POWER QUALITY IMPROVEMENT USING FUZZY LOGIC CONTROLLER BASED CMLI AND FACT DEVICES FOR MODERN POWER SYSTEMS

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ABSTRACT

Modern power systems are highly complex and are designed as such to fulfil the growing demands of power with better power quality. And electrical power quality had obtained more attention in power engineering in recent years. But due to faults in power systems many power quality problems including voltage sags and swells, harmonics and reactive power burden etc., are taking place which are effecting the power quality and stability of power supply etc.,. The fuzzy logic controller can easily demonstrate a better dynamic behaviour of the system. The CMLI and FACT devices have the capability to reduce the power quality problems. Therefore, the fuzzy logic controller based CMLI and FACT devices improve the power quality by considerably reducing THD as prescribed by IEEE-519 standard. This paper presents MATLAB/SIMULINK circuits of fuzzy logic controller based CMLI and FACT devices which can improves the power quality for modern power systems.

KEYWORDS: Power Quality, Power Quality Problems, Fuzzy Logic Controller, CMLI, FACT Device and PWM Technique

INTRODUCTION

The power quality problems include high reactive power burden, harmonics currents, load unbalance, excessive neutral current etc. Electrical Power Quality had obtained more attention in power engineering in recent years. Traditionally, current harmonics caused by non-linear loads have been dealt with using passive filters. They provide simple solutions but, very often, have large size and weight, they cannot provide flexible compensation. Moreover, the passive filters are known to cause resonance, thus affecting the stability of the power distribution systems [1]. The increased severity of harmonic pollution in power networks has attracted the attention of power electronics and power system engineers to develop dynamic and adjustable solutions to the power quality problems. Now-a-days due to usage of many non-linear loads and other faults like L-G, L-L and etc., The power quality is affecting more.

This paper deals with many technologies which are collectively improving the power quality. Due to occurring of faults in power systems the stability of the voltage get distorted which is commonly called voltage instability. Voltage instability is the inability of the power system to meet the demand for reactive power in the heavily loaded system. One of the most important causes of voltage instability in a system is the occurrence of reactive power imbalance in the system. Reactive power imbalance occurs when system is faulted, heavily loaded and voltage fluctuation is there. This problem can be effectively tackled by the introduction of high power electronic controllers which can inject or absorb reactive power as per system requirement. One of the most important reactive power sources is FACTS (Flexible A.C
The multilevel inverter has gained much attention in recent years due to its advantages in lower switching loss, better electromagnetic compatibility, higher voltage capability, and lower harmonics. Multilevel cascaded inverters have been also proposed for such applications as static Var generation, an interface with renewable energy sources, and for battery-based applications [3]. The inverter could be controlled to either regulate the power factor of the current drawn from the source or the bus voltage of the electrical system where the inverter was connected. Several topologies for multilevel inverters have been proposed, the most popular being the diode-clamped, flying capacitor, and cascade H-bridge structures. The pulse width modulation (PWM) cascaded multilevel inverter strategy reduces the total harmonic distortion and enhances the fundamental output voltage.

The control scheme, in which the required compensating currents are determined by sensing line currents only, is given in, which is simple and easy to implement. Recently, fuzzy logic controllers have generated a great deal of interest in various applications and have been introduced in the power-electronics field. The mamdani type of fuzzy controller used for the control of DSTATCOM gives better results compared with the PI controller. On the other hand, the takagi-sugeno fuzzy controller may also have following features [4].

- Number of fuzzy sets used for input fuzzification
- Number of rules to be used
- Number of coefficients to be optimized
- Computation time

The settling of dc capacitor voltage to its reference value is quite important in the context that at this condition, the real power balance between the source and load is realized. Therefore, apart from the reduction in Total Harmonic Distortion (THD), there is also a need to bring back the dc voltage as early as possible to its reference value. In this chapter, a mamdani type of fuzzy logic controller has been implemented for a three-phase DSTATCOM the power system’s power quality. The mamdani type fuzzy controller can provide a wide range of control gain variation and it can use both linear and nonlinear rules in the consequent expression of the fuzzy rule base. In this thesis, through the simulation results, it is shown that the mamdani type fuzzy controller has improved the dynamic response of the system.

**FUZZY LOGIC CONTROLLER**

**Introduction**

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The fis system is shown in figure 1. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves membership functions, fuzzy logic operators, and if-then rules. Two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox are,

- Mamdani type
- Sugeno type
Mamdani type inference expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership function rather than a distributed fuzzy set. This type of output is sometimes known as a singleton output membership function, and it can be thought of as a pre-defuzzified fuzzy set [5]. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general mamdani method, which finds the centroid of a two-dimensional function. Rather than integrating across the two-dimensional function to find the centroid, we use the weighted average of a few data points. Sugeno-type systems support this type of model. In general, Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant.

Figure 1: FIS System

Basic Fuzzy Algorithm

In a fuzzy controller as shown in figure 2, the control action is determined from the evaluation of a simple linguist rules. The development of the rules requires a thorough understanding of the process to be controlled but it does not require a mathematical model of the system.

Figure 2: Schematic Diagram of FLC

A fuzzy controller consists of fourth stages: fuzzification, knowledge base, inference mechanisms, and defuzzification. The knowledge base is composed of a data base and rule base, and is designed to obtain good dynamic response under uncertainty in process parameters and external disturbance. The data base, consisting of input and output membership functions, provides information for the appropriate fuzzification operations, the inference mechanism,
and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, defuzzification is used to convert the fuzzy outputs into control signals [6].

In order to implement the control algorithm of a SAPF in closed loop, the optimum value of \( K \) gain is calculated by a fuzzy inference system, which receives as inputs the slope of D.C. average bus voltage and D.C. voltage error. Both quantities (error and slope of DC voltage) are normalized by suitable values. Thus, each range is between -1 and 1 normalized unity. Tacking into account that the value of \( K \) is quite near unity, we consider the range of the output weight membership function between 0.6 and 1.4. We have chosen to characterize this fuzzy controller by seven and five sets respectively for the error and slope inputs. The output is defined by seven sets. The D.C. voltage error normalized, the D.C. voltage slope normalized and the output weight membership functions are shown in figure 3. The linguistic rules for the fuzzy logic controller are chosen, in most cases, depending only of the D.C. voltage error.

The desired switching signals, according to output inverter currents to follow the reference ones, a current control is made by fuzzy logic controller. The inputs variables for the necessary control action of active filter are the error and the rate change of error between the reference signal and the active filter output current. The membership functions are showed in figure 2. The current control method used in this thesis is related to fuzzy controller based PWM current controller. The switching signals are generated by means of comparing a carrier signal with the output of the fuzzy controller.

The error ‘\( e \)’ and the change of error ‘\( ce \)’ are used as numerical variables from the real system. To convert these numerical variables into linguistic variables, the following seven fuzzy sets are used: NL (Negative Large), NM (Negative Medium), NS (Negative Small), Z (zero), PS (Positive Small), PM (positive medium) and PL (Positive Large).

The fuzzy controller is characterized as follows:

- Seven fuzzy sets for each input and output
- Triangular membership functions for simplicity
- Fuzzification using continuous universe of discourse
- Implication using mandani type inference system
- Defuzzification using weighted average method
Design of Control Rules

The fuzzy control rule design involves defining rules that relate the input variables to the output model properties as FLC is independent of the system model. The design is mainly based on the intuitive feeling for and experience of the process.

The control rules are formed by using the table 1. The elements of the table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse input / output, small errors need fine control, which requires fine input / output variables. Based on this, the elements of the rule table are obtained from an understanding of the filter behaviour and modified by the simulation performance [7].

Table 1: Fuzzy Control Rules

<table>
<thead>
<tr>
<th>D.C. voltage error</th>
<th>D.C. voltage slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL</td>
<td>NM</td>
</tr>
<tr>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Z</td>
<td>Z</td>
</tr>
<tr>
<td>PS</td>
<td>PS</td>
</tr>
<tr>
<td>PM</td>
<td>PM</td>
</tr>
</tbody>
</table>
Rule Editor (Fuzzy GUI Tool)

Based on the descriptions of the input and output variables defined with the FIS Editor, the Rule Editor allows to construct the rule statements automatically, by clicking on and selecting one item in each input variable box, one item in each output box, and one connection item. Choosing none as one of the variable qualities will exclude that variable from a given rule. Choosing not under any variable name will negate the associated quality. Rules may be changed, deleted or added by clicking on the appropriate button. The rule editor is shown in figure 4.

![Rule Editor](image)

Figure 4: Rule Editor

The surface viewer of above rules is shown in figure.

![Surface Viewer](image)

Figure 5: Surface Viewer

MULTILEVEL INVERTER TOPOLOGIES

The multilevel converter has drawn tremendous interest in the power industry. The general structure of the multilevel converter is to synthesize a sinusoidal voltage from several levels of voltages, multilevel voltage source converters are emerging as a new breed of power converter options for high power applications. These converter topologies can generate high-quality voltage waveforms with power semiconductor switches operating at a frequency near the fundamental. Multilevel topologies are able to generate better output quality, while operating at lower switching frequency. This implies lower switching dissipation and higher efficiency. Moreover, this topology utilizes switches with lower breakdown voltage; therefore, it can be used in higher power applications at lower cost. Compared to the multi pulse converter, multilevel converters are more flexible and have a wide application. They can be used as active power filters.
and to handle unbalanced loads. No phase shift transformer is required in this configuration, so a lower investment cost, plus a lower power loss, can be expected [8].

The multilevel converter configuration can be further classified into three different configurations:

- Diode-clamped converter
- Flying capacitor converter
- Cascaded converter.

Compared to the multi pulse converter, multilevel converters has many advantages. They can be used as active power filters and to handle unbalanced loads. No phase shift transformer is required in this configuration, so a lower investment cost, plus a lower power loss, can be expected. The multilevel converter configuration can be further classified into three different configurations. Among the available multilevel converter topologies, the cascaded multilevel inverter constitutes a promising alternative, providing a modular design that can be extended to allow a transformer less connection. The cascaded H-bridge multilevel Inverter uses separate dc sources (SDCSs). The multilevel inverter using cascaded-inverter with SDCSs synthesizes a desired voltage from several independent sources of dc voltages, which may be obtained from batteries, fuel cells, or solar cells. In Cascaded multilevel inverter inverters are connected in series [9]. Each H-bridge converter unit provides three voltage levels (-V, 0, V). As number of levels increases the output waveform becomes perfect. The cascaded multilevel inverter is as shown in figure 6.

![Figure 6: Cascaded Multilevel Inverter](image)

Compared with the other two multilevel configurations and the multi pulse converter, the cascaded converter eliminates clamping diodes, flying capacitors, bulky zigzag transformer and requires least component mountings. The modularity of this configuration makes it much easier to implement converters with a large number of levels. Larger dc-side capacitors are required compared to the diode clamped and flying capacitor converter under balanced condition but it provides separate phase control to support significant voltage unbalance [10]. The output waveform of cascaded five level inverter is shown in figure 7.

![Figure 7: Typical Output Waveform of Cascaded Five Level Inverter](image)
FACTS

A Flexible AC Transmission System (FACTS) is an ac transmission system incorporating power electronic-based or other static controllers which provide better power flow control and enhanced dynamic stability by control of one or more ac transmission system parameters (voltage, phase angle. and impedance). Two of the most important FACTS devices, which have broad application in electric utility industry, are SVC (Static Var Compensator) and DSTATCOM (Distributed Static synchronous Compensator) [11]. DSTATCOM, also named ASVG (Advanced Static Var Generator) is one of the new-generation FACTS devices, and recognized to be one of the key technologies in future power system. DSTATCOM has played an important role in power industry since 1980s. The DSTATCOM is basically a DC-AC voltage source converter with an energy storage unit, usually a DC capacitor [12]. It operates as a controlled Synchronous Voltage Source (SVS) connected to the line through a coupling transformer. Figure 8 shows the schematic configuration of DSTATCOM. The controlled output voltage is maintained in phase with the line voltage, and can he control to draw either capacitive or inductive current from the line in a similar manner of a synchronous condenser, but much more rapidly.

![Schematic Configuration of DSTATCOM](Figure 8: Schematic Configuration of DSTATCOM)

Compared to SVC and other conventional reactive power compensators, DSTATCOM has several advantages listed below.

- DSTATCOM has a dynamic performance far exceeding the other Var compensators. The overall system response time of DSTATCOM can reach 10ms or less.
- DSTATCOM has the ability to maintain full capacitive output current at low system voltage, which also makes it more effective than SVC in improving the transient stability.
- Compared with SVC, DSTATCOM can easily realize redundancy design, which brings a higher reliability. IGCT, IGBT, used in DSTATCOM, require simpler gate drives and snubber circuits, and also make DSTATCOM more reliable [13].
- STATCOM has a smaller installation space, about 50% of that for SVC.

PWM TECHNIQUE

This modulation technique can be used to encode information for transmission. The below notches can be form based on the following equations. If the notches are more then the reduction process of harmonics is easy. This pulse width modulation provides that facility.
When $V_{\text{control}} > V_{\text{tri}}$, $V_{A0} = V_{dc}/2$. 

When $V_{\text{control}} < V_{\text{tri}}$, $V_{A0} = -V_{dc}/2$. 

Figure 9: Pulse Width Modulation

Figure 9 shows the pulse width modulation. In general, a multilevel inverter with $m$ voltage levels requires $(m-1)$ triangular carriers. In the PWM, all the triangular carriers have the same frequency and the same peak-to-peak amplitude, but there is a phase shift between any two adjacent carrier waves, given by $\phi_c = 360\degree/(m-1)$. The modulating signal is usually a three-phase sinusoidal wave with adjustable amplitude and frequency. The gate signals are generated by comparing the modulating wave with the carrier waves [14]. It means for five-level inverter, four triangular carriers are needed with a 90° phase displacement between any two adjacent carriers. In this case the phase displacement of $V_{c1} = 0\degree$, $V_{c2} = 90\degree$, $V_{c3} = 180\degree$ and $V_{c4} = 270\degree$.

MATLAB/SIMULINK CIRCUITS AND RESULTS

The power quality is increasing by decreasing the THD value, this can be done by increasing the number of levels of CMLI. If the number of levels of CMLI increases the desired output waveform will have good sinusoidal shape. The combination of CMLI with fuzzy logic controller and DSTATCOM will give the effective results.

As we know that if number of levels increases harmonics effect reduces which means that we can get better sinusoidal waveform. By comparing five, seven, nine and eleven level cascaded multilevel inverters, ninth level inverter is effective and efficient to get expected smoother sinusoidal waveform which helps us to enhance the power quality.

Matlab/Simulink Circuits

The figure 10 shows the matlab circuit of fuzzy logic controller.

Figure 10: Fuzzy Logic Controller
The matlab/simulink circuit of seven level cascaded multilevel inverter is shown in figure 11.

![Figure 11: Level CMLI](image1)

The matlab/simulink circuit of phase shift pulse with modulation is shown in figure 12.

![Figure 12: Circuit of PWM](image2)

The matlab/simulink circuit of seven level cascaded multilevel inverter without distributed static synchronous compensator is shown in figure 13.

![Figure 13: Circuit of CMLI and DSTATCOM Device Using Fuzzy Logic Controller](image3)
Matlab/Simulink Results

The matlab/simulink results of seven level cascaded multilevel inverter based distributed static synchronous compensator using fuzzy logic controller is shown in figure 14.

![Matlab/Simulink Results](image)

**Figure 14: Waveforms of Source Current, Source Voltage and Load Current**

The harmonic spectrum of seven level cascaded multilevel inverter based distributed using phase shift pulse width modulation and fuzzy logic controller is shown in figure 15.

![Harmonic Spectrum](image)

**Figure 15: Harmonic spectrum of CMLI Based**

CONCLUSIONS

The proposed fuzzy logic controller based cascaded multilevel inverter and distributed static synchronous compensator can correct the unbalance voltage in three phase system under different loading conditions. Fuzzy Logic Control based DSTATCOM is used to compensate reactive power and harmonics, produced in the case of a non-linear loads. The THD measure in the presence of a FLC based CMLI (Seven levels) and DSTATCOM is within the IEEE-519 harmonics standard. The Fuzzy Logic Controller based DSTATCOM demonstrates a better dynamic behaviour than conventional methods. It does not require any mathematical model of the system and can also work with imprecise inputs.
Therefore, the fuzzy logic controller based CMLI and DSTATCOM gives 4.03% THD which improves the power quality by considerably reducing THD as prescribed by IEEE-519 standard.

REFERENCES