of bridge connection make the development of many kinds of the energy converters possible. The bridge connection arrangement can be applied not only to DC/DC converters (DC drive, DC „transformer", etc.) or DC/AC inverters changing the amplitude and frequency of supply source, but it can be used as bi-directional „network-friendly" rectifier in the case of a suitable control, as well. In the latter case the control signal δ is to be modulated according to a sine-function in phase to the line voltage, but by an appropriate phase shifting. The value of δ is controlled by the level of DC voltage [13], [14]. The fluctuation of line current is similar to that of shown in Fig. 4.c.

Some blocks in Fig. 2. showing the sketch of energy distribution system may operate with energy converters of simpler structure than that of the bridge connection in Fig. 5.a. (half-bridge connection with condensers and asymmetrical half-bridge connection).

The qualities of three-phase bridge connections are similar to those of one-phase bridge connections and as a DC/AC inverter, it can be used for three-phase synchronous and asynchronous drives, respectively, bi-directional three-phase „network-friendly" rectifiers, as well.

6. SWITCHES, OTHER PROBLEMS

Connection with traditional and mechanical circuit-breakers to DC line of 400-600 V is problematic because of the possible striking of arc. The up-to-date semiconductors provided with protective circuits can be used for switching the consumers, connecting to DC line, on and off because they are switched by the applied control circuits. A lot of problems relating to protection, factor of degree and shock-proof measurement arise in the case of a DC bus system in the range of 400-600 V. As we can see for the time being, adequate supplementary equipment and standards for the low-voltage DC energy distribution may come into practice.

7. CONCLUSION

In our days AC networks provide energy distribution for industrial and domestic consumers, at the same time, the electronic consumers of increasing number require DC voltage. Network pollution in the local networks is due to using traditional rectifiers instead of „network-friendly" ones. In the interest of reducing the network pollution, more and more standards are initiated. To comply with the standards energy users need to be built-in „network-friendly" input circuits in most electronic equipment. This solution requires extra cost, furthermore, increases the weight and outer dimension of the equipment. In the long-run larger local object having only one common „network friendly" rectifier for providing DC voltage seems to be a more economical solution. DC voltage can be used directly or by applying further energy converters for supplying the consumers. A lot of other possibilities come up, namely, temporary energy storage, the simple interconnecting of energy producers, recuperation into the line, the elimination of robust line transformer.

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