Energy Management with TCSC Controller of Electric Arc Furnace for Harmonic Analysis in Power Quality Disturbance Using Continuous Wavelet Transform

Chamni Jaipradidtham
Dept.of Electrical Engineering, Faculty of Engineering
Kasem Bundit University, 1761 Pattanakarn Road
Suan Luang, Bangkok, Thailand, 10250
e-mail: j_chamni@hotmail.com

Mongkol Klaphachol
Dept.of Management, Faculty of Business Administration
Kasem Bundit University, 1761 Pattanakarn Road
Suan Luang, Bangkok, Thailand, 10250
e-mail: mongkol.kla@kbu.ac.th

***Abstract*---This paper presents a new control method for AC-fed electric arc furnaces (EAFs) of the metal and steel industry for harmonic analysis with controller of energy management process of the steel ladle thermal condition using continuous wavelet transform (CWT), which consists of a shunt active filter and passive components for mitigating voltage and current disturbances arising from an electric arc furnaces. This model is based on the V-I characteristic of the arc and takes into account the effect. In this paper presents, results of measurement under severe steelmaking working cycles of ladle preheating thermal condition for an analytical control with used thyristor controlled series capacitor (TCSC) controller, is proposed to enhance the transient stability of EAFs are extended into larger levels, and control of EAFs have been traced over time domain. Simulation results obtained with EAF model are compared for the spectrum harmonics for energy management is TCSC controller**

Keywords---Electric arc furnace, harmonics, TCSC controller, continuous wavelet transform, energy management

I. INTRODUCTION

The electric arc furnaces are used for melting and refining metals, mainly iron in the steel production. Nowadays, arc furnaces are designed tor very large power input ratings and due to the nature of both, the electrical arc and the meltdown process these devices. Nonlinear loads are the principal cause of power quality problems including voltage dips, harmonics distortion, flicker and voltage imbalance [1]. The voltage and current signals characteristic of the arc is nonlinear, what can cause harmonic currents analysis, when circulating using the electric, which can produce harmonic voltages and can affect other users. The AC-fed EAFs should be categorized into an unbalanced, excessively nonlinear and time varying load.

Harmonic analysis techniques of the AC-fed electric arc furnace using CWT are quite costly concerning computation domain time, and those which are accomplished on a single line diagram circuit are not quite exact concerning harmonic content, mainly the magnitude of zero sequence components, system is supported by a control of TCSC controller scheme that holds line impedances into stability. The furnace shell is isolated, if a three-phase arc furnace operation were balanced. The zero sequence components of the current wave would be null and this produces zero sequence of harmonics in the arc current, which these harmonic components do not reach the values that we would find in the current wave of operation arc [2-4]. The accuracy harmonic spectrums are achieved by the continuous Fourier transform (CFT).

II. ENERGY MANAGEMENT WITH TCSC CONTROL OF EAFS

The electrical power arrives at the studied. The hybrid energy control system studied in this work includes a diesel generator coupled with a inverter to supply a load profile demand. In the following subsection, the different energy management strategies studied are described. This strategy called "Inverter ON/OFF control" to TCSC control the hybrid system by switching ON the inverter according to climate conditions and load variation. In Fig. 1 shows the flowchart of this control strategy. As displayed in Fig. 1, the inverter is switch OFF when the remaining power to be supplied by the diesel generator is less than its minimal output power values, to overcome this drawback, we proposed in what as follows two new strategies, which aim to achieve more energy system integration in the energy management systems.

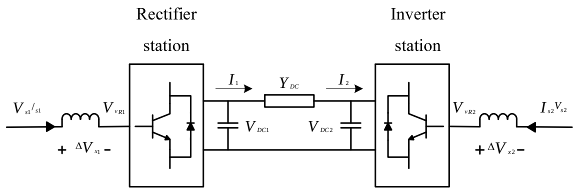

Fig.1. Schematic diagram of an HVDC-VSC transmission link

978-1-4799-4075-2/14/$31.00 © 2016 IEEE

The equivalent circuit shown in Fig. 2 is used to derive the mathematical model of the HVDC-VSC for inclusion in the power flow Newton-Raphson method. The complex voltage sources representing the two VSC stations in the HVDC-VSC link are:

$$V_{vR1} = |V_{vR1}| \angle \delta_{vR1} \tag{1}$$

$$V_{vR2} = |V_{vR2}| \angle \delta_{vR2} \tag{2}$$

If it is assumed that the power flows from the station connected at node *l* (rectifier) to the station connected at node *m* (inverter). The power flows into the rectifier are described by the following equations:

$$P_{vR1} = |V_{vR1}|^2 G_{vR1} - |V_{vR1}||V_l| \{ G_{vR1} \cos(\delta_{vR1} - \theta_l) + B_{vR1} \sin(\delta_{vR1} - \theta_l) \} \tag{3}$$

$$Q_{vR1} = |V_{vR1}|^2 B_{vR1} - |V_{vR1}||V_l| \{ G_{vR1} \sin(\delta_{vR1} - \theta_l) + B_{vR1} \cos(\delta_{vR1} - \theta_l) \} \tag{4}$$

This control strategy based on inverter switching TCSC is the simplest approach to controller energy penetration on a hybrid system. However this approach could lead to a waste of a significant amount of the energy produced.

For the performance evaluation of the electrical energy management strategies proposed, the mathematical model of each component of the hybrid power system considered for the simulation is necessary. These models are presented in subsequent sections.

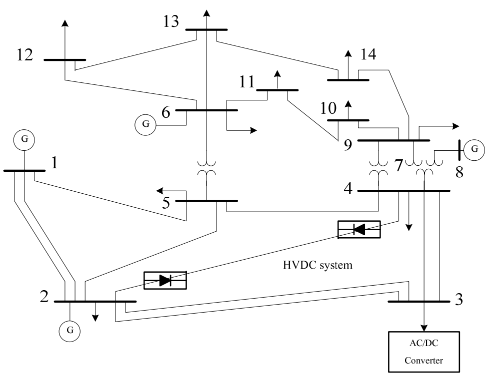

Fig.2. Single line diagram of the AC-fed arc furnace model

TCSC controller for devices are model based on voltage source converter (VSC) modules, the HVDC consists of two or more VSCs with a common DC-link. Each for VSC can provide series compensation for the selected line of system.

III. Thyristor Controller Series Capacitor (TCSC) Model Connected With Arc Furnace

AC-fed electric arc furnace (EAF) should be categorized into an unbalanced, excessively nonlinear and time. Heating effects of harmonic in distribution components are capacitor and insulation failure due to harmonic resonance. A TCSC dynamic model can be expressed as follows [4]:

$$X_{TCSC}(t) = \frac{1}{T_C}\left(-X_{TCSC}(t) + X_{TCSCO} + K_T U_C(t)\right) \tag{5}$$

where $X_{TCSC}(t)$ is the reactance controlled by the TCSC regulator, T_C is the time constant of TCSC, X_{TCSCO} is initial value of $X_{TCSC}(t)$ and K_T is the gain of TCSC regulator.

In this strategy, and whenever the energy management is higher than the load demand or the DG is in a situation to operate under its minimal output value, the controllable loads are connected to the system to consume the surplus of energy generated and consequently allow, the DG to operate up its minimal output set point. The flowchart of the TCSC control strategy developed in this case is displayed in Fig. 3.

$$i_{sd}^* = \frac{2}{3} \frac{(P_s^* V_{sd} - Q_s^* V_{sq})}{V_{sd}^2 + V_{sq}^2} \tag{6}$$

$$i_{sq}^* = \frac{2}{3} \frac{(P_s^* V_{sq} - Q_s^* V_{sd})}{V_{sd}^2 + V_{sq}^2} \tag{7}$$

Thus, the average power of the DC link could be calculated as (8) with respect to (7)

$$P_{dc} = V_{dc} i_{dc} = -C V_{dc} V_{dc}^* = \frac{1}{2} C \frac{d}{dt}\left(V_{dc}^2\right) \tag{8}$$

where C, V_{dc}, i_{dc} are capacitance, voltage and current of the DC link, respectively [5-7]. From (8) it is concluded that the dynamics of the DC link is:

$$\frac{d}{dt} V_{dc}^2 = -2 / C\left(P_{se} + P_{sh}\right) \tag{9}$$

where P_{se}, P_{sh} and P_{dc} are active powers of the series and shunt converters and DC link power, respectively [8]. Thus neglecting the converter losses [3], P_{dc} could be calculated as given in (10).

$$P_{dc} = P_{se} + P_{sh} \tag{10.1}$$

and

$$P_{dc} = \frac{3}{2}\left(V_{sed}i_d + V_{seq}i_q\right) + \frac{3}{2}\left(V_{shd}i_d + V_{shq}i_q\right) \quad (10.2)$$

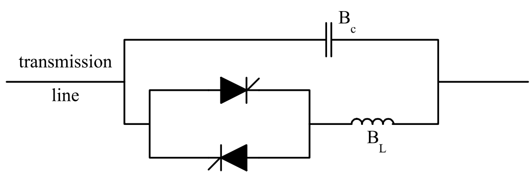

Fig.3. Single line diagram of the arc furnace of TCSC controller

IV. HARMONIC ANALYSIS OF WAVELET TRANSFORM

An algorithm based of the filter banks in Discrete Wavelet Transform (DWT) is developed to effectively analysis short duration disturbance events to accurately obtain harmonic of the AC-fed electric arc furnace are frequencies, amplitude and phases. The DWT equation can harmonic analysis and the DWT of a signal x(t) is defined following state equations:

$$DWT(a,b) = \int_{t_1}^{t_2} d_j(n)\psi^*_{a,b}(n)\,dt \quad (11)$$

where

$d_j(n)$ is the decomposed output from the DWT
$\Psi(n)$ is the sampled mother wavelet
t_1 and t_2 are the start and end times of $\Psi(n)$
a, b are the scaling and time shifting of $\Psi(n)$

forms are based on a set of signal derived Wavelet trans shifting t by adjusting the timefrom a basic mother wavele parameters [9]. The WTD .CWT is derived from a

$$DWT(m,k) = \frac{1}{\sqrt{a_0^m}} \sum_{n=-\infty}^{+\infty} x(n)\, g\left(\frac{k - nb_o a_o^m}{a_o^m}\right) \quad (12)$$

where

$g(n)$ is the mother wavelet
$x(n)$ is the discritized signal function

This scaling gives the CWT, a logarithmic frequency coverage and this is in marked contrast to the uniform frequency coverage. By simple interchange of the variables n and k, and rearrangement of the DWT gives as shown in Fig. 4.

$$DWT(m,n) = \frac{1}{\sqrt{a_o^m}} \sum_k x(k)\, g\left(a_o^{-m} n - b_o k\right) \quad (13)$$

The discrete wavelet transform signal formula is given by

$$DWT(m,n) = \left(\sum_k x[k]\psi^*\left[\left(k - na_o^m b_o\right)/a_o^m\right]\right)/a_o^m \quad (14)$$

DWT can be easily and quickly implemented by filter bank techniques if the coefficients are thought of as a filter.

$$DWT(m,n) = C(i,j) = \sum_{n=0}^{N=1} x(n)\, 2^{-j/2} g\left(2^i n - j\right) \quad (15)$$

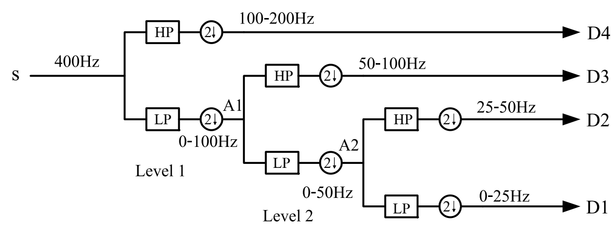

Fig.4. Architecture of a wavelet layer by neural networks

The wavelet functions is localized in time and frequency yielding wavelet coefficients at different levels, the CWT can isolate transient components in the upper frequency isolated in a shorter part of power frequency cycle. A DWT algorithm used a scheme of filters can be explained as shown in Fig. 4.

V. SIMULATION RESULTS

The numerical simulation results presented of the energy management systems is shown in Fig. 4 [10]. The harmonics are related to power rectifiers or converters with harmonic current components in percentage, as shown in Fig.5. The DC system impedances has been removed, and providing a direct coupling of the rectifier and inverter DC system. For in Fig.6 shows the characteristic harmonic voltages are present at about the same levels as those for the standard from CIGRE harmonics impedance 50 Hz models of the full HVDC-VSC link have demonstrated the computational performance of the power flow algorithm with incorporation of the HVDC-VSC models. Harmonic analysis results as shown Fig. 7 that the voltage waveforms contain mostly for integer harmonics. The voltage and current harmonics obtained for three phase are similar in frequencies and amplitudes, the DWT approach has been applied to investigate the characteristics of transients in three-phase distribution transmission lines. The data obtained from system tests and computer simulations were used to observe the variations. The MATLAB program was used to calculate DWT of the signals. We have shown a simple DWT compression technique by using a one-scale of compression scheme and the DWT of the signal, the Daubechies Db-4 type wavelet was used as a mother wavelet.

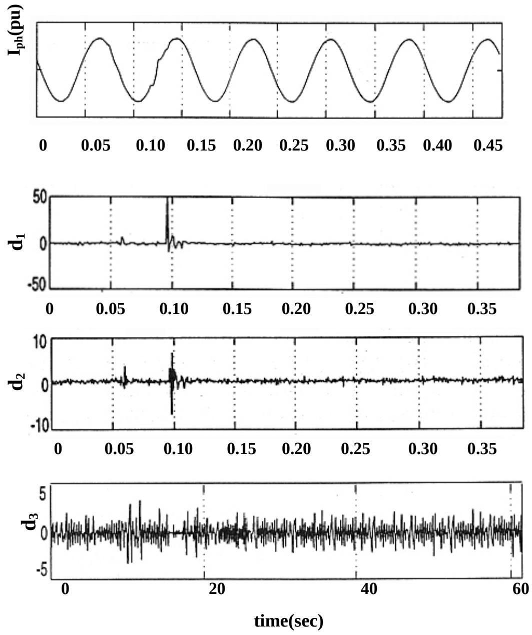

Fig.5. Results of harmonic with DWT current of the AC arc furnace

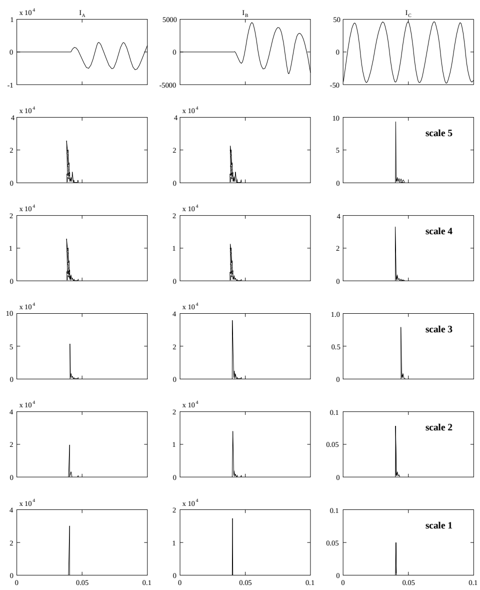

Fig.6. Spectrum harmonic current per phase of arc furnace by DWT

There are differences in levels of the others harmonics, the model validation is accomplished through continued simulation for different values of the arc length. A wavelet based technique for power system transients analysis was simulated using the ATP/EMTP program. Thus, the voltage and current harmonics obtained for three phase are similar in frequencies and amplitudes as shown in Table I and Table II. The DWT approach has been applied to investigate the characteristics of the TCSC controller in three-phase distribution transmission lines with the energy management of system.

TABLE I. VOLTAGE THD AT THE PCC AND ARC FURNACE

Harmonic at bus	THD % of Voltage
PCC* (Bus 2)	0.254
Arc furnace (Bus 4)	35.29

TABLE II. CURRENT THD AT THE PCC AND ARC FURNACE

Harmonic at bus	THD % of Current
PCC* (Bus 2)	2.07
Arc furnace (Bus 4)	15.63

*PCC is the point of common coupling of the EAF with TCSC controller.

VI. CONCLUSIONS

The proposed arc model for three-phase arc furnace simulation with circuit from harmonics of the energy management view is well adjusted to the real behavior. It takes into account the effect of the circuit configuration on the zero sequence components. The paper introduces a new technique that is based on DWT signal decomposition for classifying typical disturbances in systems. We have demonstrated the efficacy of continuous wavelet transform (CWT) methods in compressing actual disturbance signals. Numerical results on the energy management system with the HVDC-VSC have demonstrated the computational performance of the power flow algorithm with incurporation of the HVDC-VSC and harmonic impedances models. The results of the harmonics flow analysis due to system can be accurately.

REFERENCES

[1] Laver and Danai. “Statistical analysis of electric arc furnace parameter variation,” Proc. Inst. Elect. Eng., vol. 132, no. 2, pp. 82-93. Mar. 2012.

[2] M. Varan and Y. Uyaroglu, “Elimination of harmonic induced viable bifurcation with TCSC,” Journal Electrical Engineering, Turkey,vol.63, no. 5, pp. 303-309, 2012.

[3] J. Enrique, “Modeling and analysis of electric arc loads using harmonic domain techniques,” A thesis submitted to the University of Glasgow for the degree Doctor, Ortega- Calderon, October, 2008.

[4] Sayyed Mohammad Hashemi and et.al, "High-speed relay scheme for protection of transmission line in the presence of TCSC controller," *IET Gener. Transm. Distrib*., vol.8, pp.2083-2091, 2014.

[5] Y. Wang, Y.L. Tan and G. Guo, "The robust nonlinear co-ordinated generator excitation and TCSC controller for power systems," *IEE. Proc.Genter.Trans.Distri*., vol.149, no.3, pp.368-372, May 2002.

[6] Xiao-Ping Zhang,“ Multi voltage-sourced converter-based HVDC models for power flow.,” *IEEE Trans Power Syst*.,vol.19,no.4, Nov.2004.

[7] C. Angeles-Camacho *et al*., “Inclusion of a HVDC-voltage source converter model in a Newton-Raphson power flow algorithm, ” *IEE Proc.-Gene.Trans. Dist*., vol.150, Nov.2003.

[8] G.N. Bathurst *et al*., “Advanced modeling of the harmonic impedances of AC,” *IEE Pro.-Gene. Trans. Dist*.,vol.149, pp.700-704, Nov. 2002.

[9] Whei-Min Lin *et al*., “Multiple-frequency 3-phase load flow for harmonic analysis,” *IEEE Tran Power St*., pp.897-904, 2004.

[10] H. Zhao *et al*., “Computer simulation and measurements of HVDC.,” *IEE Proc.-Gen. Trans. Dist*.,vol.146, pp.131-136, 1999.