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MODELLING OF ELECTRIC ARC FURNACE AND CONTROL ALGORITHMS USING DSTATCOM WITH FUZZY LOGIC FOR IMPROVEMENT OF POWER QUALITY

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ABSTRACT

Arc furnace represents one of the most intensive and disturbing loads in the electric power system concerned about. Electric arc furnace can go from zero to full load many times an hour as arc struck and broke in the furnace. Voltage flicker, a phenomenon of annoying light intensity fluctuation is a major concern for both power companies and customers. These fluctuation contribute to the voltage variation in the electrical distribution system causing flicker. Therefore, an accurate model of an arc furnace is needed to test and verify proposed solutions to this end. This paper, presents the results of a study, where furnace arc is modelled using both chaotic and deterministic elements. Voltage fluctuations (Sag), is captured using the well-studied circuit whereas a dynamic model in the form of differential equation is used for the electric arc. Simulation model is analyzed using Fuzzy Logic.

KEYWORDS: Electrical Arc Furnace (EAF), Flicker Mitigation, Power Quality, Reactive Power, DSTATCOM, p-q Theory, d-q Theory

INTRODUCTION

Power quality (PQ) issues, especially current harmonics, current unbalance and voltage unbalance, voltage sags, and poor power factor, have drawn much attention and much research work has been performed in this area. VOLTAGE sags are regarded as one of the most harmful power-quality (PQ) disturbances due to their costly impact on industrial processes. Another PQ problem is a poor power factor to the incoming utility. This is caused by the proliferation of induction motors, thyristor rectifiers, and other nonlinear power electronics loads such as variable speed ac drives. Variation of load and diversity profiles over a day can result in wide variation in the reactive and harmonic VARs consumed by the plant.

Most utilities have strict regulations concerning the plant's power factor, often requiring the use of switched shunt capacitor banks to improve the net power factor close to unity. Significant penalties are levied on plants that do not comply with the power factor requirements. The issue of harmonic pollution is more complex. While IEEE 519, first formulated in 1982, specifies maximum harmonic current levels at the point of common coupling (PCC), there is no movement to enforce it, unless it interferes with the neighbouring loads. This is primarily because the cost of compliance has been fairly high. One means of correcting these power quality problems is to provide non-active power compensation by a parallel compensator.

Electric Arc Furnace (EAF) is a widely used device in metallurgical and processing industries. It is a nonlinear time varying load, which can cause many problems to the power system quality such as unbalance, harmonic inter harmonic and voltage flicker. Thus study of electric arc furnaces has potential benefits for both customers and utilities. An accurate modelling of an EAF will help in dealing with the problems caused by its operation. Minimization of the undesirable impact of EAFs can improve electric efficiency and reduce power fluctuations in the system.

The description of an arc furnace load depends on the following parameters: arc voltage, arc current and arc length (which is determined by the position of the electrodes). Based on the study of above essential parameters, many models are set up for the purpose of harmonic and flicker analysis. In general, they may be classified as follows:-

- Time domain analysis method (Characteristic Method, Time Domain Equivalent Nonlinear Circuit Method), and
- Frequency domain analysis method (Harmonic Voltage Source Model, Harmonic domain Solution of nonlinear differential equation). Each method has its own advantages and disadvantages

DSTATCOM

The DSTATCOM is a shunt-connected device, which can mitigate the current related power quality problems. The flicker mitigation techniques for EAF loads have used a simple and an approximate model of an EAF. In the present work a DSTATCOM is used for flicker mitigation. The EAF model chosen for the study is an accurate representation based on the non-linear V-I characteristic of arc furnace. In this paper the DSTATCOM controller is based on Instantaneous Reactive Power (IRP) theory and Synchronous Reference Frame (SRF) theory for Compensation of reactive power. This controller aids in the Mitigation of voltage flicker due to Electric Arc Furnace. The control methods are compared with simulation studies using Sim Power System model of DSTATCOM in FUZZY environment. Studies have demonstrated the effectiveness of these control philosophies of DSTATCOM for voltage flicker mitigation.

Operating Modes of D-STATCOM

This is shunt connected device operates in two control modes

Current Control

In this mode D-STATCOM acts as active filter, power factor controller, load balance etc. These functions are called load compensation.

Voltage Control

In this mode a D-STATCOM can regulate voltage against any distortion, Sag/ Swells, unbalance and even short duration interruptions.

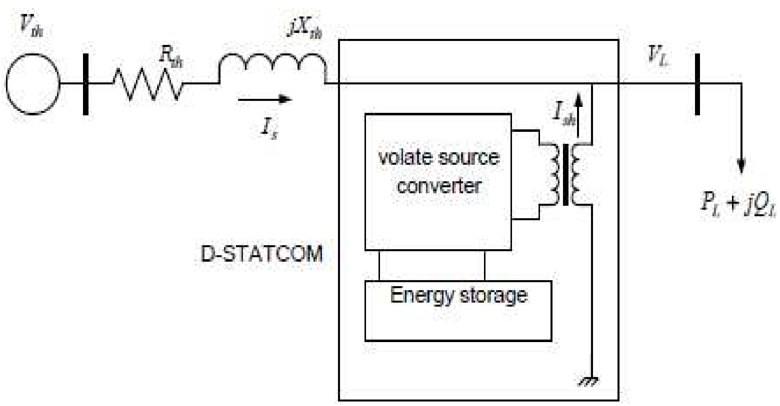

Figure 1

Voltage Sag Correction by D-STATCOM

The schematic diagram of a D-STATCOM is shown in Figure 1. In this diagram, the shunt injected current corrects the voltage sag by adjusting the voltage drop across the system impedance Z. The value of current can be controlled by adjusting the output voltage of the converter. The shunt injected current can be written as:

$I_{sh} = (I_L - I_S) = I_L - (V_{TH} / Z_{TH})$ (1)

$V_L = V_L$

$I_{sh} = I_{sh} \angle\eta$

$I_L = I_L \angle\text{-}\varphi$

$V_{TH} = V_{TH} \angle\delta$

$Z_{TH} = Z_{TH} \angle\beta$

Put this value in equation (1)

$I_{Sh}\angle\eta = I_L\angle\text{-}\ \varphi - (V_{TH} \angle\delta - V_L \angle 0) / Z_{TH} \angle\ \beta)$

$I_{Sh} \angle\eta = I_L\angle\text{-}\ \varphi - (V_{TH} \angle(\delta\text{-}\ \beta) / Z_{TH}) + (V_L \angle\text{-}\ \beta)/ Z_{TH}$ (2)

The complex power injection of the D-STATCOM can be expressed as

$S_{Sh} = V_L\ I_{Sh}\ \boldsymbol{*}$ (3)

It may be mentioned here that the effectiveness of the D-STATCOM in correcting voltage sag depends on the value of Z or fault level of the load bus. When the shunt injected current I is kept in quadrature with the desired voltage correction can again be achieved without injecting any active power into the system. On the other hand when the value of is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system.

The Proposed Fuzzy Logic Controller

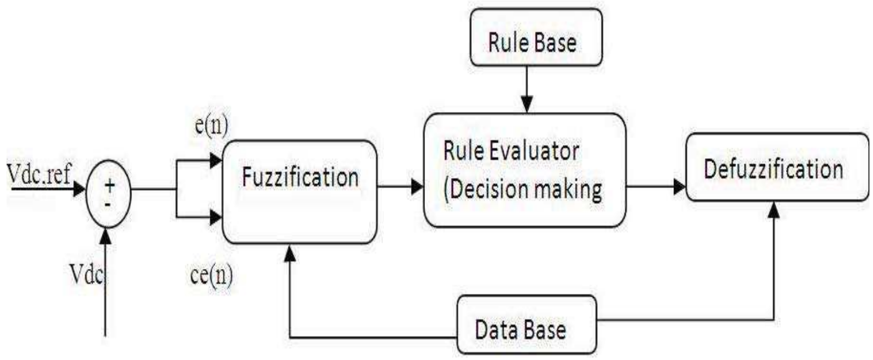

Figure 2

The performance of Fuzzy logic controller is well documented for improvements of both transient and steady State performances. The function of fuzzy logic controller is very useful since exact mathematical model of it is Not required. The fuzzy logic control system can be divided into four main functional blocks namely Knowledge base, Fuzzification, Inference mechanism and Defuzzification, Rule base Fuzzification. The knowledge base is composed of data base and rule base. Data base consists of input and output membership functions and provides information for appropriate fuzzification and defuzzification operations. The rule-base consists of a set of linguistic rules relating the fuzzified input variables to the desired control actions. Fuzzification converts a crisp input signal, the error (e), and error change (Δe) into fuzzified signals that can be identified by level of membership in the fuzzy sets. The inference mechanism uses the collection of linguistic rules to convert the input conditions to fuzzified output. Finally, the defuzzification converts the fuzzy outputs to crisp control signals, which in the system acts as the changes in the control input.

CONCLUSIONS

Harmonics is an issue that will continue growing in the future due to the wide use of solid state devices for control and energy conservation purposes. Also, electric arc furnace load used in steelmaking facilities is considered one of the most important nonlinear loads in industrial systems, which produces a considerable amount of harmonics. Finally, the paper illustrated the possibility of severe harmonic distortion in case of applying capacitor banks alone without series tuned reactor. Therefore, using capacitor banks in harmonic environment should be accomplished with thorough analysis prior to installation.

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