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## A Matlab / Simulink Model of an Active Power Filter Based on Multi-stage Inverter Architecture

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**Abstract:** - A circuit of a multi-phase active power filter based on multi-stage inverter architecture was introduced. The paper is focused on building the MATLAB / Simulink model of an AC power supply system including a single-phase active power filter with a two-stage inverter. Each stage of the filter uses the pulse-width modulation (PWM) method. The results confirmed high efficiency of such a compensating circuit. The presented model will be used for the verification of the bridge-element concept, enabling computer modelling of multi-phase bridge converters, for any number of electrical phases.

**Key-Words:** - Electric power supply system, Active power filter, Mathematical modelling, Multi-stage inverter, Power quality, Electromagnetic compatibility.

### 1 Introduction

In the near future, multi-phase systems will be considered as design alternatives during the variant design of electric power supply systems. Potential applications of multi-phase systems can be found e.g. among independent power supply systems in aircrafts, in ships, and among those using wind power. Therefore, it is necessary to develop a modelling theory for  $p$ -phase independent power supply systems, which is valid for all values of  $p = 1, 3, 5, 7, \dots$ . This would enable computer-aided design and power quality analysis of power supply systems consisting of elements with different number of phases in feeding lines.

Results of PSIM analysis of a multi-stage inverter using three-state converters for a single-phase active power filter application were provided in [1]. However, increasing the number of phases in the electric power supply system,  $p$ , leads to multiple increase of the number of bridge elements, found in active power filters which are based on multi-stage inverter architecture. For modelling of such systems a bridge-element (B-element) concept was developed and introduced in [2] and [3]. It enables easy building of mathematical models of multi-phase bridge converters, independently of the number of phases, and following integration of them into a  $p$ -phase electric power supply system model.

This paper presents a general circuit of a multi-phase active power filter based on a multi-stage inverter, with each stage using the pulse-width modulation (PWM) method. Mathematical

modelling was performed in MATLAB / Simulink for the example of a single-phase active power filter with a two-stage inverter. It is the ambition to use modelling results for verification of the B-element concept.

### 2 Multi-phase Active Power Filter

Let us consider a circuit of a  $p$ -phase filter ( $p$  is a prime integer) with a  $k$ -stage ( $k = 1, 2, 3, \dots$ ) inverter, Fig.1. In Fig.1,  $B_1^j, B_2^j, \dots, B_k^j$  are single-phase full-bridge voltage inverters connected to the  $j$ -th phase,  $j = 1, 2, \dots, p$ ;  $B_{k+1}$  is a  $p$ -phase thyristor controlled rectifier;  $L_{c1}, L_{c2}, L^1, L^2, \dots, L^p$  are chokes;  $T_1^j, T_2^j, \dots, T_k^j$  are inverters' transformers of the  $j$ -th phase,  $j = 1, 2, \dots, p$ , and  $1, 2, \dots, p$  are the nodes of connection of the active power filter to a  $p$ -phase electric power supply system. Connection of primary windings of the inverters' transformers resembles "star connection", with the following connection to the electric power supply system. Transistors (TR) in the single-phase full-bridge voltage inverters and thyristors (S) in the  $p$ -phase thyristor controlled rectifier are assigned their respective numbers.

For simplicity, the function principle of the presented active power filter can be demonstrated for a single-phase connection, Fig.2. Each full-bridge voltage inverter uses PWM being able to produce three levels of voltage.

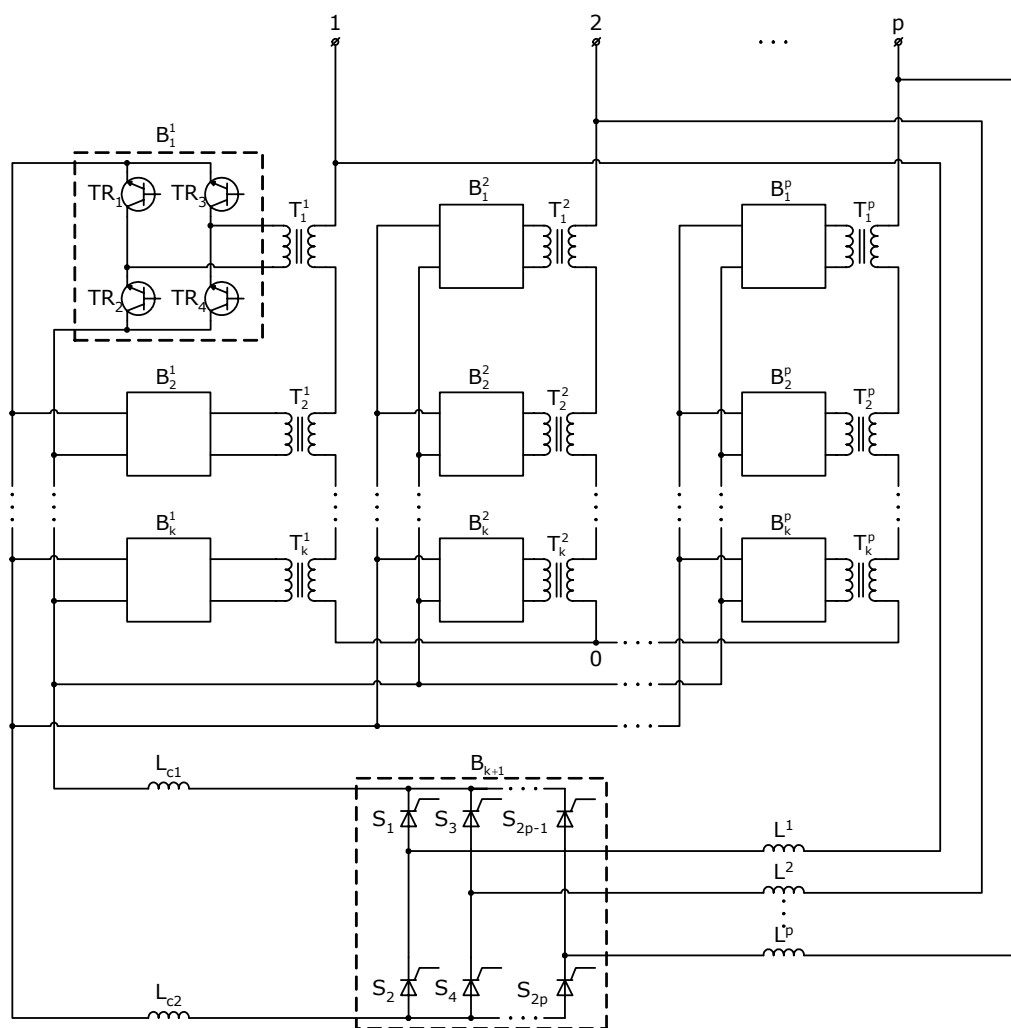


Fig.1. Circuit of a multi-phase active power filter with multi-stage inverter architecture.

Each inverter converts some part of the power supplied by the thyristor controlled rectifier. In each stage, PWM is performed by controlling of switching elements. The compensating voltage (AC) of the active power filter is equal to the sum of filtered harmonics, with certain accuracy. This compensating voltage is in anti-phase with the voltage in the node of connection of the active power filter, and thereby compensating the distortion power.

### 3 Mathematical Modelling Results

In order to demonstrate efficiency of the active power filter, a block-oriented simulation program MATLAB / Simulink was used for modelling the single-phase active power filter being a part of an electric power supply system. The system included a 1 kW synchronous generator and a single-phase rectifier bridge with a 0.75 kW active load.

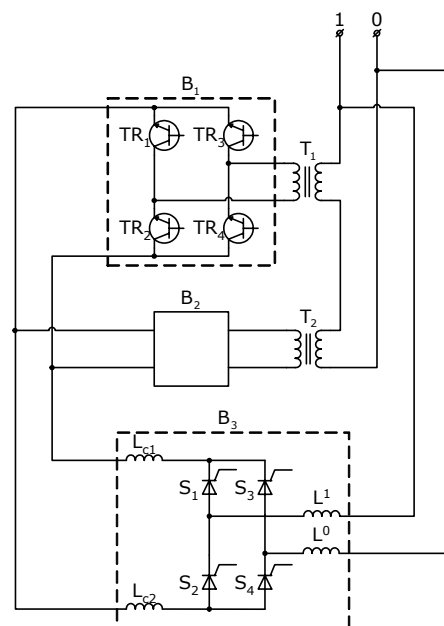


Fig.2. Single-phase filter with two-stage inverter.

MATLAB / Simulink graphical representation of the electric power supply system is shown in Fig.3, where  $L_1 = L_0 = 14 \text{ mH}$ ,  $C = 500 \text{ } \mu\text{F}$ ,  $R = 5 \text{ } \Omega$ ,  $R_{load} = 484 \text{ } \Omega$ . Fig.4 provides a graphical representation of the filter circuit, whereas the control system is shown in Fig.5. In order to construct the model of the electric power supply

system, standard blocks were used (generator, universal bridge), as well as blocks newly created (active filter) based on the standard MATLAB / Simulink elements. The universal bridge block represents the rectifier bridge whose power is defined by its load and is comparable to the power of the synchronous generator.

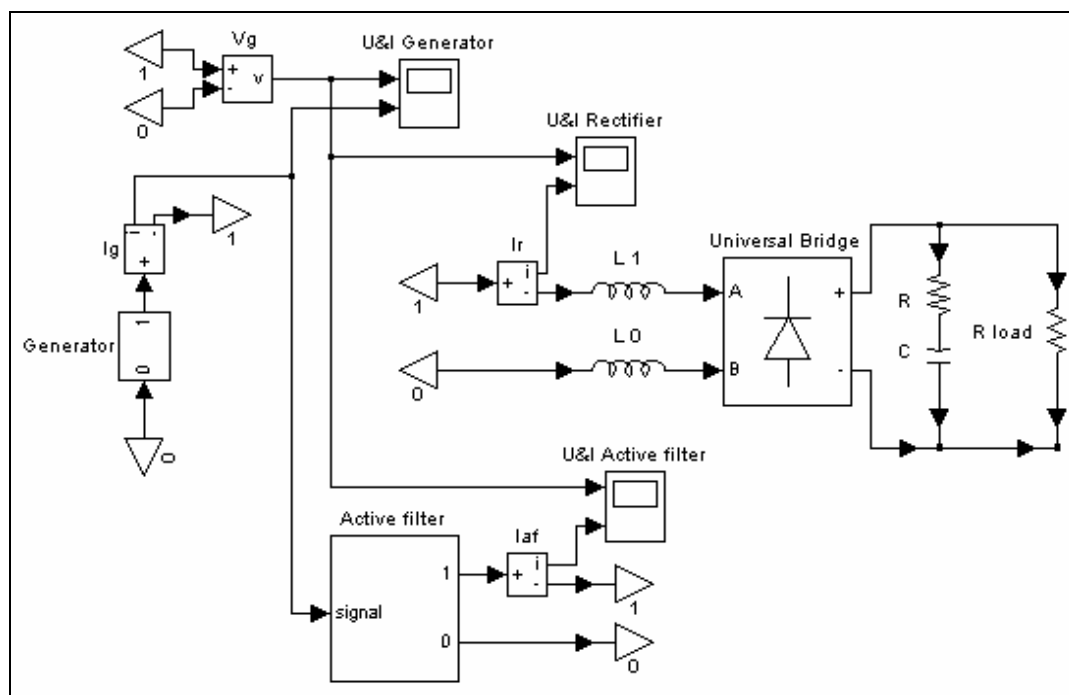


Fig.3. Graphical image of the electric power supply system.

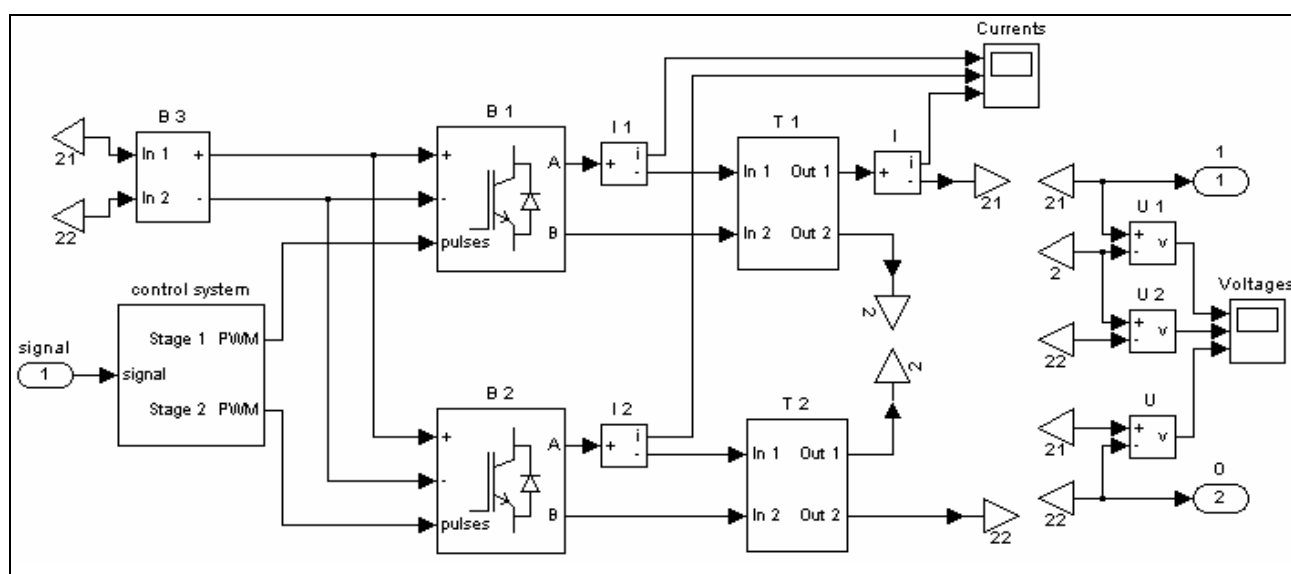


Fig.4. Graphical image of the active power filter circuit.

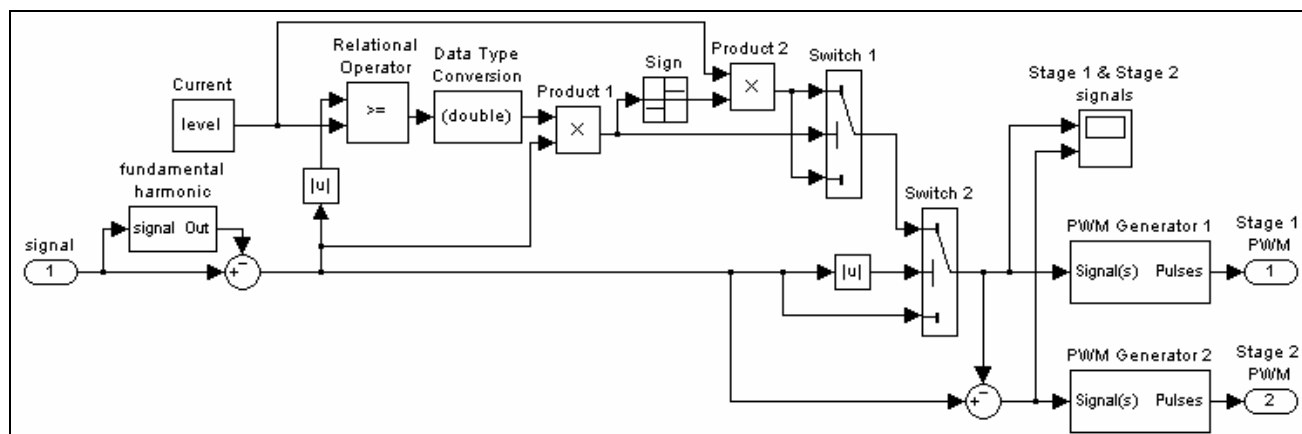


Fig.5. Graphical image of the control system.

Furthermore, MATLAB / Simulink current and voltage measurement blocks were used for measurement of instantaneous voltages and currents in the circuit. Scope blocks were used to display signals generated during simulation.

Calculation of currents and voltages were performed in time domain, and results were monitored for the time interval between 0.1 s and 0.2 s. The filter started to function at the time  $t = 0.145$  s. The chosen time interval enabled to observe the currents and voltages before and after filtering.

Fig.6(a)-(b) shows compensating currents generated by inverters  $B_1$  and  $B_2$  in the primary winding of transformers  $T_1$  and  $T_2$ , respectively. In Fig.6(c), the total compensating current is presented. Fig.7 provides time-domain results for the voltage and current of the synchronous generator. The voltage and current waveforms before and after filtering can be seen.

In Fig.8, current and voltage spectra are presented in order to demonstrate the filter efficiency in the frequency domain. As can be seen in Fig.8, the higher order harmonics almost disappeared after filtering (white bars). The active power filter significantly improved power quality in the electric power supply system.

## 4 Conclusion

The general circuit of a multi-phase active power filter based on a multi-stage inverter with PWM was introduced. Mathematical modelling results obtained for the example of a single-phase active power filter with a two-stage inverter, confirmed high efficiency of the studied compensating circuit. The MATLAB / Simulink model of the AC power supply system including the active power filter will

be used in verification of the B-element concept for easy building of mathematical models of multi-phase bridge converters, independently of the number of phases.

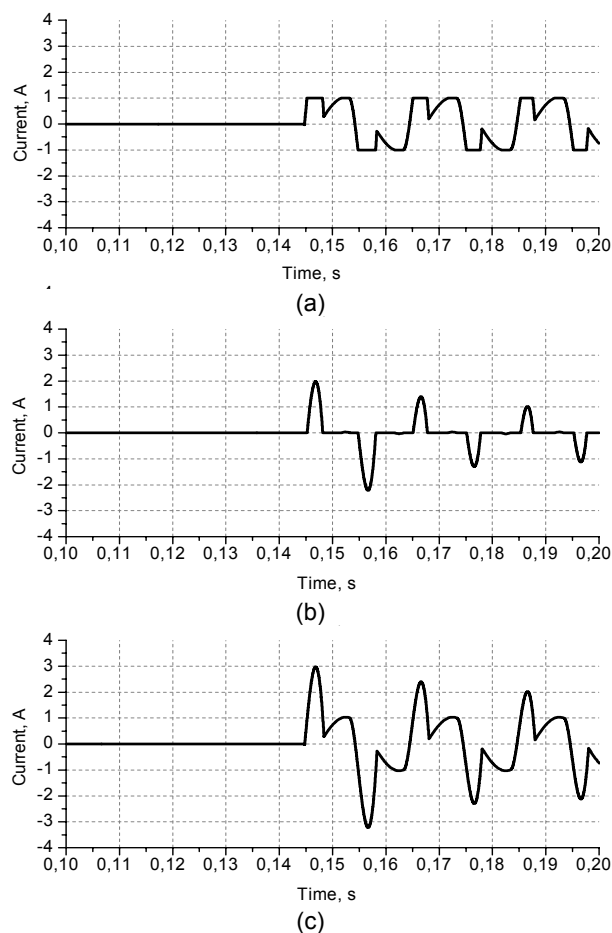


Fig.6. Compensating current: (a) generated by  $B_1$  in the primary winding of  $T_1$ ; (b) generated by  $B_2$  in the primary winding of  $T_2$ ; (c) total current, generated by the two-stage inverter.

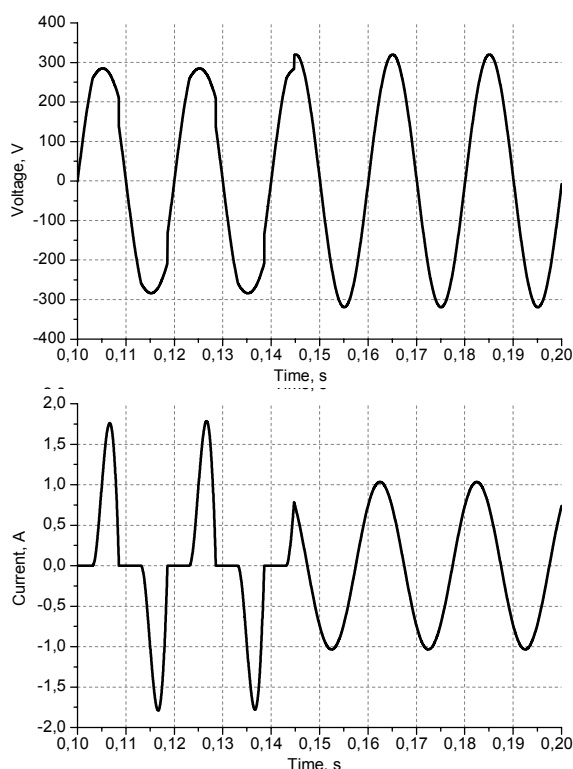


Fig.7. Voltage and current of the synchronous generator as functions of time.

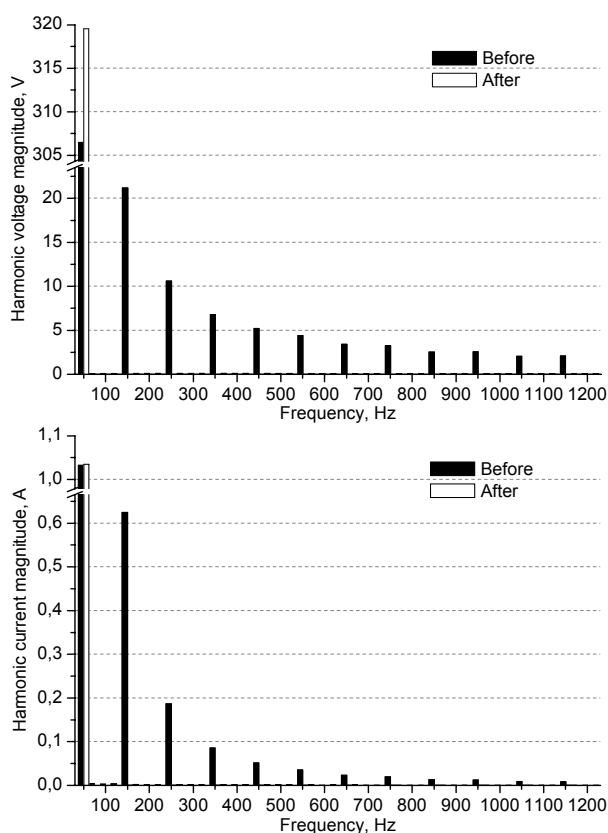


Fig.8. Voltage and current spectra of the synchronous generator before and after filtering.

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