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Comprehensive Study on Control Strategies of Unified Harmonics Compensator for Distribution System

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Abstract:

Unified harmonic compensator is a versatile custom power device used to improve the quality of power for end users. The objective of this study is to provide the current status of controlling Unified harmonic compensator which can help the researchers to select the effective controlling technique based on its application. The structure and controlling techniques are elaborated to find its suitability and selection for application in distribution power systems. The generation of reference voltage/ current signal time domain and frequency domain based methods are discussed. The gate signal generation using various adaptive methods and their effectiveness is discussed. Further this study will be helpful to find the cost effective design of Unified harmonic compensator.

Keywords: *Unified harmonic compensator, Adaptive control, custom power devices, Voltage source inverter.*

1. Introduction

Electrical components combined in different manners to generate, transmit and distribute the electric power in the form of a network known as power system. Power system can be categorized as power generation, power transmission and power distribution systems. At the generation station the power obtained is of high quality, whereas it keeps on reducing during power transmission and distribution process due to various internal and external factors. The internal factors includes transformer excitation, capacitor or feeder switching, Switching on/off of load, power electronic loads, induction heating systems and external factors such as environment changes like lightning strike and mostly due to usage of nonlinear loads.

In this process of electricity transmission from regional grids to substations/distribution stations the power quality problems are categorized into power quality problems/events like voltage swell, voltage sag, interruptions, transients and harmonics etcetera, which may affect the efficiency of power system as well as appliances/equipments used by customers .Therefore the power electronics based devices are used at power transmission and distribution levels in power systems for the protection of end-users' equipments, which are known as flexible alternating transmission (FACTS) devices and custom power devices respectively.

The focus is on custom power devices, which were introduced in 1980-90's and furthermore classified into two main categories i.e networked configuring type devices and the compensating

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devices[1-7]. The network configured incorporate the modifications in configuration of the power system networks for improving the power quality and the network configured devices used are TCR (thyristor controlled reactor), FC-TCR (fixed capacitor-TCR), SVC (Static VAR compensator), SSSC (static synchronous series compensator) and UPFC (unified power flow controller) and the the custom power devices are SSCL (Solid State current limiter), SSCB (Solid state circuit breaker) and SSTS (Solid state transfer switch).

These devices shift/transfers the load from a fault line to an alternative line to protect the sensitive equipments, while DVR (Dynamic voltage restorer), D-STATCOM (Distribution static synchronous compensator) and UHC (Unified harmonic compensator) are compensating devices generate a compensating signal to equalize the effect of fault in the system and make the system again work on within the range of fundamental voltage, current, phase and frequency [3-8]. This paper is briefing the basic structure of UHC and its controlling techniques in the below sections.

2. Basic Structure of Unified harmonic compensator

Unified harmonic compensator (UHC) is a cascade connection of series and shunt converters via a common dc link capacitor or inductor based on its topology. This device deals with the imperfections in load current and supply voltage, which are due to the deviation in fundamental supply parameters [4-6]. Earlier passive filters were used and had drawbacks like dependence on filtering characteristics of system components, reliance on source impedance, parallel /series resonance between power system components. Thus practically have high no load losses, bulky size and fixed compensation range. To overcome these difficulties with the passive filters, active filters have been deployed in the distribution system.

These filters are providing dynamic stability and adjustable solutions to power quality issues. Active power filters are majorly categorized based on their place in the system as series active filters, shunt active filters and as switched capacitors, standard inverters, lattice structures and voltage regulators. The series inverter injects voltage at the point of common coupling (PCC) so that the voltage at the load remains unaffected by any voltage disturbance in the distribution line/feeder[7-10]. Moreover the shunt inverter compensate the reactive power demand by load, unbalances in three phase supply system and simultaneously eliminate the voltage harmonics from the network. The possible combinations of two standard inverters as series-series, shunt-shunt and series-shunt can be made, out of this series and shunt combination is the popular one because it feeds both voltage and current for compensation in the feeder as per the requirement.

The injection transformer is installed in series with the feeder line to detect the line parameters and connected to the series inverter, while an inductor is used to connect the shunt inverter referring to the figure 1a and figure 1b. Generally the standard inverters are known as voltage source inverters (VSI) and the current source inverters (CSI) have difference in their topologies and both the configurations are shown in figure 1a and 1b respectively[10].

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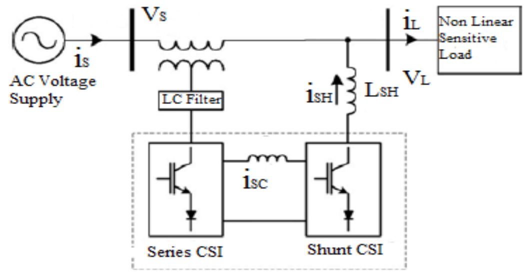

Figure 1a Current Source Inverter Topology

Among these two topologies CSI has an advantage of high efficiency in case load power is low, but the major disadvantage of CSI is that it cannot be used in multilevel operations, whereas VSI is preferred due to low cost, smaller size, light weight, capability of multilevel operation, high efficiency and flexible control at the PCC.

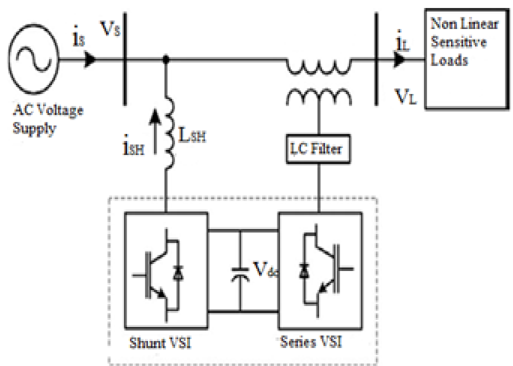

Figure 1b Voltage Source Inverter Topology

Beside this, the current drawn by the shunt inverter is utilized to maintain the DC link voltage and the overall power balance in the network. The location of UHC also plays an important role in compensating power quality issues such as harmonics and inter-harmonics, transients, noise etc.

3. Filter Circuit

Inverters as power electronic devices also generate harmonics their effect can be minimized using filters placed either on inverter side or in line side. Inverter side filtering scheme is preferred because of filtering the higher order harmonics, whereas this scheme causes phase angle shift and voltage drop in fundamental components of inverter output [9-11]. Thus practically a combination of inductor and capacitor known as LC low pass filter is used as inverter side filtering for series side inverter and simple inductor i.e. L filtering is preferred for shunt side inverter circuit.

Most of the time series inverter circuit is on standby mode, thus injection transformer works as current transformer which is short circuited from its secondary side and these switches delivering power directly to the load, however a transformer less cross phase connected UHC configuration is also being designed for the distribution power system and used now a days for low voltage distribution systems.

4. Dc-Link Voltage Regulation

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The direct link inductors and capacitors are employed to regulate the voltage across both the inverter circuits[11]. The capacitors are preferred over inductors for maintaining voltage because of advantages such as size, cost, and life.

In normal operation of UHC the active power flows between series and shunt inverters, while during switching, due to instigation of power quality events in the system; the voltage across direct current link capacitor changes from its rated voltage and this leads to change in load voltage. It also inserts unwanted source current harmonics in the system [11-14]. Thus earlier the external DC sources were used to as input and the PI (Proportional Integral) controllers were used to maintain the voltage level across the DC link capacitor.

The actuating signal for the PI controller is the difference between the reference and the actual voltage of capacitor. Therefore the voltage of DC link capacitor can be maintained. The other improved methods of controlling voltage are PID (Potential integral derivative control), rechargeable battery control, and super capacitors and also by using renewable energy systems like PV solar modules, wind energy and integrated controlling techniques[14-20].

5. Controlling Techniques

Controlling is done to improve the system performance. The control strategies of UHC are discussed below and elaborated in figure 2 and are implemented in the following ways first of all by using potential transformer or voltage sensors voltage signals are sensed and using current transformer or current sensors current signals are sensed, the hall effect sensors and isolation amplifies can also be utilized for gathering information about the system as well as line parameters. Then the fundamental and harmonics quantities of sensed signals are separated by employing one form these two methods

(i) Time domain method which is further divided as instantaneous active and reactive power method, stationary reference frame method (p-q theory) and synchronously rotating reference frame method (d-q theory)[14-15].

(ii) Frequency domain method which is based on Fourier Transform and also helpful in generating reference signal for the inverters. The frequency domain methods are tedious and are not so popular in extracting the line parameters because it takes larger time than time domain methods to detect the event and to generate the compensating signal. An improved method for generating the reference as well as gate signal for inverters is Wavelet Transforms and Discrete Wavelet Transform which gives better and faster results than the Fourier Transforms and Fast Fourier Transforms because of moving window feature [13-19].

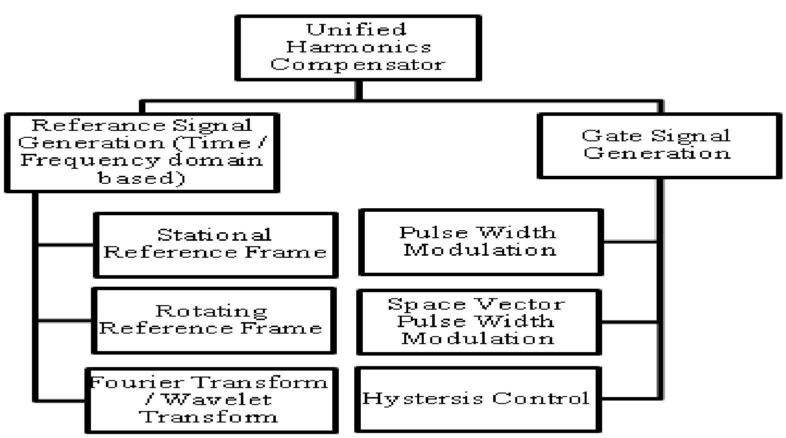

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Figure 2 Control of unified harmonic compensator

After the reference signal calculations the compensating commands are given as gate signals to the semiconductor switches used in manufacturing of inverters to compensate the effects of power quality events. These gating signals for the semiconductor switches can be controlled implementing PWM (Pulse Width Modulation) technique, Space Vector Pulse Width Modulation (SVPWM), hysteresis controllers and adaptive control techniques [12-17].

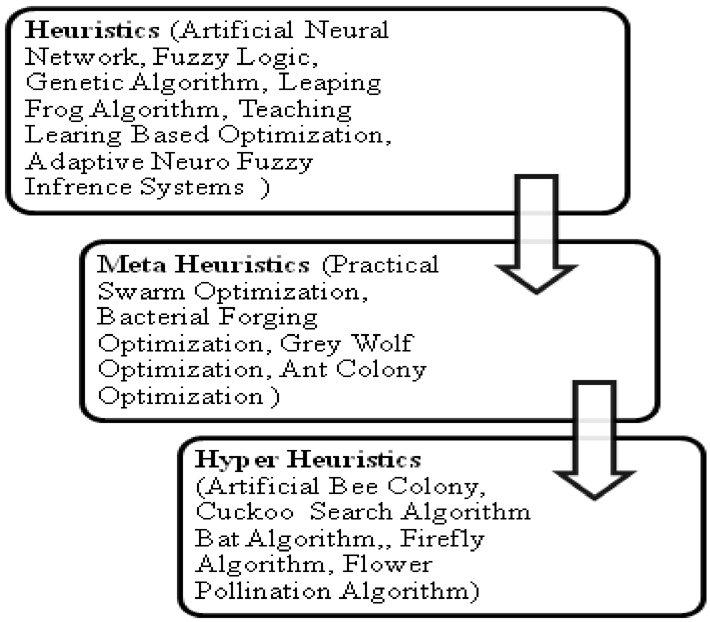

Figure 3 Bio-inspired Control Algorithms

With the advancement of control technologies the artificial intelligence based machine learning and bio inspired algorithms tries to replicate the biological organisms to achieve high level of power system stability. This section is dedicated to the evolution from heuristic, meta heuristic to hyper heuristic algorithms presented in figure 3 for finding the optimal solution for power quality issues and for the efficient operation of the system [20].
Artificial neural network (ANN) and fuzzy logic based algorithms are used to detect the features of nonlinearities in the system to provide the effective solution and for probabilistic prediction. The rules are extracted based on the supervised and unsupervised learning patterns of the system under training. The deep learning neural network models are also being implemented to train the systems for reliable operation [21-23].
The genetic algorithm (GA) is a multi objective decision making algorithm to handle the load balancing, intrusion detection, formulation of fitness function etc. The leaping frog algorithm (LFA) is advantageous to use for the timely and cost effective solutions to the system controlling. The shuffled leaping frog is extension of the LFA for the effective and timely solution. The quality of the solution depends upon the range of feasibility point of the system [24]. The Teaching learning based optimization (TLBO) algorithm is a popular and powerful optimization algorithm provides high quality solution to get the stable convergence [26].

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It consists of two phases' i.e teacher and learner applied to optimally control the controller parameters. The adaptive neuro-fuzzy inference system (ANFIS) navigates the change in load conditions and responds at faster than the other controlling techniques to normalize the controller parameters. The progress heads to the meta-heuristic algorithms and the practical swarm optimization (PSO) algorithm is used for the finding the solutions to the power system problems such as load scheduling, thresh-holding and power flow affecting the overall system response [25]. The bacterial foraging algorithm (BFA) facilitates easy implementation but the convergence speed and accuracy of the algorithm for power system problems is poor compare to the other techniques [27].

The grey wolf optimization (GWO) has the supremacy on other methods due to fast convergence but the pattern followed by this approach is complex in the larger ring type distribution systems. The ant colony optimization (ACO) algorithm can tackle mixed variable problems and problems related to economic dispatch, target tracking, multilevel feature extraction of dynamic system etc. The hyper heuristic approaches have predominance due to high scalability and the intensification process can be controlled by stochastic and greedy selection method.

Furthermore the artificial bee colony (ABC) algorithm address multidimensional and multi objective optimization problems and the performance of this approach for both local and global selection are appreciable. The cuckoo search (CS) algorithm deals with the multi-objective, gradient based, gradient free, load allocation and phase equilibrium problems [22]. It is used in the situations where objective function evaluations are complex computationally.

The bat algorithm (BA) is used for the structural design optimization, classification, clustering parameter optimization, vector matching and constrained optimization. The firefly algorithm (FA) solves the multimodal functions, both continuous and discrete search problems. This is a popular method because of less computational complexity and used deterministic signals instead of constants.

The flower pollination algorithm (FPA) is used in almost all the areas of engineering applications for local and global optimization problems [28]. All the mentioned algorithms can be clubbed with other methods such as pattern recognition , rough set theory, Levy's flights, cellular learning automate etcetera to make the hybrid approaches for the better results as the application area in power system.

Conclusion

The integration of UHC in distribution power system is interesting to obtain the uninterrupted power supply and simultaneously deals with the reliability and stability of the system. The control of UHC with various methods gives insight into the reference and gate signal generation. The bio inspired approaches are effective and result oriented. Furthermore, the controlling algorithms presented in this paper have witnessed lot of attention for solving the real time issues related to power system. The strategic decision making by the algorithms saves the system performance and stability. The newly emerging technologies in this field contribute in addressing the highly complex system problems.

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