Active Power Ramp Characteristics and Frequency Instability in a 230 kV Industrial Transmission Corridor with Clustered Steel Plants

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Abstract

Large steel plants employing Electric Arc Furnaces (EAFs) and Induction Furnaces (IFs) impose rapid and stochastic active-power variations on power systems [1]. When such plants are clustered along a transmission corridor with limited inertia, aggregated MW ramps can propagate beyond local substations and manifest as measurable grid-frequency deviations [2]. This short paper presents a corridor-level technical analysis of frequency behavior observed in the Dhaka–Chattogram 230 kV industrial transmission corridor supplying three major steel producers. System-operator trend data indicate aggregate MW fluctuations of approximately 150–350 MW associated with frequency variations in the range of 49.85–51.10 Hz. The paper explains the physical origin of industrial MW ramping, highlights the moderating effect of Quantum EAF flat-bath and scrap-preheating operation at one plant, clarifies the limitations of Static Var Compensators (SVCs) for such disturbances, and outlines mitigation strategies aligned with the time scale of modern steelmaking load dynamics.

1. Introduction

Electric steelmaking loads are among the most challenging industrial consumers from a power-system dynamics perspective [3]. Unlike conventional industrial loads, melting furnaces exhibit rapid and non-uniform changes in active power driven by metallurgical process constraints rather than electrical optimization. When multiple steel plants operate concurrently within a limited electrical corridor, the superposition of their active-power ramps can significantly stress grid-frequency control, particularly in systems with low synchronous inertia [2], [4].

While voltage flicker and harmonic effects of EAFs are well documented [1], grid-level frequency impacts arising from aggregated industrial MW ramping remain comparatively under-reported, especially in developing power systems.

2. Industrial Load Composition of the Studied Corridor

The studied 230 kV corridor supplies three major steel producers with different furnace technologies. GPH Ispat Ltd. operates a single large-capacity Quantum Electric Arc Furnace (EAF) equipped with flat-bath operation and off-gas scrap preheating, which moderates instantaneous MW steps during charging [5]. Abul Khair Steel (AKS) operates two conventional EAFs without flat-bath operation, while BSRM Steel operates multiple medium-capacity Induction Furnaces (IFs), typically 6–8 units of approximately 50-ton capacity.

Each induction furnace draws up to approximately 20 MW, with active power increasing from near zero to full load within a few minutes after charging. Asynchronous operation of these furnaces produces significant aggregate MW variation at the transmission-system level.

3. Active Power Ramp Characteristics of Steelmaking Furnaces

Independent of manufacturer, most large EAFs exhibit a broadly similar active-power trend during a heat. Following scrap charging, furnace power increases rapidly as the arc stabilizes, reaches a high-power melting plateau, and later fluctuates during refining. These ramps are dictated by metallurgical requirements and electrode control limits rather than grid-frequency considerations [3].

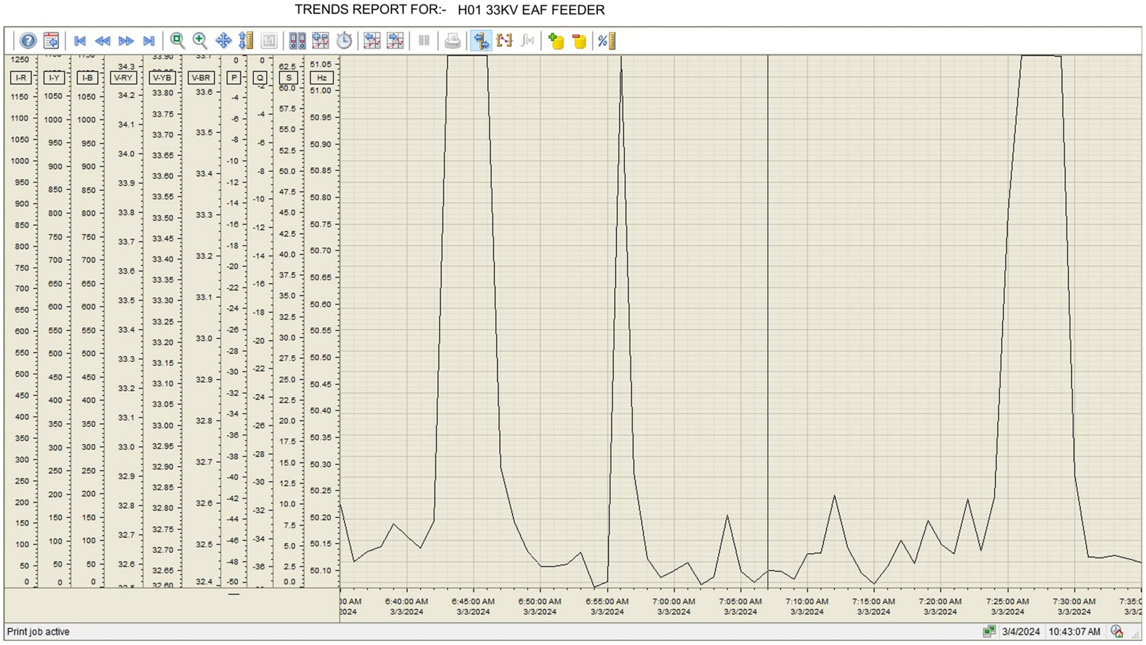

TRENDS REPORT FOR:- H01 33KV EAF FEEDER

Figure 1: Typical EAF active-power trend during a heat cycle.

The Quantum EAF incorporates flat-bath operation and scrap preheating, whereby scrap is preheated and a hot heel of molten steel is retained between heats. This improves arc stability and reduces peak MW demand and ramp severity compared to conventional cold-scrap EAFs [5]. However, active-power variability persists during melting and refining stages.

Induction furnaces introduce quasi-continuous MW variation due to rectifier–inverter operation and changing electromagnetic coupling with the molten metal [6]. When several IF units ramp independently from 0 to approximately 20 MW and EAFs operate concurrently, the transmission system experiences a composite MW ramp characterized by high rates of change of power (dP/dt).

4. Observed Frequency Trends in the 230 kV Corridor

MW–frequency trend data presented by the transmission system operator indicate aggregate active-power fluctuations of approximately 150–350 MW, associated with frequency variations in the range of 49.85–51.10 Hz, even in the absence of transmission faults.

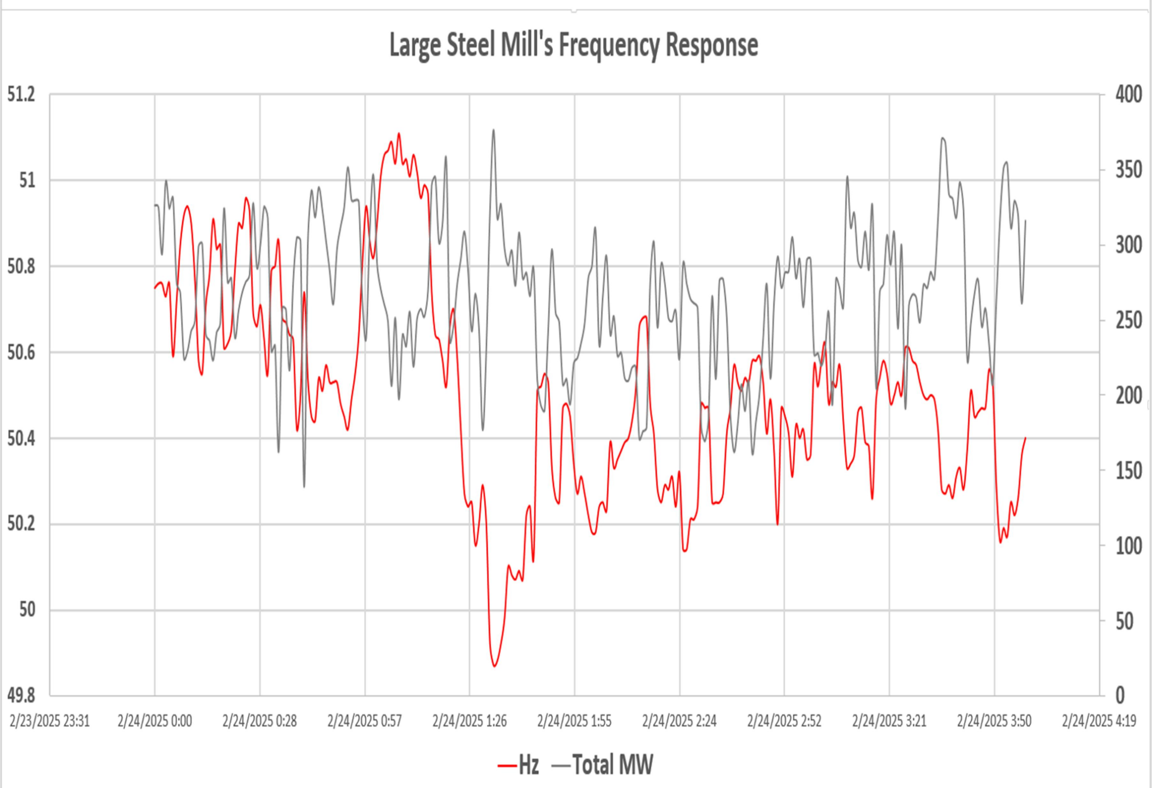


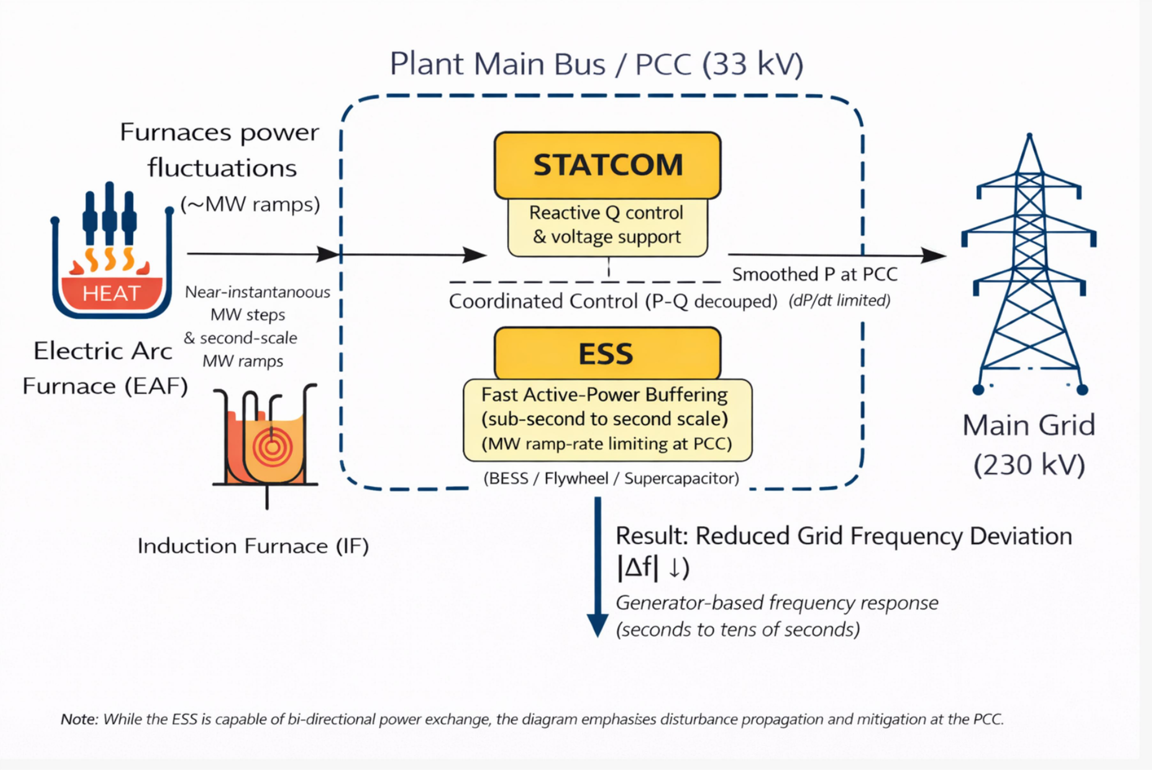
Figure 2: MW versus frequency trend for the industrial corridor (system operator data).

5. Limitations of SVC-Based Mitigation

Static Var Compensators (SVCs) are designed to regulate reactive power and stabilize voltage by dynamically adjusting reactive current injection or absorption [7]. SVCs are effective in mitigating voltage flicker and improving power factor at arc furnace buses. However, SVCs do not control active power and therefore cannot mitigate MW ramps or compensate for active-power imbalances that directly influence system frequency [2], [4].

6. Mitigation Strategy

Effective mitigation of industrial MW ramp–induced frequency deviations requires control strategies aligned with the intrinsic disturbance time scale of steelmaking loads. Plant-level fast active-power buffering using STATCOM–ESS hybrids, flywheel energy storage, or supercapacitors can reduce the rate of change of power seen by the grid [8]. Grid-scale battery energy storage systems can further support fast frequency response and reduce reliance on spinning reserves.



Note: *While the ESS is capable of bi-directional power exchange, the diagram emphasises disturbance propagation and mitigation at the PCC.*

Fig. 3: Conceptual illustration of furnace-induced MW ramps, plant-level active-power buffering at the PCC using coordinated STATCOM–ESS control, and the resulting reduction in grid frequency deviation through dP/dt limitation prior to generator-based frequency response.

From a physical standpoint, active and reactive power regulate distinct and largely orthogonal dynamics in AC power systems. Active power imbalance directly affects generator rotor acceleration and system frequency ($\Delta f \propto \Delta P$), whereas reactive power primarily governs voltage magnitude ($\Delta V \propto \Delta Q$) with negligible direct influence on frequency. Accordingly, the coordinated STATCOM–ESS control illustrated in Fig. 3 adopts a P–Q decoupled structure, in which the ESS mitigates fast active-power ramps at the PCC while the STATCOM independently provides reactive-power and voltage support. This separation aligns with classical power-system control principles and enables effective attenuation of frequency-relevant disturbances without compromising voltage regulation.

From the grid perspective, frequency deviation is governed by the net active-power imbalance observed at the point of common coupling (PCC), rather than by internal furnace dynamics. This relationship can be expressed as

$$\Delta P_{\text{PCC}} = P_{\text{furnace}} + P_{\text{ESS}},$$

where fast ESS response absorbs or injects active power to smooth furnace-induced MW ramps before they propagate into the transmission network.

Effective mitigation of industrial MW ramp–induced frequency deviations requires control strategies aligned with the intrinsic disturbance time scales of steelmaking loads. Plant-level fast active-power buffering using STATCOM–ESS hybrids, flywheel energy storage, or supercapacitors can significantly reduce the rate of change of active power observed at the PCC by the transmission grid [8]. While the STATCOM primarily provides reactive-power support and voltage regulation, the co-located energy storage system injects or absorbs active power to compensate rapid furnace-induced MW variations. By attenuating net active-power fluctuations before they propagate beyond the PCC, such buffering schemes reduce the burden on generator-based frequency regulation and diminish reliance on spinning reserves. Grid-scale battery energy storage systems can further complement this approach by providing sustained fast frequency response during large or persistent disturbances. This PCC-centric buffering approach directly addresses the time-scale mismatch between fast industrial load dynamics and slower generator-based frequency control.

From a grid-stability perspective, mitigation is effective only if active-power fluctuations are attenuated before they reach the point of common coupling (PCC). Frequency deviations are driven by the net active-power imbalance observed at the PCC, rather than by internal furnace dynamics. While furnace-level measures such as flat-bath operation and scrap preheating reduce the severity of individual MW ramps, they cannot eliminate stochastic power variations arising from multiple asynchronous furnaces. Consequently, the most effective mitigation strategy is the deployment of fast-response active-power buffering at the plant main bus (33 kV or 230 kV PCC), using technologies such as STATCOM–ESS hybrids, flywheels, or battery energy storage systems. By absorbing or injecting active power during furnace ramp events, these systems limit the rate of change of power (dP/dt) seen by the transmission network, thereby directly supporting grid frequency stability and reducing reliance on system-wide spinning reserves.

This PCC-centric mitigation approach directly targets the fundamental mismatch between near-instantaneous EAF MW steps, second-scale IF ramps, and the inherently slower dynamics of generator-based frequency regulation.

7. Conclusions

Aggregated active-power ramps from clustered steel plants can excite measurable frequency deviations in a low-inertia 230 kV transmission corridor. While Quantum EAF flat-bath and scrap-preheating operation reduce the severity of individual MW steps, they do not eliminate corridor-level stochastic variability. SVC-based voltage control alone is insufficient to address MW-induced frequency deviations, motivating fast-response active-power buffering solutions.

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