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An artificial intelligence based controller for multilevel harmonic filter

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ABSTRACT

This paper demonstrates an Artificial Intelligence (AI) based controller for 5-level, cascade H-bridge inverter for harmonic compensation and dc voltage regulation under different loading conditions for high voltage applications. In the proposed topology, the artificial neural network (ANN) is applied for obtaining compensating current and two Fuzzy Logic Controllers (FLC) are designed for dc voltage regulation and current error adjustment. The fuzzy logic controlled current error is then used for multicarrier Phase Shifted Pulse Width Modulation (PSPWM) for generating gate pulses for the inverter. The 5-level, Cascade H-bridge Multilevel Inverter (CHBMLI) is used as active harmonic filter. The ANN based instantaneous power theory is applied for reference current estimation. Simulation results are obtained in MATLAB/SIMULINK for diode bridge rectifier with RL/RC as nonlinear loads, using simpower system and fuzzy tool box. The proposed topology performance is justified through exhaustive simulation under various loading conditions. The total harmonic distortion in source current (THD_i) is being used as evaluation criteria to quantify the results. The THD_i obtained by applying PI and AI based controller are compared and are well within the IEEE 519, 1992 std. limits. The proposed method is verified through experimentation by developing prototype with dSPACE 1103 interface.

1. Introduction

In recent years many industrial applications need high level of power/voltage and better power quality in terms of minimum harmonic distortion with unity power factor. The Multilevel Inverter (MLI) allows the expansion of system rating with increased efficiency and better performance. The MLI can generate approximately sinusoidal voltages at less switching frequency with lower switching stress and almost have negligible Electromagnetic Interference (EMI) or common-mode voltage [1–3]. The rating of MLI is increased by adding more voltage levels without increasing individual device rating with reduced harmonics at the output voltage [2]. Mostly, the active harmonic filter uses a standard 2-level Voltage Source Inverter (VSI) for low power, low voltage applications. However, for medium/high voltage applications, MLI VSIs provide more advantages [4–10]. The 2-level inverter has many disadvantages such as it requires coupling transformer, large smoothing reactors, snubber components, complicated control and higher cost when applied in a medium or high voltage system [5,8,11]. As compared to 2-level inverter, MLI provides many advantages such as no coupling transformer, small smoothing reactor, less switching stress, modular structure for medium or high voltage application [5,7]. Furthermore, MLI has lesser harmonic distortion for more number of voltage levels with justified increase in cost.

The MLIs are mainly classified in three topologies [2,12]: (a) Diode Clamped Multilevel Inverter (DCMLI) (b) Flying Capacitor Multilevel Inverter (FCMLI) (c) Cascade H-bridge Multilevel Inverter (CHBMLI). The selection of MLI topology and number of levels depends upon the system parameters, such as voltage/power rating, cost etc.

Recently, Artificial Intelligence (AI) based controllers are used in harmonic filtering using MLI with higher efficiency and more dynamics; the researchers have reported various methods in the literature for various applications [3,8,13–22]. A single-phase CHBMLI with different dc sources is proposed in [3]. The topology uses a fuzzy logic based controller for frequency and output voltage. In [13], Genetic Algorithm (GA) optimization is applied to decide the switching angles for a CHBMLI with any number of levels. In [14] ANN based FLC for inverter current control is implemented, which demonstrates the efficiency of AI controllers for power quality improvement. A FLC in combination with Genetic Algorithm (GA) for harmonic reduction in fuel cell plants in designed in [15]. This scheme uses the GA optimized scaling factors for FLC. The performance of 3 and 5-level, Neutral Point Clamped (NPC) inverter for PV system using FLC/PI are compared in [16]. The FLC for dc voltage for a 3-level inverter for grid integration is proposed in

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[17]. The system performance is investigated for steady/dynamic states with FLC and proportional-resonant controller for comparison. However, the system is not tested for higher levels of inverter. A similar FLC dc voltage controller and current control is demonstrated in [18]. In [19] the instantaneous power theory and NN for extracting harmonics individually of a two-level inverter based APF has been demonstrated. In [20] the PI controller tuning by using particle swarm optimization for voltage controller of a APF has been demonstrated for harmonic minimization. An extensive survey of various AI based techniques of power quality analysis, which is useful for further research and applications for system performance improvement has been presented in [21]. The GA for tuning the unified power flow controller and optimizing its location in a distribution network has been given in [22]. The literature survey indicates that the researchers have used only one AI based controller for system performance improvement. In most of the reported literature the voltage controller has been implemented using AI based techniques. The APF topology is either two-level inverter based or three-level inverter based and higher levels of inverter have not been explored.

In most of the methods reported, the AI technique is used for dc voltage control for 3/5-level MLI and uses traditional (IPT/SRF) compensating techniques and PI controllers with its inherent limitation of fine tuning. To overcome these drawbacks multilevel harmonic filter with AI for current control and voltage regulation is proposed in this paper. The focus of the present work is to develop an AI controller based 3-phase, 5-level, multilevel Shunt Active Power Filter (SAPF) to improve total harmonic distortions in source current (THD_i) and to reduce higher order harmonics in high voltage system. This paper presents the complete design methodology, modeling, simulation and experimentation of the projected scheme. For the proposed work, the CHB topology using Phase Shifted Pulse Width Modulation (PSPWM) is preferred over the other MLI topologies because of its comparatively simple control and modular layout [12]. This scheme is advantageous as it uses AI, which is self adaptive and self adjusting and thereby less susceptible to change in system parameters. The performance of the proposed method is investigated through simulation in MATLAB/SIMULINK, which is further verified by experimentation using dSPACE 1103 interface. The efficacy is demonstrated via exhaustive simulation and experimental results for different nonlinear loads and change in load. The simulation is carried out at high voltage rating of the system; however the experimentation is carried out at low voltage due to practical limitations.

2. Proposed artificial intelligence controller based multilevel harmonic filter

The proposed harmonic filter has a 5-level, Cascade H-bridge inverter (CHB) as filter and Artificial Intelligence (AI) based control scheme as shown in Fig. 1. As compared with 2-level filter, the proposed method achieves better compensation performance by using smaller filter inductors, with reduced switching stress at higher switching frequency and higher voltage. However, filters based on MLIs are generally more expensive and more complicated to control as it has more number of inverter switching states. Moreover, the application of these filters in medium and high voltage with high power level is justified in terms of cost and performance. In the proposed scheme the instantaneous power theory is modified and the reference/compensating component is extracted by using Artificial Neural Network (ANN). Further, the scheme uses two separate Fuzzy Logic Controllers (FLC), one is for regulating dc voltage (V_{dc}) and the other is for generating gate pulses for the IGBTs in the inverter circuit (Fig. 1). In CHBMLI, the clamping diodes are not required, which reduces the control complexity, therefore has simple modular structure for expansion. The proposed harmonic filter is a shunt/parallel connected, current harmonic compensating device, which injects the harmonic cancellation component in the power circuit at the point of common coupling (PCC) and thereby reduces the harmonic distortion in current and also improves the power factor. The proposed AI controllers are robust, do not necessitate a mathematical model, and accommodates unpredictability. The ANN is selected because of its adaptability and harmonic separation capability. The ANN continuously monitors the load current for its harmonic composition. This continuous observation is adapted by ANN and the controller parameters are accordingly adjusted so as to count for the required correction. The ANN adaptability is faster as compared to traditional controllers such as PI or low/high pass filters. The ANN allows the easy and quick estimation of Fourier coefficients corresponding to harmonics. Moreover, the ANN does not require the mathematical model for its implementation. Therefore, the ANN is being selected and designed. The use of fuzzy logic based controller permits simple control structure with uncertainties to be implemented. Therefore, the fuzzy logic based controller is selected for the dc side capacitor voltage equilibrium and current error adjustment for modulation. These controllers require very less tuning efforts as they have intelligent mapping between input and output, which is linguistic rather than mathematical. The PI controller performance data is used as training data for ANN and is converted into linguistic data for FLC. The combination of ANN based harmonic extraction using IPT, FLC for voltage and current control for MLI based APF makes the proposed scheme more efficient and adaptable. Further the batch control method of voltage regulation reduces the number of voltage controllers and there by the system is faster as compared the system with individual voltage controllers.

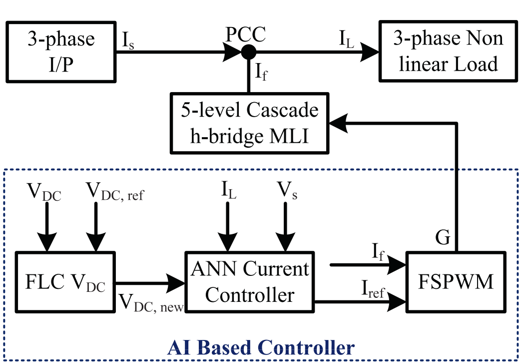

Fig. 1. Block diagram of Artificial Intelligence (AI) based controller for multilevel harmonic filter.

3. Artificial neural network based instantaneous power theory

In the proposed current controller the reference signal is obtained by using the ANN based instantaneous power (p–q) theory (IPT), which uses the basic IPT theory introduced and developed by Akagi in 1982. This uses Clarke/Inverse Clarke transformation and is based on time domain [23,24]. The IPT is more efficient and feasible as compared to other methods and can be applied to balanced/unbalanced systems under both steady state and/or transient condition [23,24]. For the projected scheme, the ANN is applied for harmonic component extraction. For the proposed controller only average/constant component is desirable and all other are undesirable and are to be eliminated. Traditionally a low pass filter is used for separating harmonic component, which requires tuning for changes in system. The use of ANN eliminates the repeated tuning and is self adjusting according to the system parameter variation. The harmonic component with ANN from ac-