Correlation between Generator Trips and Locational Marginal Prices (LMPs)

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Abstract— Generally, disturbances in an interconnected network have an influence the stability and the economy of the power grid. Some phenomenon such as load shedding have proven to have a huge impact on real time electricity prices. Generation trip is considered one of the most common events in a power grid that may change the wholesale electricity market. In this paper, a locational marginal price (LMP) measure is used to notice how the electricity prices change with generator trip events at different locations of U.S. power grid. The study results help to find whether there is a clear correlation between generator trips and the changes in the electricity real-time market.

Keywords— Electrical Disturbances, Generator Trip, Electricity Real-Time Market, Locational Marginal Prices (LMPs), Frequency Monitoring Network (FNET/GridEye).

I. INTRODUCTION

In general, different electrical or mechanical failures in a certain generator can lead the generator to be disconnected from the electrical grid [1]. Generator trips change the energy balance in the power grid, which is the sum of all generation must meet all loads and losses at all times [2]. Therefore, a generator trip is considered as one of the main challenges that may have an impact on electricity real-time market [3, 4]. This research aims to correlate generator trips to changes in the market prices for next hour and to find a correlation that can help for better predicting the electrical prices. Also, it is necessary to know how many hours it takes the market to respond and stabilize after the trip event, and the persistence a price increase, if there is any. It is assumed that price changes near the generator that tripped should correlate the most while those far should correlate less.

The first topic of this paper provides a brief summary about locational marginal prices (LMPs). It is followed by a topic presenting an overview about the Frequency Monitoring Network (FNET/GridEye). Then the data requirements and approach are discussed. Results and findings are shown and discussed in depth in the following topic. Finally, conclusion drawn from this work and possible future works are outlined.

II. LOCATIONAL MARGINAL PRICES (LMPS)

Real-time electricity markets are based on linearized DC optimal power flow model. This enables solving large number of power flows within a very short time frame [5-8]. Locational marginal price (LMP), which has been used since 1999, is the cost of supplying the next increment of electric demand at a specific location in the power grid at a given time, taking into consideration both supply bids and load offers and assuring that all operation constraints are satisfied. Locations of LMPs are divided into internal and external nodes, load zones, and hubs. Node is referred to a physical bus in a network while a load zone corresponds to a collection of buses and its price is an average of the prices of the all nodes within that zone. Hub, on the other hand, is a selection of nodes to enable long-term commercial energy trading [9]. LMPs mainly depend on generation marginal cost, total demand, and the transmission cost. Usually, LMPs are calculated for all locations every five minutes during the operating day within the physical constraints of the electricity network, taking into account generation offer prices and physical aspects of the transmission system including congestion and losses. They are usually produced as a result of economic dispatch. Economic dispatch is being run every five minutes to re-optimize the generation to meet load at minimum cost while keeping the system in balance [10]. LMPs are influenced by nearby generation and load level. Generators trips could potentially have serious reliability and economic consequences [11].

III. FREQUENCY MONITORING NETWORK (FNET/GRIDEYE)

Wide-area measurement systems (WAMS) make it easy to monitor and control the entire power grid and to understand the status of the electric network stability in real-time. The Frequency Monitoring Network (FNET/GridEye), which was proposed in 2001 by Virginia Tech and was established in 2004, is an Internet based, wide-area frequency monitoring system. It measures the voltage phase angle, voltage amplitude, and frequency from a single-phase voltage source at the distribution system level. Mainly FNET/GridEye is composed of two major components: GPS-time synchronized frequency disturbance

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recorders (FDRs, as shown in Figure 1) and an information management system (IMS, as shown in Figure 2). The FDRs are single-phase phasor measurement units (PMUs) that can measure voltage magnitude, voltage angle, and computes frequency from low voltage (110V) outlets while The IMS consists of three main components: data collection and storage service, the database operation service, and the web service.

Figure 1. Frequency disturbance recorder (FDR).

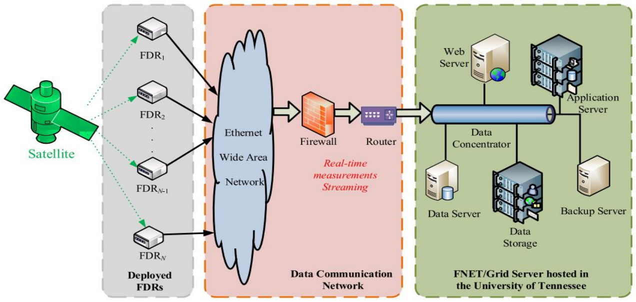

Figure 2. FNET/GridEye architecture.

The measured quantities are attached with GPS timestamp and then transmitted across the Internet to a central processing server, which simultaneously analyzes and archives the measurements in a database and updates the real-time web display.

Many FDRs are distributed worldwide and in each of the three interconnections in North America: the Eastern Interconnection System (EI), the Western Electric Coordinating Council (WECC), and the Electric Reliability Council of Texas (ERCOT), as shown in Figure 3. FNET/GridEye also covers many power grids in the world (Figure 4). Generally, they are installed in various locations, such as power plants, substations, offices, and private residences. They can be simply relocated if necessary.

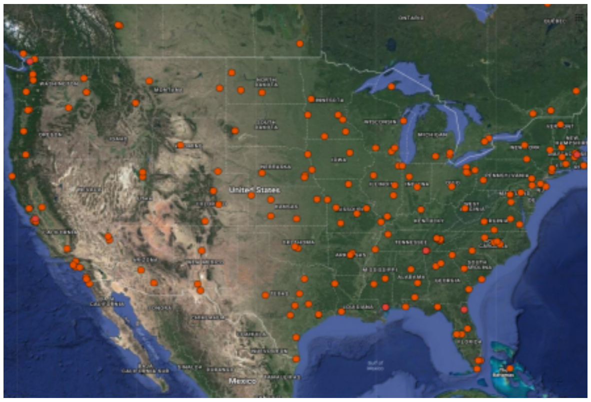

Figure 3. FDR deployed in North America.

Figure 4. FDR deployed around the world.

FNET/GridEye is a low cost and quickly deployable wide-area phasor measurement system with stable performance and high dynamic accuracy measurements that requires minimal installation cost. All of these advantages are possible due to The fact that the FDRs are plugged into low voltage outlets (120/220V). The FNET/GridEye provides a variety of situational awareness applications such as real-time event alerts, accurate event location estimation, event visualization, and post event analysis [12-23]. It can provide valuable data about generation electromechanical transients, generation-demand dynamics, load shedding, and oscillation. Figure 5 displays a typical generation tripping event. More information about FNET/GridEye can be found in [24-26].

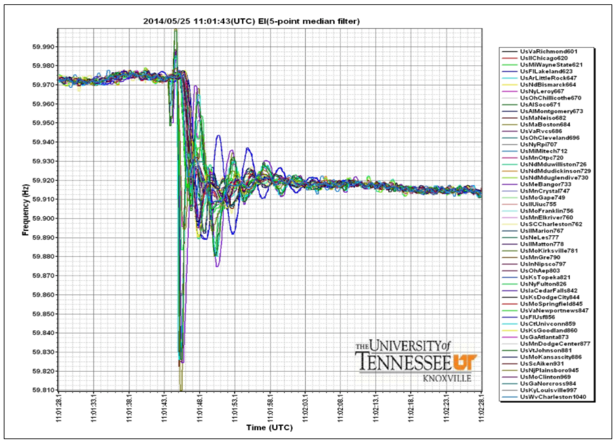

Figure 5: Generation Trip Event

II. DATA REQUIREMENTS AND APPROACH

The generators trips events information, including event date, time, location, as well as the lost amount are provided from FNET/GridEye events reports. Five-minutes LMPs data in real time for all pricing nodes (pnodes) in Eastern Interconnection are provided by Independent Service Organizations including, ISO New England (ISO-NE), New York ISO (NYISO), Midcontinent ISO (MISO), and Southwest Power Pool (SPP).

The findings of these data will be presented mainly by plotting the LMPs for each trip event. The time frame for each plot is 12 hours before and after the event. The impact of the generator trip on the LMPs is considered by looking at the maximum spike in LMPs pattern happened during this time frame. Here, the generator trip is considered to have high impact on the market price if the maximum increase occurs during the first 30 minutes after the event.

III. RESULTS AND FINDINGS

To come up with reliable results of the correlation between generator trips and electricity market price changes, 50 cases of generator trips with known locations are studied. All of these cases are from ISO-NE, NYISO, MISO, and SPP. The locations of these balancing authorities are shown in Figure 6.

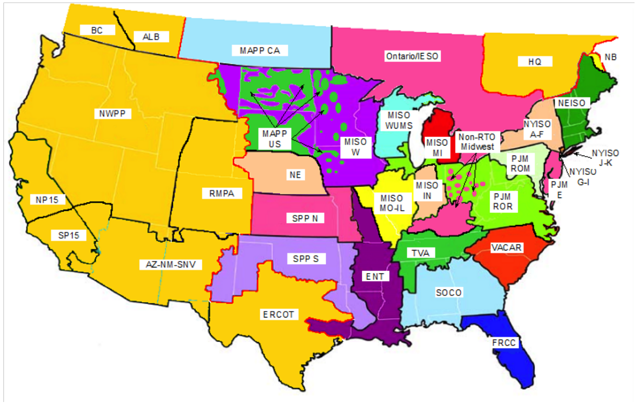

Figure 6. Balancing authorities in the U.S.

A. Cases showing clear correlation between the trip events and the prices changes

It is found that 20 cases, which represents about 40 precents of the studied cases, show a clear correlation between the trip events and the prices changes. This direct correlation, which occurs within 30 minutes after the trip, are shown in the following five representative cases.

1) Case 1

Generator tripped at (Oswego, NY) at 12:10 PM and the maximum increase in the LMPs happened 28 minutes later as shown in Figure 7. This case shows that the price increased immediately after the generation trip event, and then after a few short spikes, the price returned to the level before the generation trip after around five hours. Map in Figure 8 shows the approximate trip location and the price change location, which are located in the same region in NYISO.

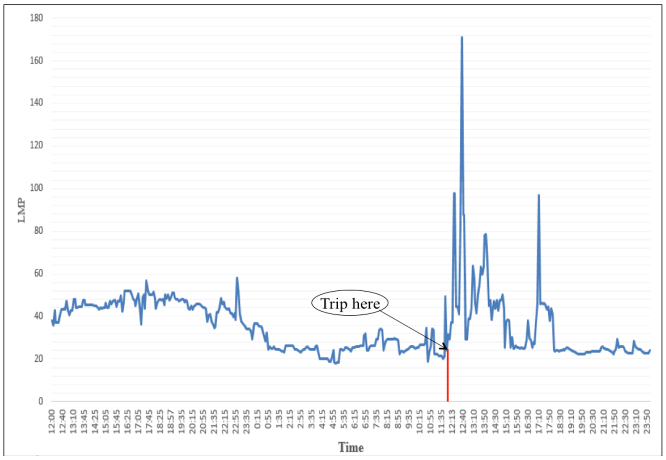

Figure 7. LMPs for Case 1 that shows direct correlation.

Figure 8: Generator trip and price change locations for Case 1.

2) Case 2

Generator tripped at (Waterford, CT) at 7:01 AM and the maximum increase in the LMPs occurred at 7:15 AM as can be seen in Figure 9. Map that shows the approximate trip location and the price change location is shown in Figure 10. In this case, the LMP increased by around 6 times (from $11 to $ 69 per MWh) after the generation trip. This high LMP lasted for around 3 hours before gradually decreasing to between $30-40 per MWh.

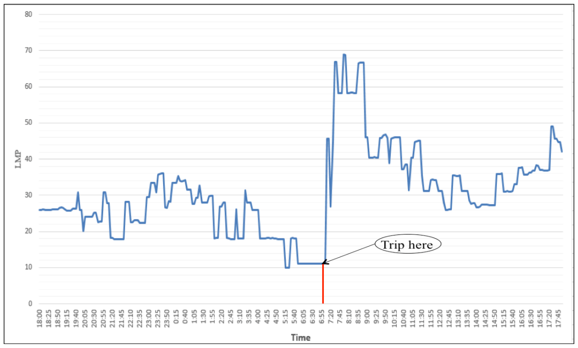

Figure 9. LMPs for Case 2 that shows direct correlation.

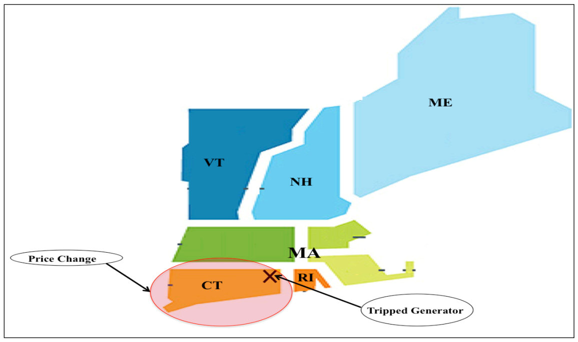

Figure 10: Generator trip and price change locations for Case 2.

3) Case 3

Generator tripped at (Somerset, MA) at 2:06 PM and the maximum increase in the LMP happened after 11 minutes as shown in Figure 11. Figure 12 shows the map of the approximate trip location and the price change location.

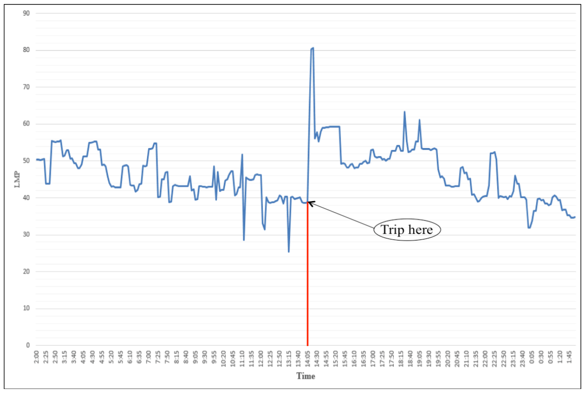

Figure 11. LMPs for Case 3 that shows direct correlation.

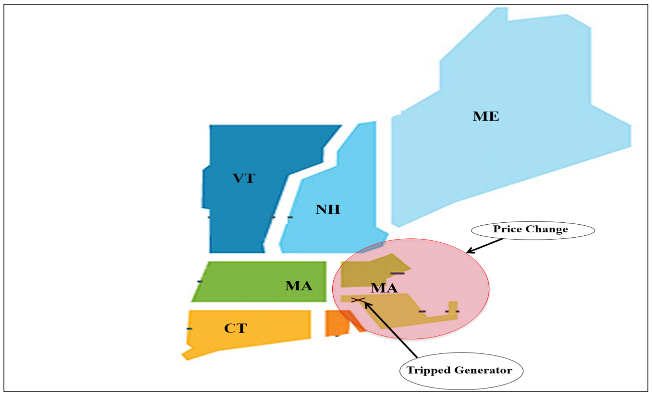

Figure 12. Generator trip and price change locations for Case 3.

4) Case 4

Generator tripped at (Road Island) at 1:34 PM and the maximum increase in the LMP happened at 1:45 PM as shown in Figure 13. Map in Figure 14 shows the approximate trip location and the price change location.

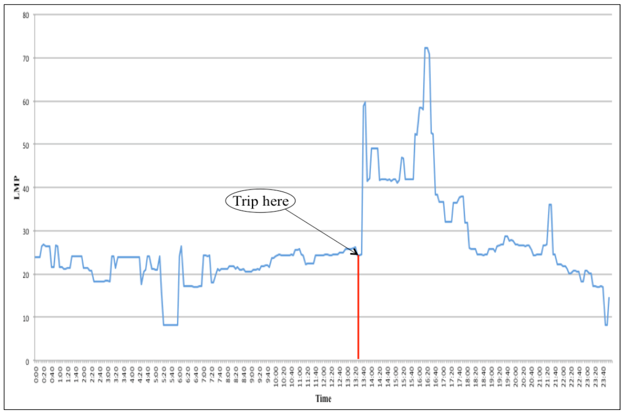

Figure 13. Generator Trip and Price Change Locations for Case 4.

5) Case 5

Generator tripped at (Harrison, TX) at 8:51 AM and the maximum increase in the LMP happened at 9:05 AM as shown in Figure 15. Map that shows the approximate trip location and the price change location is shown in Figure 16.

It has been noticed that these trips, which show an obvious correlation with price change, do not show any impact on the electricity market in other zones. That means their impacts go directly only to their zones if there is any.

On the other hand, seven cases show changes in the price from 30 minutes to 4 hours after the trip event; however, these are not considered as a result of generator trip according to the assumption that the generator trip impact is counted only if the spike happens during the first 30 minutes. In those cases, this increase in the market price might be due to load level increase or transmission line constraints.

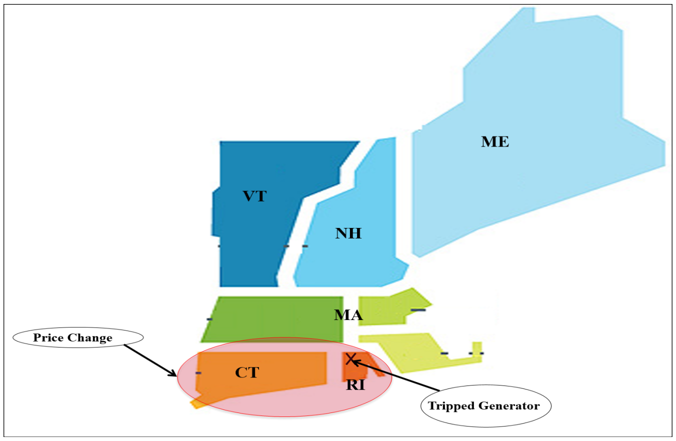

Figure 14. Generator Trip and Price Change Locations for Case 4.

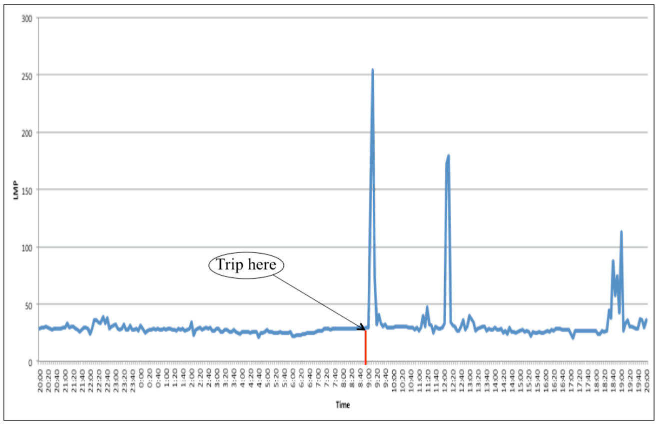

Figure 15. LMPs for Case 5 that Shows Direct Correlation.

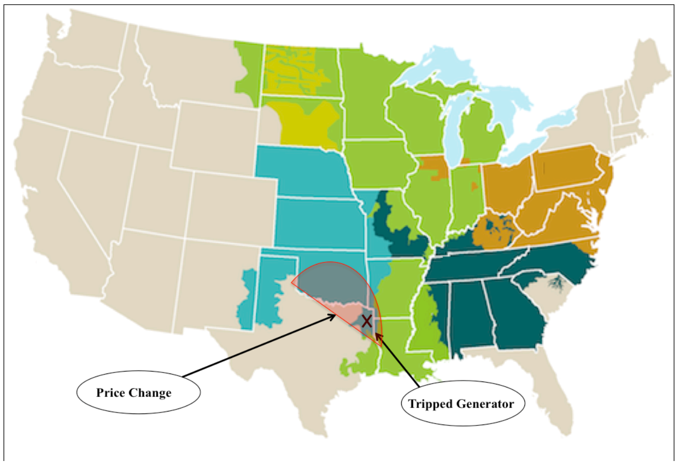

Figure 16: Generator Trip and Price Change Locations for Case 5.

B. Cases without obvious correlation between LMP and generator trip events

The remaining 23 cases do not show any correlation with generator trip events in any zone. This might be because these generators do not carry much of the load in that area. Another possible reason is that contingency reserves are kept such that there is sufficient online generation that can replace the generator that tripped offline. The following cases are examples of trip events that do not have an impact on the LMP prices pattern in the same zone.

A. Case 1

Generator tripped at (Oswego, NY) at 3:27 PM and there is no impact on the electricity prices in the zone where the tripped generator is located. This is shown in Figure 17.

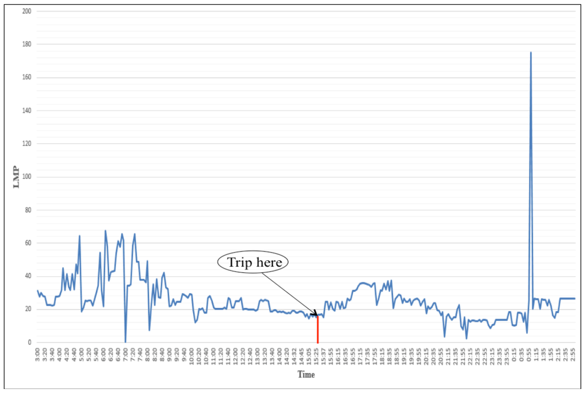

Figure 17. LMPs for Case 1 that does not Show Direct Correlation

B. Case 2

Generator tripped at (Barnstable, MA) at 5:13 PM and there is no big change in the LMP patterns in the zone where the tripped generator is located as depicted in Figure 18.

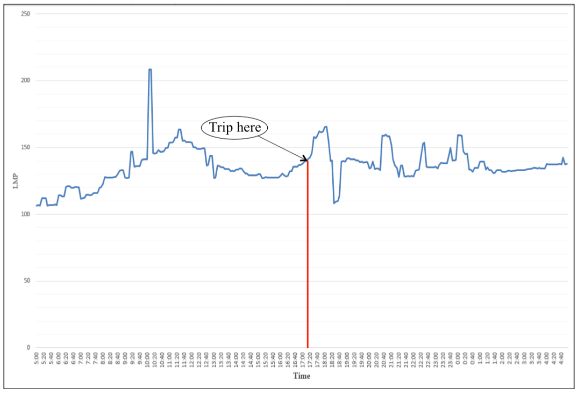

Figure 18. LMPs for Case 2 that does not Show Direct Correlation.

C. Case 3

Generator tripped at (Yarmouth, ME) at 9:14 PM and there is no clear impact on the LMP patterns in the zone where the tripped generator is located as shown in Figure 19.

D. Case 4

Generator tripped at (Queens, NY) at 11:57 AM while the maximum increase in the LMP happened after 5 hours from the trip event as shown in Figure 20.

E. Case 5

Generator tripped at (Rogers, OK) at 1:16 AM and there is no obvious change in the LMP patterns in the zone where the tripped generator is located as depicted in Figure 21.

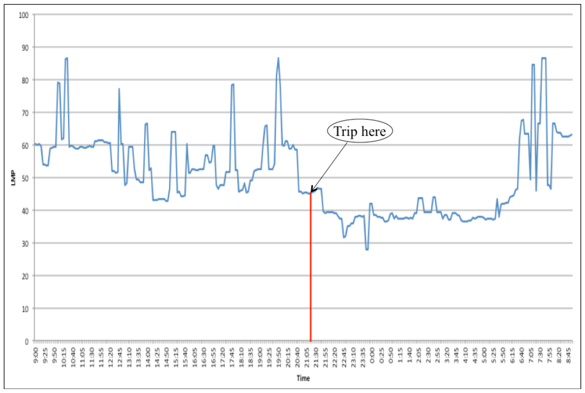

Figure 19. LMPs for Case 3 that does not Show Direct Correlation.

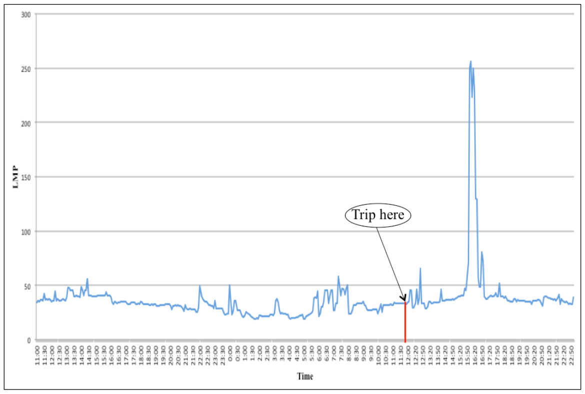

Figure 20. LMPs for Case 4 that does not Show Direct Correlation.

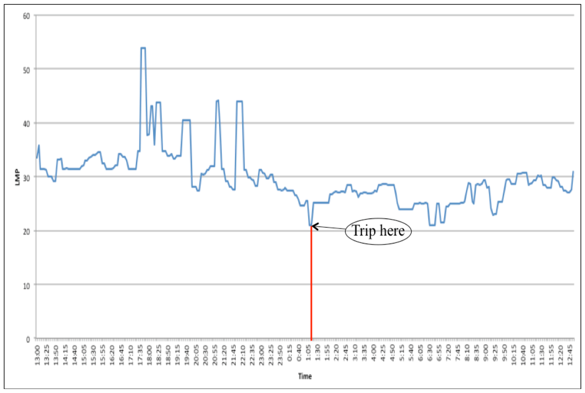

Figure 21. LMPs for Case 5 that does not Show Direct Correlation.

IV. CONCLUSIONS

With the help of FNET/GridEye reports and LMPs data, the influence of generator trip on the real-time market of electricity is observed and analyzed. The significant number of cases that show a clear correlation between generator trip events and LMPs increase verifies that the losing MW amount has a direct impact on the price of the electricity. Generator trip can be added to the other causes that change electricity prices such as transmission line congestion and load level increase.

V. FUTURE WORK

More cases that show a direct correlation between generator trip events and LMPs changes need to be found and investigated in order to determine common characteristics between these cases and to make general guidelines for determining generator trips that have impact on LMPs.

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