Active-Based Capacitive Coupling Circuit for Narrowband PLC Systems

Gustavo Henrique Borges Gonçalves, Luís Guilherme da Silva Costa, Ândrei Campanogara, Marlio José do Couto Bonfim, and Moisés Vidal Ribeiro

***Abstract*— Aiming to introduce new directions to improve the performance of narrow-band power line communication (PLC) systems in low-voltage electric power grids, this study presents an active-based capacitive PLC coupling circuit for duplex communication. Simulations show that transmission and reflection parameters achieved good results while the Op-Amp provided a desired signal gain in the pass-band.**

***Keywords*— coupling circuit, active filter, power line communication.**

I. Introduction

The coupling circuit is an essential and crucial component of power line communication (PLC) systems because it ensures the isolation between the data communication system and the electric power grid. Moreover, it prevents potential damage to the PLC transceiver by blocking the main signal (50 or 60 Hz) and filtering signals beyond the operative frequency [1]. In low-voltage electric power grids, capacitive coupling has gained prominence and is predominantly used in most commercial PLC systems due to its straightforward design, simplicity, and cost-effectiveness [2]. On the other hand, inductive coupling has yet to be widely adopted due to its cost-effectiveness in particular scenarios. Therefore, active circuits are an innovative coupling method to be explored by the PLC community.

Incorporating active circuits into capacitive PLC coupling presents several advantages over traditional ones (i.e., based on passive analog filtering). Firstly, an active filter can amplify signals and offers superior isolation from the electric power grid. Secondly, it eliminates the necessity for a costly and often bulky inductor, typically required for managing low frequencies [3]. Lastly, its tuning can be finely adjusted using a trimmer resistor, allowing for high-accuracy adjustments of parameters such as the cut-off frequency, center frequency, or Q-factor.

This study introduces single-phase, narrowband, and active-based capacitive coupling circuits for low-voltage electric power grids. The active coupling circuit consists of an Op-Amp, an radio frequency (RF) transformer, which provides galvanic isolation between the PLC transceivers and the electric power grid with a working frequency of $9 - 500$ kHz.

This research was supported in part by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) under Grant 001, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) under grants 404068/2020-0 and 314741/2020-8, Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) under grants APQ-03609-17, TEC-PPM 00787-18, and APQ-04623-22, and Instituto Nacional de Energia Elétrica (INERGE).

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II. The proposed PLC coupling circuit

Fig. 1 shows the block diagram of the proposed active-based capacitive PLC coupling circuit. The block filter attenuates the mains signals (i.e., 50 or 60 Hz), while the RF transformer allows galvanic isolation and the maximum power transfer. In the following, the concatenation of high-pass and low-pass active filters results in a band-pass active filter. This pass-band active filter is of 10^{th}-order and synthesizes a Chebyshev Voltage-Controlled Voltage Source (VCVS) transfer function [4], often implemented as a concatenation of low-order active filters. Note that designing high-order active filters can be challenging because stability issues arise as the number of poles increases due to the sensitivity to component values.

For the proposed active-based capacitive PLC coupling circuit, the concatenation of a 5^{th}-order high-pass and 5^{th}-order low-pass VCVS active filters results in the 10^{th}-order Chebyshev band-pass filter, which is designed and simulated using the advanced design system (ADS) software. Also, the optimization tool in the ADS software is used to fine-tune the scattering parameter requirements.

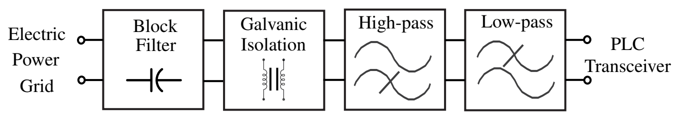

Fig. 1: The block diagram of the proposed active-based capacitive PLC coupling circuit.

Fig. 2 shows the schematic circuit for the active-based capacitive PLC coupling circuit designed when the pass-band is delimited by the frequencies 9 kHz and 500 kHz (3 dB cut-off frequency criterion), 50 Ω for input and output impedance, a pass-band ripple of 0.5 dB, stop-band attenuation of 40 dB, and a gain of 10 dB in the pass-band. Note that the designed active-based capacitive PLC coupling circuit allows transmitting and receiving PLC signals in the duplex mode. Moreover, components C_2 to C_6, R_1 to R_8, and A_1 to A_3 refers to the high-pass analog filter, while R_9 to R_{16}, C_7 to C_{11}, and A_4 to A_6 to the low-pass one. Also, a 1:1 RF transformer, T_{RF}, between the electric power grid and the filter to achieve galvanic isolation, while capacitor C_1 serves as a high-pass filter to attenuate the mains signal. To obtain the values of

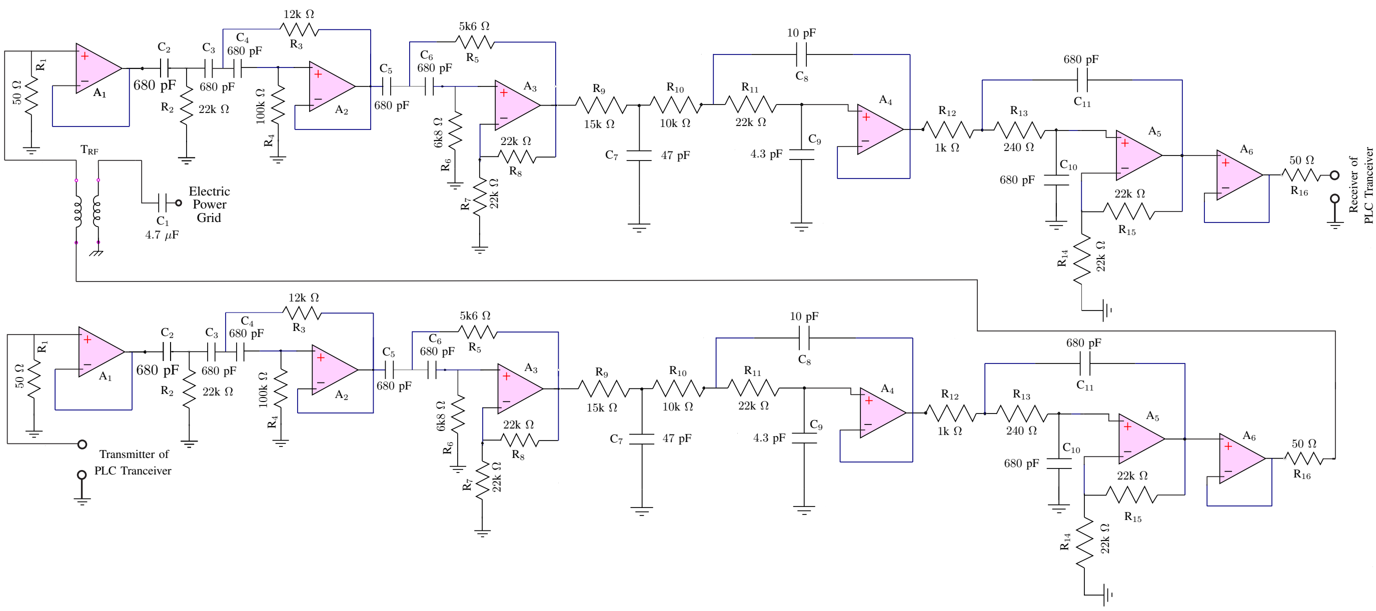

Fig. 2: The schematic of the active-based PLC coupling circuit for narrowband PLC applications in low-voltage electric power grids.

resistors and capacitors (i.e., R_1 to R_{16} and C_1 to C_{11}), we used equations in [4]. Afterward, we optimized the values of these components using ADS software.

III. Simulation Results

This section presents the numerically obtained scattering parameters of the proposed active-based capacitive PLC coupling circuit. We picked up the scattering parameters of the RF transformer PWB-1010-1L from Coilcraft to do so. Also, we considered the Pspice model of the dual model Op-Amp OPA-2830 (A_1 to A_6) from Texas Instruments. Consequently, it allows us to consider real-world circuit conditions and obtain realistic scattering parameters in numerical simulations. The choice of the Op-Amp OPA-2830 for designing the analog active filter is due to the typical gain for bandwidth over 100 MHz, the low sensitivity to noise, and the low distortion level. These features make it ideal for designing analog filters requiring high accuracy, precision, and input impedance. Consequently, this Op-Amp is suitable for interfacing with low-impedance loads and high-current output.

Fig. 3 shows numerical simulations of the magnitude of input insertion loss $S_{11}(f)$, output insertion loss $S_{22}(f)$ and transmission $S_{21}(f)$ of the proposed active-based capacitive PLC coupling circuit, carried out by ADS software. Note that the magnitude of the transmission $S_{21}(f)$ shows a gain of 10 dB, agreeing with the design specification. Regarding the magnitude of the insertion losses, $S_{22}(f)$ and $S_{11}(f)$, Fig. 3 shows values below -40 dB and -70 dB, respectively, meaning a good impedance matching was attained.

IV. Conclusion

This study has introduced active-based capacitive PLC coupling circuit for narrowband ($9 - 500$ kHz) PLC systems operating in low-voltage electric power grids. The simulation outcomes have shown the proposal exhibits satisfactory performance regarding insertion losses, implying its efficacy in injecting/extracting PLC signals into/from the electrical power grid. Furthermore, using Op-Amps in the capacitive PLC coupling leads to a controllable gain within the passband. Future work is to build the prototype of the designed active-based capacitive PLC coupling circuit and conduct field tests.

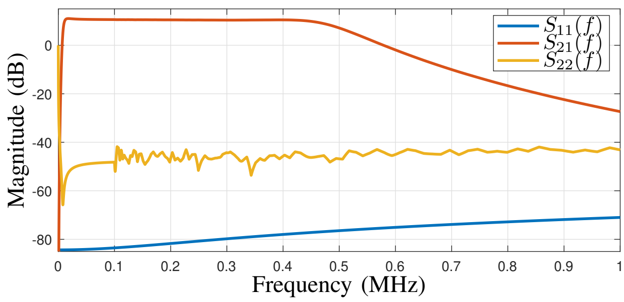

Fig. 3: Magnitude of the scattering parameters of the active PLC VCVS coupling circuit.

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