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Li Zhang

Yilu Liu

Mark Baldwin

Michael R. Ingram

et. al. For a complete list of authors, see https://scholarsmine.mst.edu/ele_comeng_facwork/826

A Solution for EAF Induced Problems in Bulk Power Systems by FACTS/ESS

Li Zhang, Mark Baldwin, Yilu Liu — Virginia Tech, USA
Michael R. Ingram, Dale T. Bradshaw — Tennessee Valley Authority, USA
Steve Eckroad — EPRI, USA
Mariesa L. Crow — Univ. of Missouri-Rolla, USA

***Abstract*-- Electrical Arc Furnaces (EAF's) are commonly employed in industry to produce molten steel by melting iron and scrap steel. EAF's can be a source of power quality problems and a potential threat to nearby generators. This study examines the effects of a 40MVA EAF operating at Hoeganaes in the Tennessee Valley Authority (TVA) power system, particularly the effects on the power generators at Gallatin Plant. It also attempts to define the role of FACTS/ESS in correcting EAF induced problems in the TVA system. The authors analyzed how EAF operation can affect a power system by giving a detailed discussion about the function of X/R ratio. The simulation results show that energy storage system can offer improvements over more conventional FACTS methods in curtailing the effects of EAF induced problems.**

***Index Terms*-- bulk power system, electrical arc furnace, energy storage system, FACTS, modeling, PSS/E, power quality problem, simulation.**

I. Introduction

The operation of an arc furnace does not only generate harmonics, but also voltage dips. The voltage across an arc varies because the lengths of the arcs vary with a degree of randomness. This causes the phenomenon of voltage flicker. Both the harmonic currents and voltage flickers caused by the operation of an EAF can affect the operation of other equipment or machines in the same factory or nearby factories in the same distribution system. In a strong power system where short circuit capacity is large, the power quality problems caused by an EAF may not be serious. But the story is quite different for today's bulk power systems because of their operation near limits [1].

Several studies reported voltage flickers from the operation of an EAF on the power feeders in nearby factories. The studies also discovered that the neighboring distribution network inherently resonated an active oscillation [2], [3], [5]. As mentioned above, instantaneous fluctuations with large amplitudes of active and reactive power in EAF's are source of power quality disturbances in an electric power system. Traditionally, for a mainly inductive supply system, power quality can be improved by using reactive power control methods. But for the EAF load, only adjusting reactive power is not enough.

Power electronics capable of switching at high power have led to the applications of SVC's and STATCOM's. These devices have been able to solve the power quality problems in distribution and transmission systems by rapidly controlling reactive power [2], [3], [4]. But for the power quality problems caused by an EAF, things are quite different. Real power fluctuation can cause phase angle variations at critical buses. These phase angle variations and active power fluctuations can cause damage to nearby generators [5].

Advances in both energy storage technologies and the necessary power electronics interface have made energy storage systems (ESS) a viable technology for high power utility. The power industry's demands for more flexible, reliable and fast active power compensation devices make the ideal opportunity for ESS applications [6], [7].

In this paper, the authors use a simple EAF model based on the PSS/E software. Using this simple model, the problems caused by the operation of an EAF in a bulk power system have been deeply studied. The authors analyze the exact reason why the EAF can affect a power system, especially the EAF's neighboring system, by giving a detailed discussion of the role of X/R ratio. The authors studied the solutions for the EAF induced problems by FACTS/ESS including FACTS/SMES and FACTS/BESS, especially the compensation of active power to solve the voltage oscillation and power fluctuation problems. The study results show that the FACTS/ESS system holds an advantage over more conventional methods because of its real power control capability.

II. Arc Furnace Practical Model For PSS/E

An accurate three-phase arc furnace model is needed for the purpose of harmonic analysis and flicker compensation. Since the arc melting process is a dynamic stochastic process, it is difficult to make a precise deterministic model for an arc furnace load. The factors that affect the arc furnace operation are the melting or refining materials, the melting stage, the electrode position, the electrode arm control scheme, the supply system voltage and impedance. Many complex methods have been proposed to more accurately represent EAF characteristics and study its impacts on power systems. These include nonlinear resistance models, current source models, voltage source models, nonlinear time varying voltage source models, nonlinear time varying resistance models, frequency domain models, and power balance models, etc, [8], [9], [10], [11].

In this paper, the focus of research is based on the effects of an EAF's periodic draw of active and reactive power from a bulk power system and the problems created by it. At this time there is no detailed generic EAF model. PSS/E is power system simulation software which has the ability to deal with a large scale power system. It contains an extensive power equipment model library. Unfortunately, there is no EAF model in this library.

The authors create a practical EAF model to study the problems caused by the periodic draw of active and reactive power of an EAF in a bulk power system. The EAF model contains the resistance and reactance which is switched in and out of the circuit in a periodic manner to emulate the dynamic characteristics of EAF. In this research, the EAF is about 40MVA containing 33MW active load and 24MVAR reactive load at the normal bus voltage. The frequency of this periodic draw of power is 5 Hz.

The general scheme of EAF and FACTS/ESS is shown in Fig. 1. In Fig. 1 the point of common coupling (PCC) is a 161kV bus in the Hoeganaes substation.

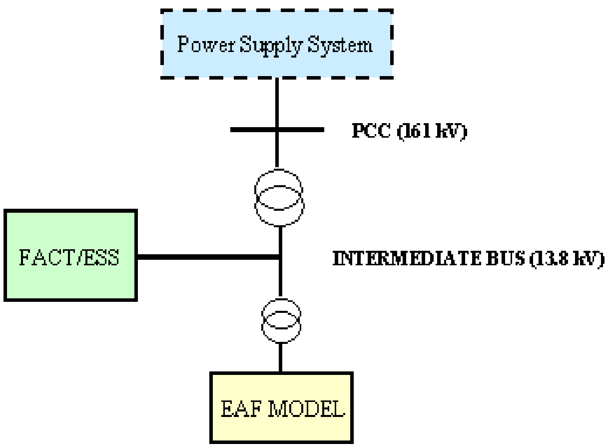

Fig. 1. The general scheme of EAF and FACTS/ESS.

In this study, we use the Eastern U.S. system that contains the major portion of the NERC (North American Electric Reliability Council). The simulated system is comprehensive, containing high level 765kV transmission circuits and lower voltage distribution circuits. There are about 2313 generators and 10808 buses in the system data. The capacity of the entire system is about 60.8GVA, containing 59.2GW active generation and 13.7GVAR reactive generation. The load of the system is about 58.5GW active load and 20.4GVAR reactive load. The 40MVA EAF is installed in the substation which belongs to HOEGANAES Corp. Nearby, there is a steam station containing 4 generator units at Gallatin in Tennessee. Fig. 2 is the detail of the system structure.

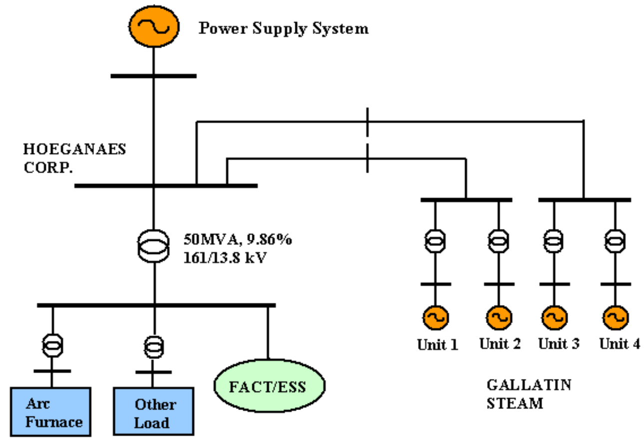

Fig. 2. One-line diagram of the subject system.

Fig. 3 shows the active and reactive power drawn by the EAF with a frequency of about 5Hz. Fig. 4 shows the PCC bus voltage magnitude and angle fluctuation due to the EAF. Fig. 5 is the angle dynamics of Unit4 generator at Gallatin Steam Station, whose changes are the same as Unit3 but larger than the other two units. Fig. 6 is the output active and reactive power fluctuation of Unit4 generator. It should be noted that Unit1, Unit2 and Unit3 exhibit the same active power, reactive power, and angle fluctuation characteristics as that of Unit4.

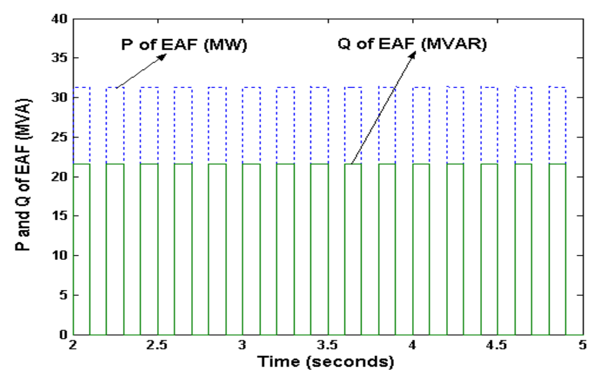

Fig. 3. The rapid change power drawn by 40MVA EAF.

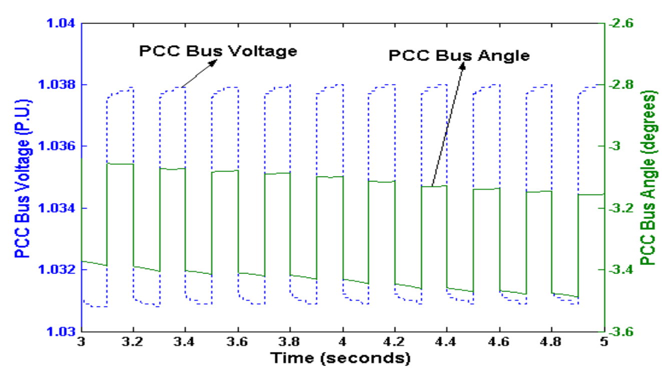

Fig. 4. PCC bus voltage and angle fluctuations caused by EAF.

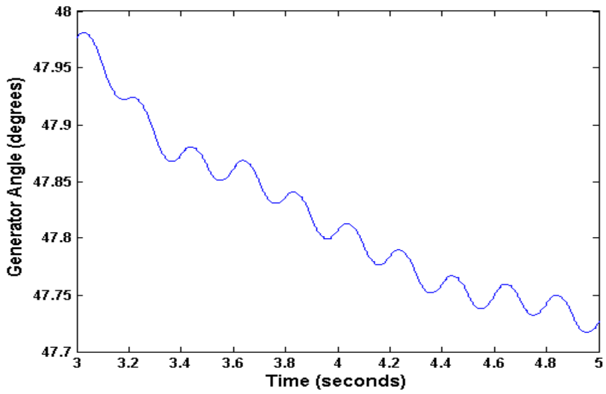

Fig. 5 Angle change of Unit4 generator.

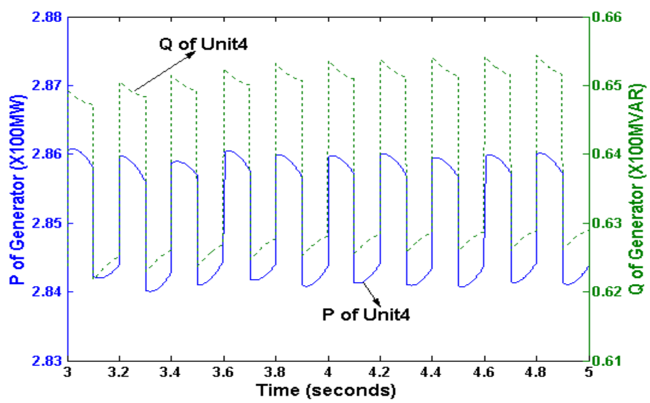

Fig. 6 Output active and reactive power of Unit4 generator.

From the above figures we can see that the operation of an EAF can cause not only the fluctuation of the voltage and angle of the PCC bus, but also cause the fluctuation of generator angle, generator output active and reactive power in the nearby system. Of course, the active and reactive power of generators oscillate at the EAF operation frequency as well. That can cause very serious power quality and stability problems in a bulk power system.

Following is an analysis of the above phenomena. The generator stator voltage equations are as follows:

$$\begin{cases} u_a = p\psi_a - r_a i_a \\ u_b = p\psi_b - r_a i_b \\ u_c = p\psi_b - r_a i_c \end{cases} \quad (1)$$

where p=d/dt, r_a is the coil resistance of each phase.

The rotor voltage equations of generator are as follows:

$$\begin{cases} u_f = p\psi_f + r_f i_f \\ u_D = p\psi_D + r_D i_D \equiv 0 \\ u_Q = p\psi_Q + r_Q i_Q \equiv 0 \end{cases} \quad (2)$$

where r_f, r_D and r_Q are the resistances of the f, D and Q coil, respectively.

Combining equations (1) and (2), we get the following vector equation:

$$\mathbf{u} = \mathbf{p}\boldsymbol{\psi} + \mathbf{r} \bullet \mathbf{i} \quad (3)$$

where,

$$\mathbf{u} = (u_a, u_b, u_c, u_f, u_D, u_Q)^T$$

$$\boldsymbol{\psi} = (\psi_a, \psi_b, \psi_c, \psi_f, \psi_D, \psi_Q)^T$$

$$\mathbf{r} = diag(r_a, r_a, r_a, r_f, r_D, r_Q)$$

$$\mathbf{i} = (-i_a, -i_b, -i_c, i_f, i_D, i_Q)^T$$

The instant output active power of generator is as follows:

$$P_e = u_a i_a + u_b i_b + u_c i_c \quad (4)$$

The magnetic-electric torque is as follows:

$$\begin{aligned} T_e &= p_p \frac{1}{\sqrt{3}}[\psi_a(i_b - i_c) + \psi_b(i_c - i_a) + \psi_c(i_a - i_b)] \\ &= p_p \frac{1}{\sqrt{3}} \boldsymbol{\psi}_{abc}^T \begin{bmatrix} 0 & 1 & -1 \\ -1 & 0 & 1 \\ 1 & -1 & 0 \end{bmatrix} \mathbf{i}_{abc} \end{aligned} \quad (5)$$

where p_p is the pole pairs of generator.

The generator rotor motion equation is as follows:

$$\begin{cases} J\dfrac{d^2\theta_m}{dt^2} = M_m - M_e \\ \dfrac{d\theta_m}{dt} = \omega_m \end{cases} \quad (6)$$

The voltage flicker caused by the operation of an EAF can cause not only the voltage and angle fluctuation of the PCC bus, but can also cause the voltage and angle fluctuation on other feeders connected to the PCC bus, including the feeders of generators in Gallatin Steam substation. From equation (1), (2) and (3) we know that the voltage $\mathbf{U}_{abc}$ change can cause the change of current $\mathbf{i}_{abc}$. The fluctuation of $\mathbf{U}_{abc}$ and $\mathbf{i}_{abc}$ will cause the generator output active power fluctuation according to equation (4). The change of $\mathbf{i}_{abc}$ will cause the change of $\mathbf{T}_e$. Because the input mechanical power (or torque) of the generator cannot change within such a short period of time, the swing of $\mathbf{T}_e$ finally causes the generator angle fluctuation with the same frequency.

In a multi-machine system, the output active and reactive power of the generator are as shown in equation set (7).

$$\begin{cases} P_{ei} = E_i^2 G_{ii} + \sum\limits_{\substack{j=1 \\ j\neq i}}^{n} (E_i E_j B_{ij} \sin\delta_{ij} + E_i E_j G_{ij} \cos\delta_{ij} \\ Q_{ei} = -E_i^2 B_{ii} + \sum\limits_{\substack{j=1 \\ j\neq i}}^{n} (E_i E_j G_{ij} \sin\delta_{ij} - E_i E_j B_{ij} \cos\delta_{ij}) \end{cases} \quad (7)$$

The fluctuation of generator angles will cause the fluctuation of active and reactive power output of every generator which affects the active and reactive power fluctuation of the EAF. The power flow of the system changes because of this fluctuation, which means the power distribution of the entire system will change. That may create serious stability problems in the bulk power system, especially with the critical bus and generators. The operation of the EAF may bring the power system into an unstable mode.

III. X/R Ratio Discussion

X/R ratio is very important when we study the effect of active and reactive load on the voltage and angle fluctuation in the system [12]. The voltage effect of active power drawn by an EAF is reflected by the real part of system impedance (Thevenin Impedance) R_n. A very common mistake is to assume that in the power system, the X/R ratio is large enough to omit the voltage drop caused by the active power of the EAF. An incorrect approach to calculating X/R ratio is by considering only the upper transformer or branch. Using this approach one will certainly arrive at a X/R of over 10. The correct approach is by looking at all of the parameters including the load. In other words, the R and X are not proportional to the impedance of the upper transformers and lines; instead they should be the Thevenin Impedance seen from the PCC bus of the entire system. From the simulation results in Fig. 9, Fig. 10 and Fig. 11, we can see that the active load component of the arc furnace plays an important role on the bus voltage drop. The PSS/E software has the ability to calculate the Thevenin Impedance automatically if the zero and negative sequence impedance are available.

Because it is difficult to calculate the precise Thevenin equivalent circuit for a particular bus in a power system with 10808 buses, we use a method to estimate the Thevenin equivalent R_n, X_n, and X_n/R_n ratio in Fig. 7 and Fig. 8.

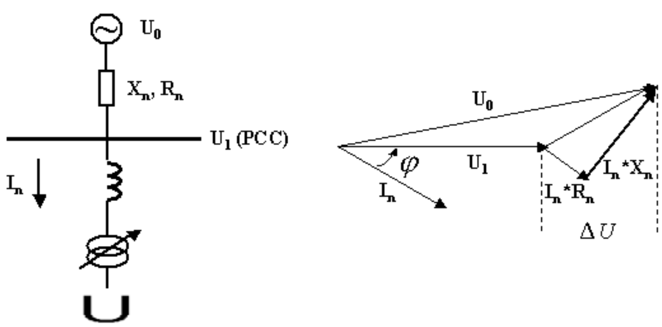

Fig. 7 X/R ratio discussion

In Fig. 7, the voltage drop ΔU caused by the EAF load is analyzed as follows in equations (8) through (11):

$$\Delta U = \frac{\sqrt{3}}{3} I_n * X_n (\sin \varphi + \frac{R_n}{X_n} * \cos \varphi) \tag{8}$$

$$\begin{cases} \Delta U_p = \frac{\sqrt{3}}{3} I_{np} * R_n \\ \Delta U_q = \frac{\sqrt{3}}{3} I_{nq} * X_n \end{cases} \tag{9}$$

$$\begin{cases} I_{np} = I_n \cos \varphi \\ I_{nq} = I_n \sin \varphi \end{cases} \tag{10}$$

$$\frac{\Delta U_p}{\Delta U_q} = \frac{I_{np}}{I_{nq}} * \frac{R_n}{X_n} = \frac{R_n}{X_n} * (\tan \varphi)^{-1} \tag{11}$$

In Fig. 9, we can check the ratio of voltage drop caused by 33MW active load and 24MVAR reactive load is about 0.458 in the real system.

The level of PCC bus voltage angle change caused by 33MW active load is much larger than that caused by 24MVAR reactive load in Fig. 10.

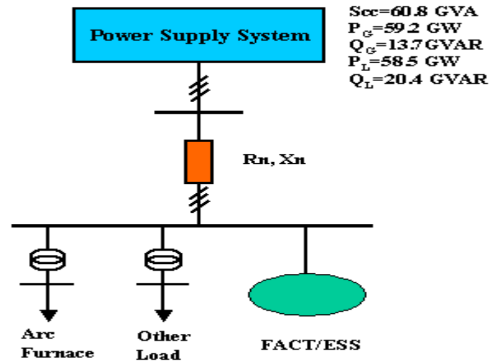

Fig. 8 PCC bus Thevenin equivalent circuit of the whole system.

Also, generator angle fluctuation caused by 33MW active load is much greater than that caused by 24MVAR reactive load in Fig. 11. The reason is explained in section II.

Another interesting phenomenon is that the generator angle fluctuation caused by the combined 33MW+j24MVAR load is slightly less than the fluctuation caused by the 33MW active load alone. The reason is that the generator angle fluctuation caused by 33MW active load is not in phase with the fluctuation caused by the 24MVAR reactive load. Their trends are opposite in Fig. 11. A canceling effect occurs.

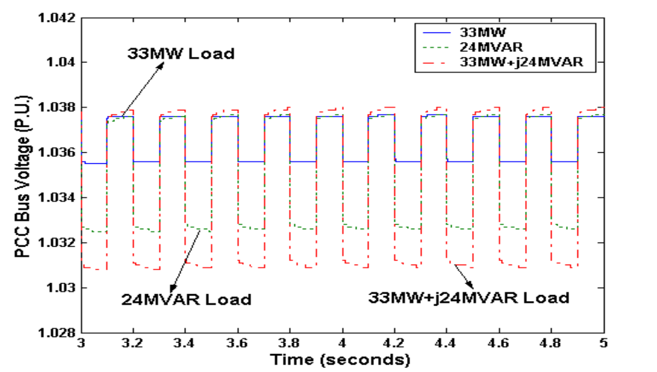

Fig. 9 Comparison of PCC bus voltage drop by active load (33MW), reactive load (24MVAR) and their combination (33MW+j24MVAR).

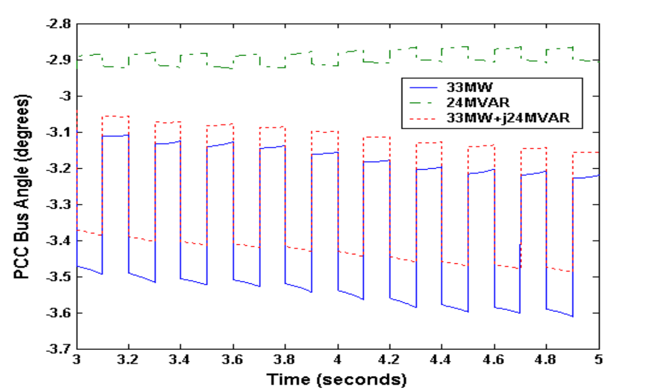

Fig. 10 Comparison of the PCC bus angle change by active load (33MW), reactive load (24MVAR) and their combination (33MW+j24MVAR).

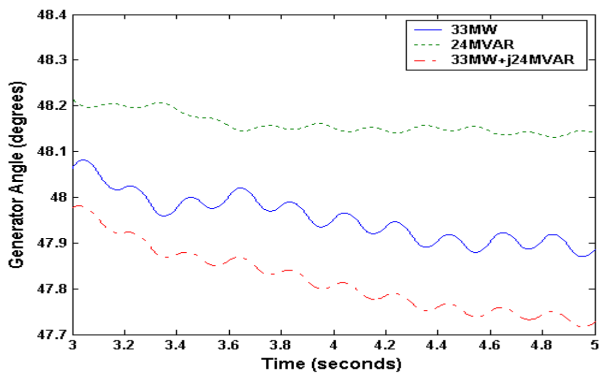

Fig. 11 Comparison of Unit4 generator angle change caused by active load (33MW), reactive load (24MVAR) and their combination (33MW+j24MVAR).

IV. SOLUTION FOR EAF INDUCED PROBLEMS IN BULK POWER SYSTEMS

The construction of the FACTS/ESS in this paper consists of three main parts: an energy storage system such as battery and SMES, a power converter, and a transformer. The converter produces a three-phase voltage at the primary winding of the transformer. This voltage can be varied in magnitude and phase with respect to the voltage on the high voltage side of the transformer. The reactive power exchange between the converter and the ac system is controlled by varying the phase of the primary side voltage. The converter is effectively a STATCOM that has the added feature of controlling active power flow between its DC side and the AC side. Fig. 12 is the structure of FACTS/ESS. Fig. 13 is a sample FACTS/SMES system [9]. Fig. 14 is the P-Q plane for each operation mode of FACTS/ESS devices [9], [13].

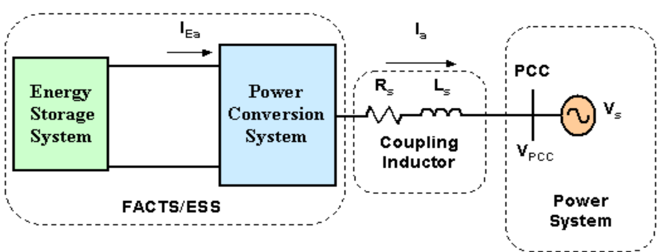

Fig. 12 The configuration of FACTS/ESS.

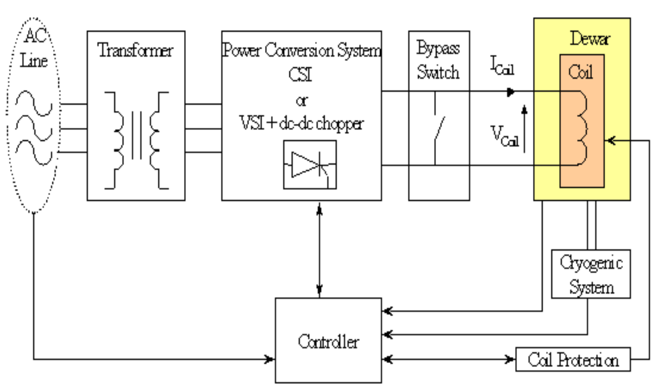

Fig. 13 The sample configuration of FACTS/SMES.

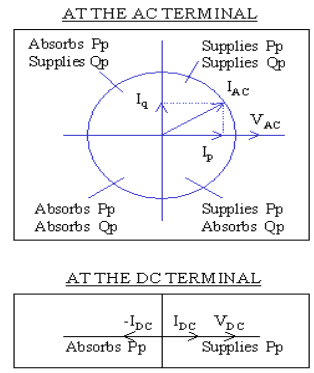

Fig. 14 FACTS/ESS P-Q plane for each operating mode when it is connected to system in parallel.

In this study, the TVA plans to install an 8MVA FACTS/ESS device at the Hoeganaes substation. It may be a FACTS/SMES (also called D-SMES created by American Super Conductor) or a FACTS/SuperCap. The following study is based on the above background, which means the capacity of FACTS/ESS is 8MVA with 3.2MW active capacity.

Fig. 15 through Fig. 19 are the comparison of compensation effects by different devices such as STATCOM, FACTS/SMES and FACTS/BESS with 8MVA capacity. The FACTS/ESS devices operate in such a mode that they absorb active power from the system when the EAF draws no power, active or reactive, from the system. From these simulation results we can see that even though the compensation effects are not substantial because of the limit of device capacity, the FACTS/ESS devices do compensate at an acceptable level. In the reactive power and voltage fluctuation aspect the FACTS/ESS has no obvious advantage over STATCOM, which are shown in Fig. 15 and Fig. 19. However, concerning active power, bus angle, and generator angle fluctuation control, the FACTS/ESS devices have obvious advantages over STATCOM. For example, FACTS/SMES and FACTS/BESS reduce the generator angle fluctuation substantially as shown in Fig. 17. The SMES and BESS offer a reduction in output active power fluctuation of Unit4 over the reduction provided by STATCOM.

The FACTS/ESS devices cannot offer a significant advantage over the STATCOM in reducing the voltage flicker and generator reactive power output fluctuation.

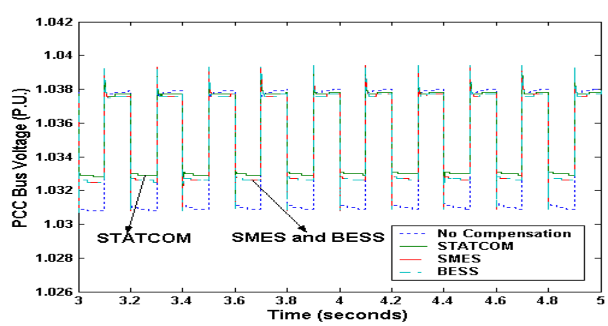

Fig. 15 Comparison of PCC bus voltage compensation effects by 8MVA FACTS/ESS (10MVAR output of STATCOM, 3.2MW+7.3MVAR output of FACTS/ESS).

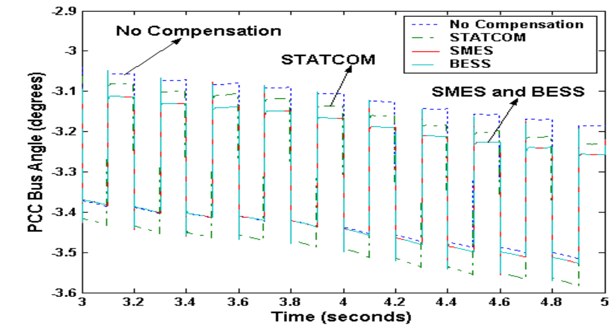

Fig. 16 Comparison of PCC bus angle compensation effects by 8MVA FACTS/ESS (10MVAR output of STATCOM, 3.2MW+7.3MVAR output of FACTS/ESS).

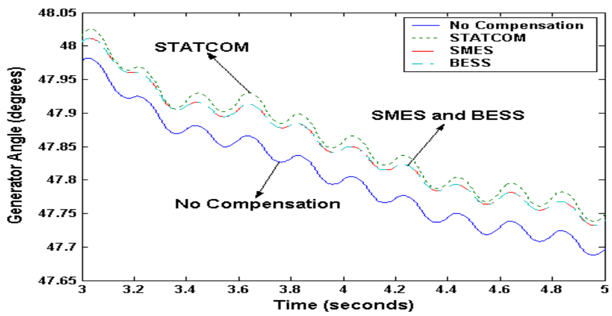

Fig. 17 Comparison of generator angle control effects by 8MVA FACTS/ESS (10MVAR output of STATCOM, 3.2MW+7.3MVAR output of FACTS/ESS).

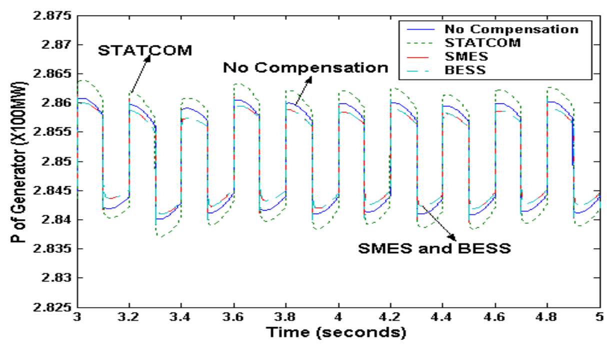

Fig. 18 Generator output active power control by 8MVA FACTS/ESS (10MVAR output of STATCOM, 3.2MW+7.3MVAR output of FACTS/ESS).

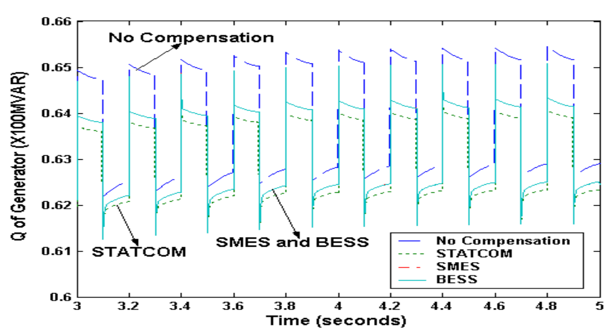

Fig. 19 Generator output reactive power control by 8MVA FACTS/ESS (10MVAR output of STATCOM, 3.2MW+7.3MVAR output of FACTS/ESS).

Fig. 20 and Fig. 21 are the output active power and reactive power of FACTS/ESS. Of course, the active power output of STATCOM is zero. But its reactive power output is larger than that of FACTS/ESS to improve the voltage to a desired level.

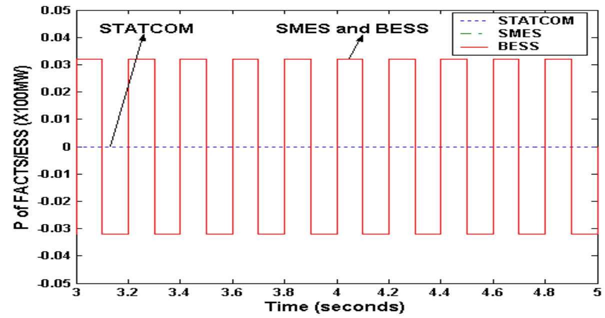

Fig. 20 Output active power of 8MVA FACTS/ESS (3.2MW active power output of FACTS/ESS, 0MW output of STATCOM).

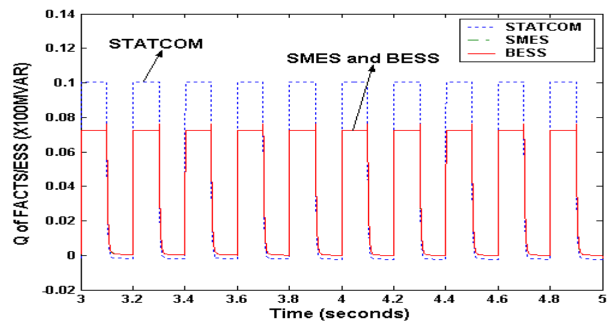

Fig. 21 Output reactive power of 8MVA FACTS/ESS (10MVAR output of STATCOM, 3.2MW+7.3MVAR output of FACTS/ESS).

Fig. 22 through Fig. 24 show the simulation results when we use a FACTS/ESS with a capacity large enough to supply the EAF load. Here the rated capacity of FACTS/ESS is 50MVA with 20MW active capacity. The simulation results show that this high capacity FACTS/ESS provides satisfactory results. In Fig. 22 and Fig. 23, the FACTS/ESS devices perform slightly better than STATCOM in mitigating the PCC bus voltage but significantly better for angle fluctuation and generator angle swing.

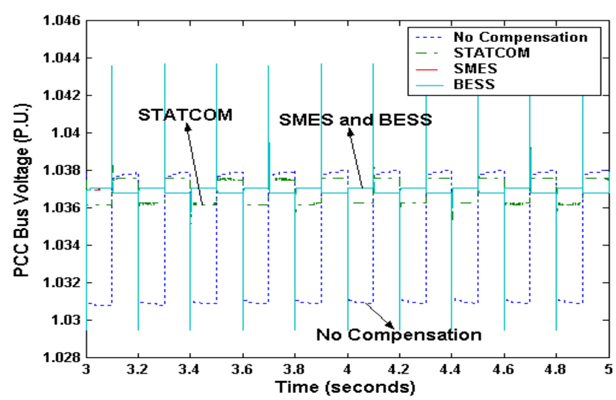

Fig. 22 PCC bus voltage control by 50MVA FACTS/ESS (20MW+25MVAR output of FACTS/ESS, 27.5MVAR output of STATCOM).

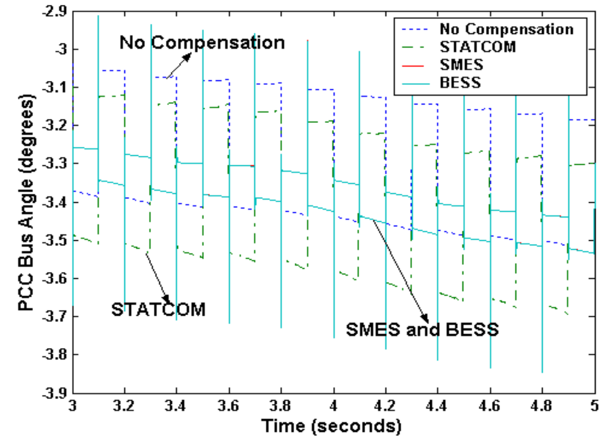

Fig. 23 PCC bus angle control by 50 MVAFACTS/ESS (20MW+25MVAR output of FACTS/ESS, 27.5MVAR output of STATCOM).

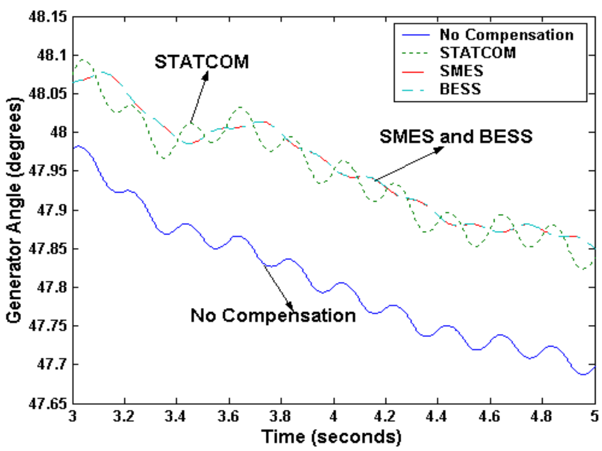

Fig. 24 Generator angle control by 50 MVA FACTS/ESS (20MW+25MVAR output of FACTS/ESS, 27.5MVAR output of STATCOM).

V. Conclusion

In this paper, the problems caused by the operation of an EAF in a bulk power system have been studied. The authors analyze the exact reason why the real power drawn from an EAF can affect a power system, especially the neighboring system that is connected to it, by giving a detailed discussion of the role of X/R ratio. The authors studied the solutions for the EAF problem by FACTS/ESS. The study results show that reactive power compensation alone can deal very well with the voltage improvement. The reactive power cannot solve the problems about the voltage angle fluctuation and power fluctuation. The active power compensation can be a very good solution for the problems of angle oscillation and power fluctuation induced by the operation of electrical arc furnace. The study shows that the energy storage systems can provide significant improvements in mitigating EAF induced problem over more conventional compensation methods, e.g. STATCOM, because of its active power control capability.

The purpose of introducing energy storage in this case is not for the voltage improvement though this is possible given the low X/R ratio (X/R≈3). More importantly, the ESS is essential in reducing real power (or voltage angle) oscillations caused by EAF. Many earlier studies have shown that the pulsing load in an EAF could be very harmful to the generator shaft and may reduce the life of generator dramatically. Dynamic active power compensation as offered by FACTS with ESS may offer the solution.

VI. References

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VII. Biographies

Li Zhang is a visiting scientist and Ph.D. candidate of the Electrical and Computer Engineering Department of Virginia Tech. He received B.S degree from the Northeastern University, M.S. degree from the Harbin Polytechnic University, Ph.D degree from Tsinghua University, P.R. China. Currently, he is in charge of power system and power electronics application research at ECE Department of Virginia Tech, USA. From 1997 to 2001, he was with the Beijing Power Supply Company as an engineer. From May 2001 to October 2001, he was a research fellow in the Building Service Engineering Department of Hong Kong Polytechnic University. He is the main contributor for several National Science Foundation (NSF) and utility projects. His current research interests are power system analysis, power system stability control, power system planning, power electronics, FACTS, energy storage system, and Internet applications in power systems. His E-mail address is zhangli@vt.edu.

Yilu Liu is a Professor of Electrical Engineering at Virginia Tech. Her current research interests are power system analysis, power quality and transient analysis, power system equipment modeling and diagnoses. She is in charge of the Virginia Tech effect for the FACTS/ESS power system application study. She received her BS degree from Xian Jiaotong University, her MS and PhD degrees from The Ohio State University. Dr. Liu is a Fellow of IEEE and leads the effort of building a Nationwide Power System Frequency Disturbance Monitoring Network (FNET). Her E-mail address is yilu@vt.edu

Mark W. Baldwin is a graduate student of Electrical Engineering at Virginia Tech. His research interests are in electric machines and power electronics applications in bulk power systems. His industrial background is in power transformer monitoring and controls. He received his BS degree in 1993 from Virginia Tech. His email address is mwbaldwi@vt.edu.

Michael R. Ingram, P.E. is currently a Senior Manager of the Transmission Technologies group with Tennessee Valley Authority (TVA) in Chattanooga, Tennessee. He is responsible for the development and demonstration of new technologies which improve electrical quality and reliability, increase power flow, and reduce operating expense of the TVA transmission system. He has seventeen years with TVA, working in technical project management, protection and control engineering, and substation design. He received the B.E.E. degree, with honor, from Auburn University and an M.S. degree from the University of Tennessee at Chattanooga. Ingram was a 2001 top-ten finalist for "Federal Engineer of the Year."

Dale T. Bradshaw was a senior manager at the Tennessee Valley Authority's (TVA) Energy Research & Technology Applications organization managing Power Delivery Technologies specializing in research, development, demonstration, and deployment (RDD&D) of new, or first-of-a-kind technologies like the SuperVARtm project, chemical vapor deposition of diamond tips and edges in a vacuum field effect transistor, by improving transmission lines and substation equipment, upgrading power system communications, enhancing TVA's grid operations, and evaluating the use of energy storage technologies, etc.; that seek to increase revenues, reduce operating and capital costs, improve reliability, and increase the system security for TVA's Transmission system. He has been with TVA for 28 years, and has been involved in RDD&D of advanced solid oxide fuel cells, coal gasification, alternate lower cost fuels for fossil power plants, coal refineries, biomass conversion technologies and other renewable fuels, advanced combustion turbines technologies, etc. Before coming to TVA, he spent two years at Public Service of New Mexico. He is a retired LTC in the Army Reserves, is married and has three children and four grand children. He holds a BS in Engineering Physics from the University of Oklahoma, MS in mechanical engineering from the University of Oklahoma, ABD in Nuclear Engineering from the University of New Mexico, and an MBA in finance from the University of Tennessee at Chattanooga, TN.

Steve Eckroad received his BA degree in Physics from Antioch College in 1965, and carried out postgraduate studies in Electrical Engineering at the University of Missouri-Rolla in 1990-1992. Mr. Eckroad is a Senior Member of the IEEE, and is a registered professional electrical engineer in California. He is the author or co-author of many publications in the fields of energy storage and electric generation and transmission technology. Prior to joining ERPI in 1992, Mr. Eckroad was the principal at EnerTech Energy Tecnology Consulting (1990-92). From 1979 to 1990 he was a project engineer and later project manager in the Research and Development Division of Bechtel Group, Inc. where he provided consulting services to he utility industry in planning for designing and assessing the performance of energy storage systems. Mr. Eckroad is currently Manager of Substation and Energy Storage, for EPRI where he is responsible for conceiving, funding, and managing research and development for the application of advanced technologies to the electric power delivery system.

Mariesa L. Crow (SM'94) received B.S.E degree from the University of Michigan at Ann Arbor, and the Ph.D degree from the University of Illinois, at Urbana-Champaign. Currently, she is the Associate Dean for Research and Graduate Affairs and a Professor of Electrical and Computer Engineering at the University of Missouri-Rolla, Rolla. Her research interests include developing computational methods for dynamic security assessment and the application of power electronics in bulk power system. Dr. Crow is the Vice-President for Education/Industry relations of the IEEE Power Engineering Society.