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Automatic Generation Control (AGC) Enhancement for Fast-Ramping Resources

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SUMMARY

In 2016, the Midcontinent Independent System Operator (MISO) began evaluating potential enhancements to Automatic Generation Control (AGC) to more efficiently utilize the resource fleet, including better leveraging the use of emerging fast-ramping capabilities of resources. In 2019, MISO began implementation of its new design. The new design is intended to enhance MISO system reliability, improve efficiency and enhance flexibility. To guide the design of enhancements, MISO developed five design principles. These include focusing on system reliability before meeting individual unit needs; avoiding positioning fast and slow resources to work against one another; maximizing the use of both fast and slow resources; avoiding charging fast regulation resources with slow regulation resources; and enabling flexible signals to attract various technologies to support reliability and market efficiency. Based on these design principles, analysis to simulate design options and discussions with MISO stakeholders, MISO developed a design that allows resources to qualify as a fast-ramping resource and uses two separate signals to target standard, or slow-ramping resources, and newly categorized of fast-ramping resources. The design deploys and un-deploys fast-ramping resources first, then gradually replaces deployment of fast-ramping resources with slow-response resources after the initial response. The design also addresses energy-limited resources by taking advantage of opportunities to move energy-limited resources back to their Start of Charge neutral zone and thereby prolong their participation in the regulation reserve market. Based on its analysis, MISO expects to improve reliability and save millions annually in total product costs. This paper presents recent MISO's development and implementation of a new design.

KEYWORDS

Automatic Generation Control (AGC), Fast-Ramping Resource, Energy Storage, Regulation Reserve

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BACKGROUND

Automatic Generation Control (AGC) is one of the many Balancing Authority (BA) functions performed by MISO and guided by NERC BAL standards. AGC calculates Area Control Error (ACE) and routinely deploys regulation reserve to manage ACE with NERC limits. Regulation reserve deployment is used to continuously balance the total output of all resources with the total demand of all the loads (including losses) within the MISO BA area plus the net interchange of the MISO BA area. Regulation deployment is determined based on ACE correction needs.

MISO AGC sends four-second control signals to generation fleets and maintains ACE within limited range for system reliability. The following chart demonstrates different MISO processes and signals which MISO sends to generation fleets.

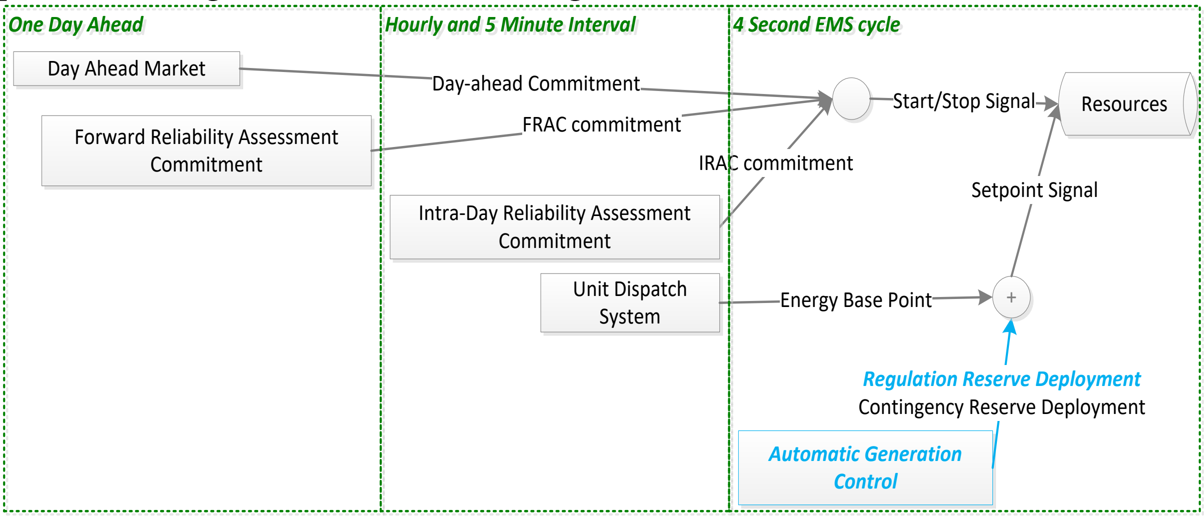

Figure 1 Signals that generation resources received from MISO

Fast-ramping resources such as advanced battery technologies provide the capability to rapidly change power output and have successfully provided frequency regulation in bulk electric power systems. Recent studies have explored the response of battery storage units to AGC signals compared to conventional generators. [1], [2] Within limits, having resources that provide highly accurate, fast response to AGC signals can potentially lower the overall need for system-wide regulation requirement.

In 2016, MISO began exploring potential enhancements to AGC to better utilize resource capabilities and enhance the deployment of fast-ramping resources. This paper proposes a new AGC signal design to separate the AGC signal for slow-ramping resources and fast-ramping resource and this new AGC signal design aims to improve the system operation efficiency and encourage the entries of new technologies into MISO.

DESIGN PRINCIPLES

MISO found that in order to achieve the objectives of maintaining reliability and balancing efficiency and flexibility, it is important to implement the following principles in the new enhancement design.

Principle1. Maintain system reliability before meeting individual unit needs.

In order to continue provide regulation reserve, energy limited resources need to be charged when it is empty or need to discharge when it is full. New enhancement design should provide mechanisms to support this resource continuously provide services. However, these mechanisms have to function after system reliability needs are satisfied.

Principle 2. Avoid fast/slow competing against each other

New design should be careful on sending fast/slow signals directions. If fast/slow signals are on opposite directions, there will be one helping signal and another hurting signal for ACE correction. In the real system, a part of resources might not follow signal very well for variety of reasons. In the situations of hurting signal is followed and helping signal is missed, system reliability could be damaged.

Principle 3. Keep in mind slow resource capability

New design is not only designing a new signal for fast resources but also might change signals that sends to slow resources as well. Design team should check slow signals as well to make sure that slow resource can follow the signal and help ACE correction with their limited ramp-rate.

Principle 4. Avoid charging fast regulation resources with slow regulation resources

MISO regulation reserve is dedicated resource for responding to ACE correction. Due to its bi-direction and fast respond nature, regulation reserve is limited and expensive. For market efficiency, charging/discharge needs of energy limit resources are relatively predictable and persistent in longer time frame than four-second AGC process cycles. These needs should be addressed in unit dispatch process in five-minute time frame and participate economic dispatch optimization for efficiency.

Principle 5. Signal flexibility to attract various technologies for reliability and market efficiency.

MISO wants to attract various technologies into the market as long as they can help. Different type of resources might have various energy durations. It is not fair to favor certain types of resources. New design should avoid use fixed energy duration signals to meet certain resource needs.

DESIGN ELEMENTS

With the design principles in mind, MISO then explored what sub-elements of the existing design it might adjust. For each one, MISO evaluated several possible options.

Element 1. Input Signal

MISO decided to use total filtered ACE instead of direct raw ACE as the starting point for the enhanced AGC logic. While re-designing the ACE filter would have taken longer to complete and the existing logic was flexible and had parameters that could be tuned to work well with fast-ramping resources.

Element 2. Fast Signal Design

The design of the fast signal focused on what signal AGC would send to fast-ramping resources. MISO explored several options and decided to use a new logic to deploy and un-deploy fast-ramping resource for first response. MISO excluded the option of using a signal with a fixed duration filter (fixed parameter high pass filter). This signal responds to changes of the input signal and pulls back the fast signal to zero within a fixed duration (for example, 30 minutes) as shown in below chart. The benefit of this filter is that it can limit the energy usage of a signal within a fixed duration.

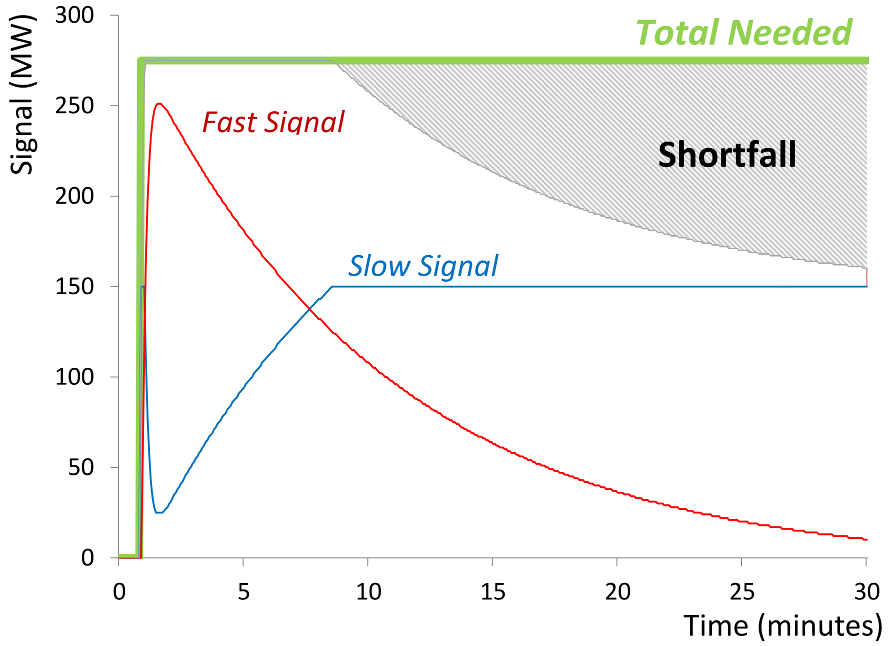

Figure 3 Signals from fixed duration filter

However, this filter can also lead to insufficient response to total ACE correction need. This is true where the fast signal begins to withdraw back even though slow-response resources are reaching their limit of cleared reserve. In one case using a 30-minute filter, after ten minutes of persistent deployment, the total signal started to deviate from total need. In turn, system frequency would deviate by losing the regulation deployment support. This shortfall would become more and more significant with the percentage of fast resource increasing in regulation reserve. It will limit the percentage of fast resource in regulation reserve.

MISO developed a new logic to deploy and un-deploy fast resource first. It lets fast resources to respond to the instant changes of total ACE correction need.

$$R_{fast}'(t) = [R_{total}(t) - R_{total}(t-1)] + R_{fast}(t-1)$$

Where

$R_{total}(t)$	AGC deployed total regulating reserve for MISO at time slot t
$R_{fast}(t)$	AGC deployed regulating reserve on fast-ramp resources at time slot t
$R_{fast}'(t)$	The term of fast signal responding to changes of total deployment

By doing this, the new logic takes advantage of the fast-ramping character and promotes the response rate of the overall fleet of regulation resources. It increases the fast signal regulation deployment mileage, which therefore increases the regulation mileage payment, creating a greater incentive for fast-ramping resources in the MISO market.

Element 3. Fast-Slow Resource Coordination

To enhance system flexibility, fast-ramping resources can be preserved for future ACE changes during persistent regulation deployment. Also, some fast-ramping resources, such as energy storage, are energy limited. If they are required to provide continuously single direction output to the grid, they cannot fulfill the request in extended periods of time due to energy limits. To take advantage of their fast-ramp capabilities for ACE correction while reducing their energy outputs, fast/slow resources could work together towards meeting system need. The Fast-First logic coordinates fast and slow signals to allow fast-ramping resources to enhance system response capability and slow-ramping to provide persistent support by gradually replacing deployment on fast-ramping resources with slow-ramping resources.

The following formula conceptually shows how Fast-First logic could be designed to achieve the goals of fast-ramping resources responding to transitional changes and the slow resources responding to persistent deployment. The fast—ramping resource signal is made up of multiple components. The first term, R_{fast}', orients fast-ramping resources to respond to transitional changes. The second term, $\varepsilon*\{...\}$, coordinates the slow and fast response resources to meet the total ACE correction need. As slow response resources ramp, the fast response resources will adjust according to the total need. The rate at which fast-ramp resources adjust is determined by ε. This would result in greater movement of fast-ramping resources, and the ability to use slow-ramping resources for persistent signals as needed.

$$R_{fast}'(t) = [R_{total}(t) - R_{total}(t-1)] + R_{fast}(t-1)$$

$$R_{fast}(t) = R_{fast}'(t) + \varepsilon * \{sign(R_{total}(t)) * max[|R_{total}(t)| - RClr_{slow}(t), 0] - R_{fast}'(t)\}$$

Where

$RClr_{slow}(t)$ UDS cleared regulating reserve MW on slow-ramping resources at time slot t

ε Damping factor, which is a positive value and less than one

The slow signal is created by subtracting the fast signal from the total deployment.

$$R_{slow}(t) = R_{total}(t) - R_{fast}(t)$$

Where

$R_{slow}(t)$ AGC deployed regulating reserve on slow-ramping resources at time slot t

Overall, the fast-signal responds to instant changes of total deployment and gradually adjusts so as to make room for slower ramp resources as they catch up. This approach provides slow-ramping resources with smooth changing signals. It would create a slow signal, making compliance easier. Figure 4 demonstrates how the logic works. Together with slow and fast-ramping resources, total deployment satisfies the ACE correction need in all times.

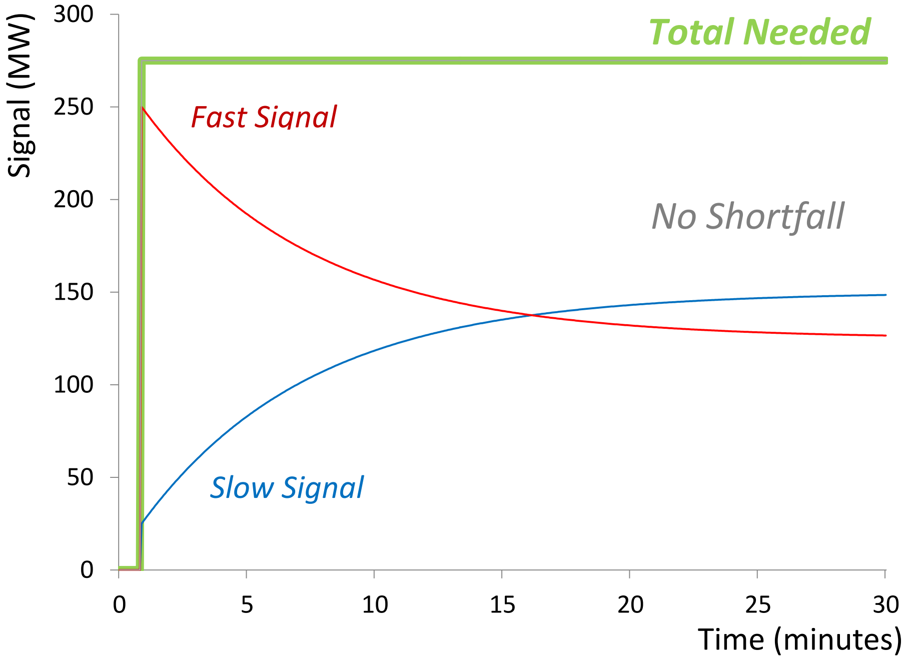

Figure 4: Signals from 'Fast-First' logic

Element 4. Energy Neutrality of Fast Signal

Many fast-response resources are also energy limited resource, such as battery energy storage. Some AGC designs have contemplated a guarantee or conditional guaranteed of an energy neutral signal. Guaranteeing that a fast signal would have minimal amounts of energy over a fixed duration can help keep the energy level of energy-limited resource within neutral zone. However, MISO found that variability and uncertainty in the MISO system makes that very hard to implement while maintaining reliability and efficiency. In particular, MISO cannot guarantee ACE minimal energy component over a fixed duration. Therefore, as an ACE correction, total regulation deployment cannot guarantee energy neutrality over a fixed duration. Instead of guaranteeing energy neutrality in the fast signal, and potentially having resources work against the aggregate system need in order to guarantee neutrality, MISO decided to address energy duration concerns by helping a device's state of charge back to neutral zone signal while the ACE correction need is satisfied, reducing the energy components of the fast signal and monitoring resource energy levels.

With the process of gradually pulling back regulation deployment on fast-ramping resources, Fast-First logic could reduce energy components in the fast signal. Meanwhile, with knowledge of resource energy levels, AGC logic could choose to only pull back when the energy component drags resource energy levels away from the energy neutral point. If the energy component helps to return energy levels back to neutral, AGC could keep that part of the energy in the signal. Fast-First logic moves limited-duration resources back to neutral whenever the situation permits, by Permissively Charging, based on the energy level. Permissively charging works differently under different situations (Figure 5).

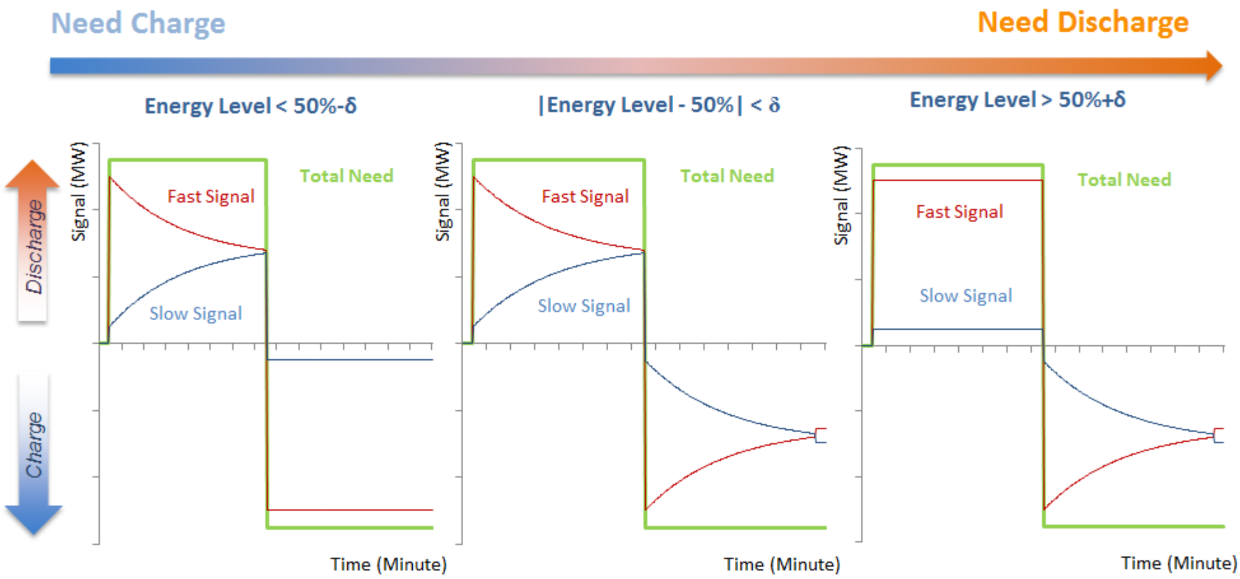

Figure 5: Permissively charging signals scenarios

After total regulation deployment determined ACE correction need, AGC split the deployment into a total fast signal and total slow signal. AGC then needed enhanced logic to allocate the total fast signal to each individual fast resource. The new allocation approach uses a preferred energy level position for energy-limit resources within a limited range of its total capacity, e.g., 50 percent. When the energy level deviates from this preferred position, the AGC takes opportunities to move it back to this neutral point. This requires resources to provide MISO with real-time data on the resource's energy level (e.g., state of charge for battery resources). Fast-ramping resources without energy limitation are considered as always neutral. With information on energy levels for energy-limited devices, AGC can create a dispatch order based on the degree of deviation from the neutral state. The AGC allocation logic then needs to consider the current deployment direction and deploy accordingly. If the total signal is discharging resources, the resource closest to full would be discharged as much as possible (Figure 6). Meanwhile, the resource closest to empty would be deployed as little as possible. If the total fast signal is enabling charging of the resources, the resource closest to empty should be deployed to its fullest extent. This approach can potentially help limited-energy resources continuously provide regulating reserve by reducing the chance of reaching energy limits.

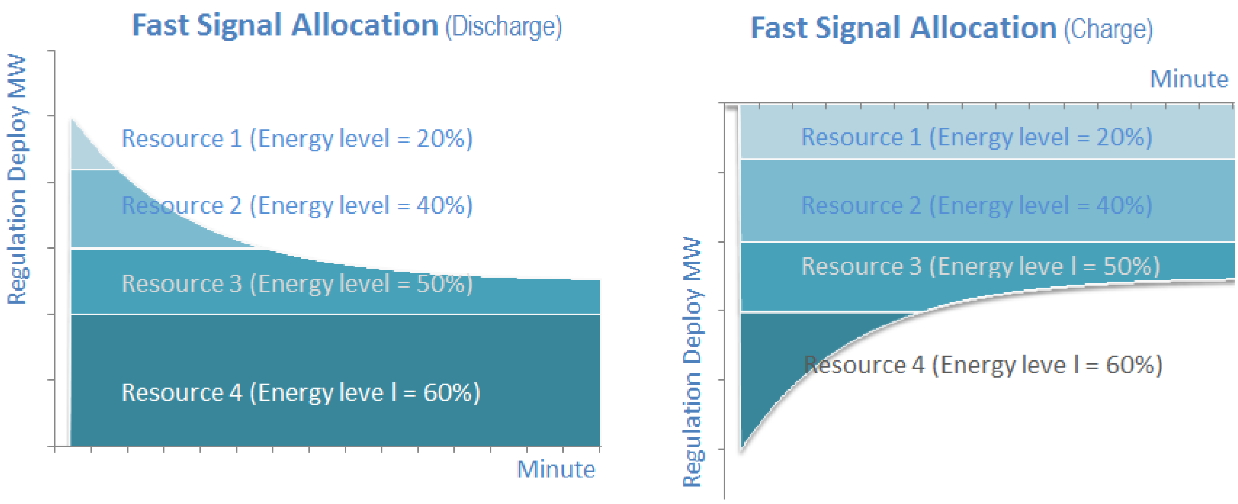

Figure 6: Sample signals for allocation based on energy level deviation from neutral state

Element 5. Performance validation

In implementation of this enhancement, MISO dynamically evaluates performance of fast-ramp resources and qualify/disqualify resources eligible to fast AGC logic. Performance calculation on a Regulating Reserve qualified Resource is calculated on a rolling 5 min basis based on four-second sampled actual output and set point while accounting for measurement communication delay. Disqualified resources will pull back to slow regulation reserve pull and not participating total fast deployment allocation.

SMULATION AND RESULTS

Before implementation, MISO did many scenarios study with a simulation tool to generate ACE and frequency deviations. The CPS1 score was then calculated over the simulated period. Although MISO operations currently use NERC BAAL as compliance metric, CPS1 performance measure provides a continuous performance score, other than just a discrete number of violations as measured for BAAL compliance. This mechanism provided for an easy comparison between design options.

Figure 7 provides a glimpse of how Fast-First logic works in real-time system conditions. This is a result of a simulation for a MISO operation day with Fast-First logic. Each feature is highlighted in blocks.

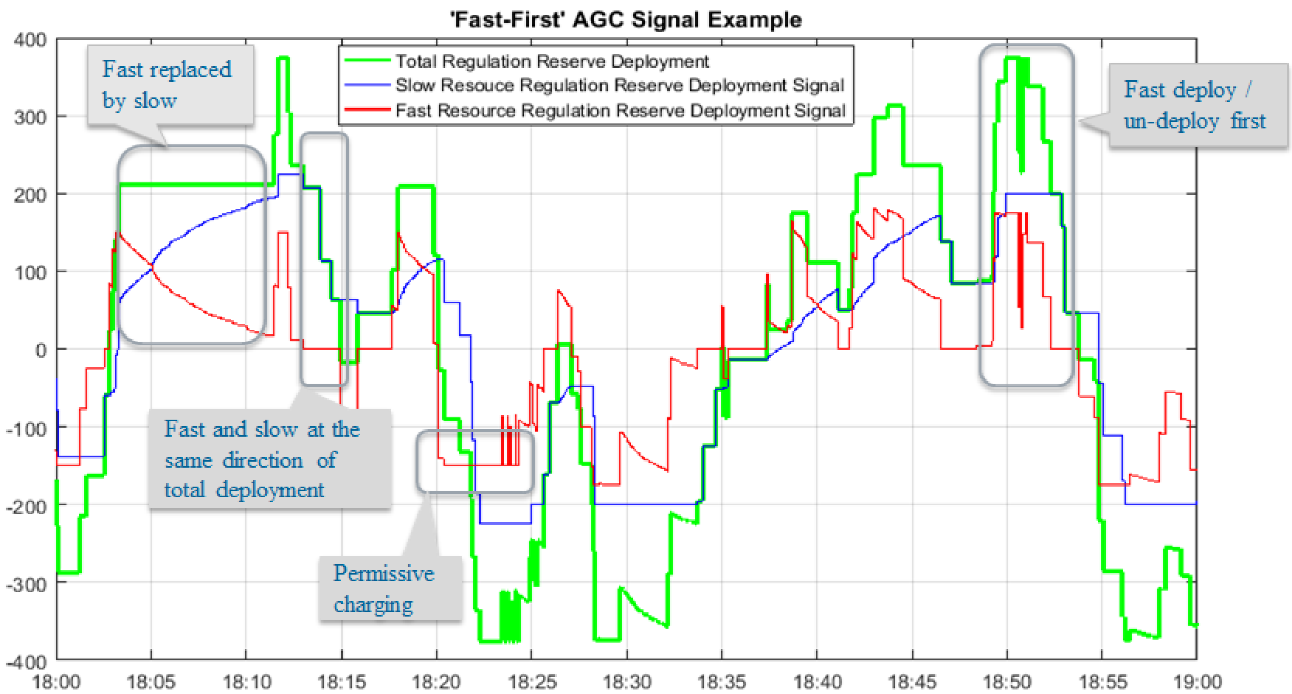

Figure 7: Sample signals from recommended Fast-First logic

In the study, MISO simulated fast AGC logic with different fast signal designs and with the same operation data. Fast-First with permissive charging provides the best CPS1 score while keeping unperformed mileage due to energy limits under control (Figure 8).

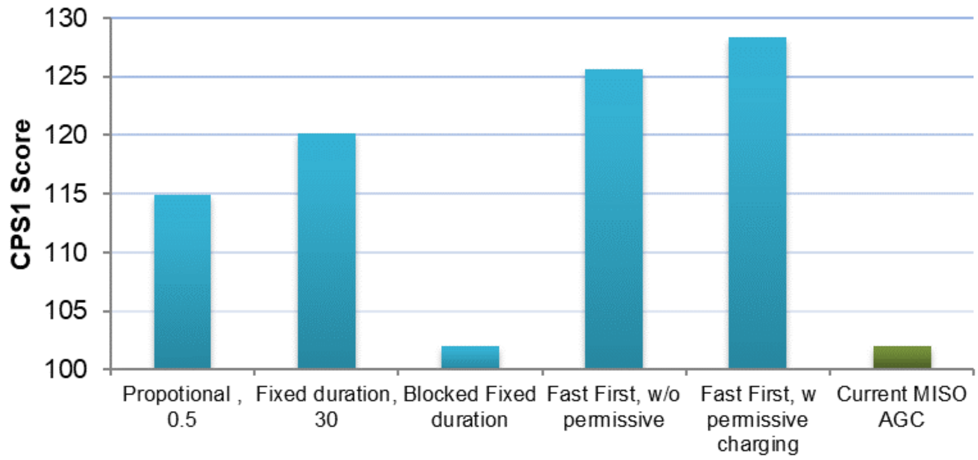

Figure 8: Simulation CPS1 score comparison with different fast signal design

In the simulation, it is assumed that fast-ramping resources provides half of MSIO current regulation reserve and with energy capacity to support 1-hour operation. When a resource's energy level reaches full or empty states, the resource is unable to respond to the AGC signal. That part of undelivered regulation mileage is calculated. Figure 9 shows percentages of undelivered versus total regulation deployment signal mileage. This demonstrates new design best utilizing energy limited resource. Both CPS1 score and undelivered mileage supports Fast-First with permissive charging is the best choice of design.

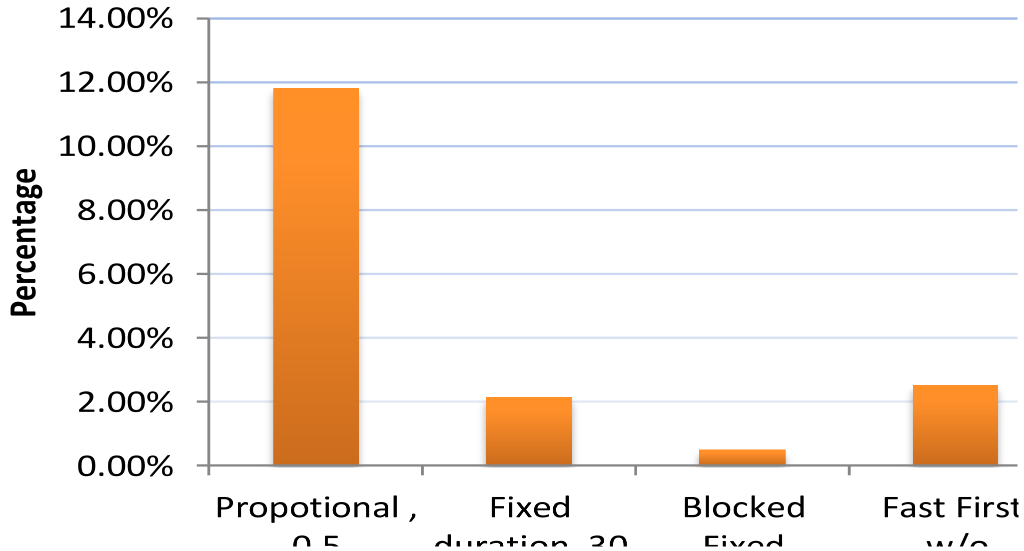

Figure 9: Simulation CPS1 score comparison with different fast signal designs

AGC enhancements will provide incentive to attract more fast-ramping resources into MISO system. Fast-ramping resources can enhance the flexibility of the system by increasing system operators' control of the system during normal and emergency conditions. Considerations and features recommended and specifically designed to accommodate energy-limited resources would allow resources to provide more continuous quality service to MISO markets while enhancing MISO market efficiency. Simulation shows this design works with different levels of fast-ramping resource penetration (Figure 10).

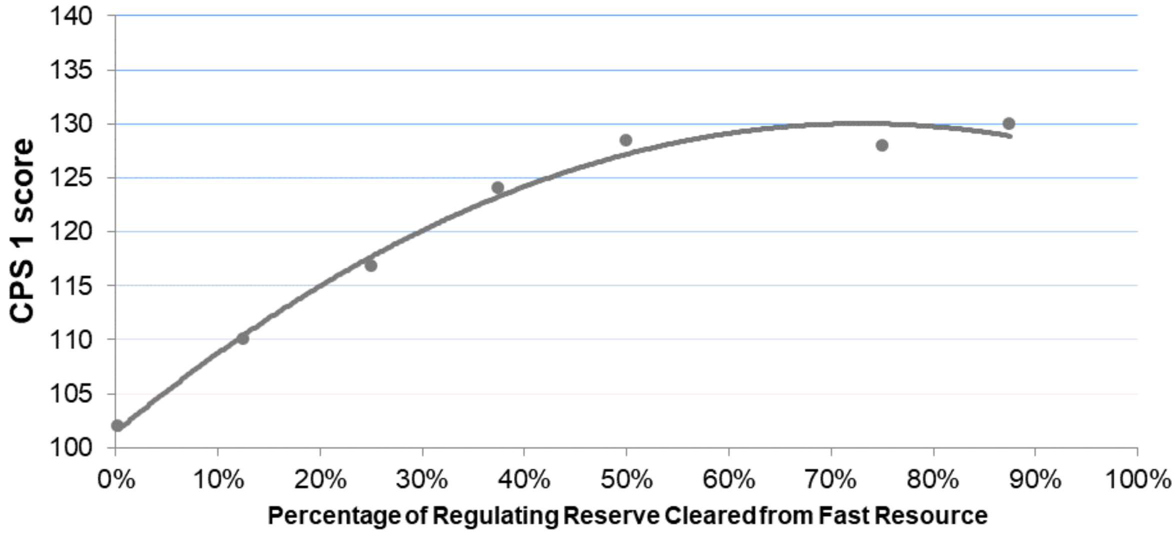

Figure 10: Simulated CPS1 score under different fast-ramping resource capacities

This chart is simulated with different fast-ramping resource capacities and assumes one-hour energy duration. In each scenario, regulation requirements were set same as production. As the percentage of regulation cleared from fast-ramping resources increases, CPS1 scores improved when compared to scenarios without fast-ramping resources. With large amounts of fast regulation from energy-limited resources, the risk of hitting energy limits increases. That is the reason that, after the 70 percent mark, CPS1 score improvement is less significant. However, since MISO monitors the resource's state of charge, when energy limits are constrained, UDS will adjust dispatch and clear slow resources for regulating reserve. Therefore, with slow regulation resource as backup, the risk is limited within 5-minute intervals.

Since fast-ramping resources can respond quickly to ACE correction, simulation indicates that fast-ramping resources could improve the CPS1/BAAL score. Alternative, fast-ramping resources could potentially reduce regulation requirements while maintain the same score. MISO simulated scenarios of different level regulation requirements based on the capture of MISO system conditions for one of summer peak, with or without 200 MW of fast-ramping resources providing regulating reserve. Simulated CPS1 scores are different under each scenario (Figure 11). Simulation results show that MISO only needs 80 percent of the normal regulation requirement to achieve the same CPS1 score. However, due to uncertainty with future renewable energy penetration, MISO does not recommend a reduction of regulation requirement. Increasing fast-ramping resources in the MISO system could put MISO in a better position to face future challenges.

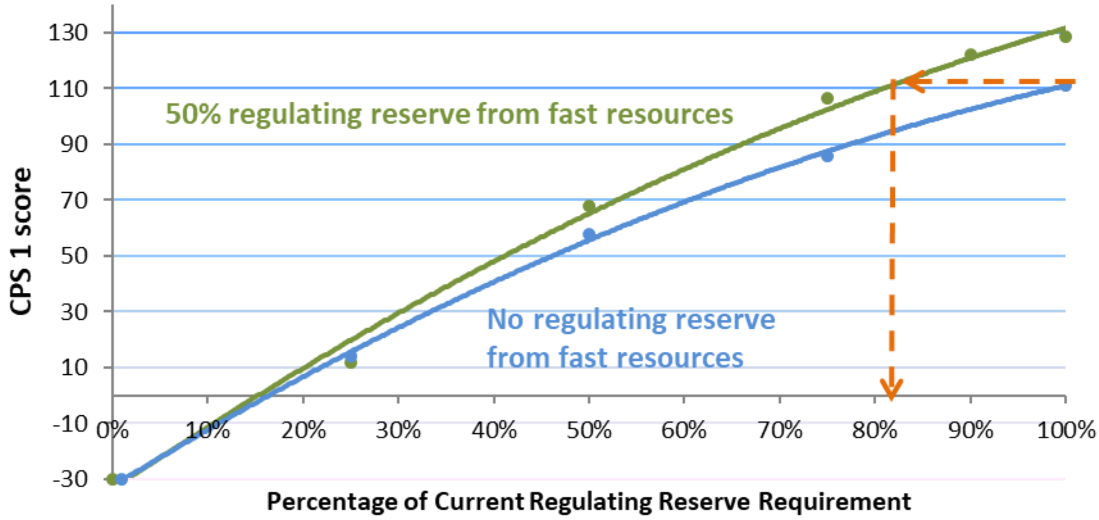

Figure 11: Daily CPS1 scores under different levels of regulating reserve requirements

Regulating reserve in MISO is defined as a bidirectional product. In economic dispatch, clearing regulating reserve constrains traditional resource limits on both the minimum and maximum of their operation ranges. With additional fast-ramping resources providing regulating reserve, total production cost could be reduced by freeing up resources to provide energy or contingency reserves. The simulation estimated annual savings is $14 million if fast-ramping resources provides half of MISO regulation reserve, for example. There is a cost associated with this enhancement. Apart from implementation costs, it is likely that mileage compensation would increase. However, in the total cost-to-benefit ratio, this cost is relatively small compared to the amount of benefit received.

GLOSSARY

AGC	Automatic generation control (AGC) is a system for adjusting the power output of multiple generators at different power plants, in response to changes in the load, frequency, interchanges, etc.
ACE	Area Control Error (ACE) of a Balancing Authority, the magnitude and direction of which are sought to be limited by measures to comply with NERC control performance standards.
BAAL	The Balancing Authority ACE Limit (BAAL)
CPS	Control Performance Standard. NERC-established standards to measure Balancing Authorities' performance in maintaining energy balance and scheduled frequency.
KERMIT	A Renewable Market Integration Tool developed by DNV-GL, formally KEMA, to study how integrating large penetrations of renewable power affects sub-hourly operations
NERC	The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to assure the reliability and security of the bulk power system in North America.
SOC	State of charge (SOC) is a measurement of energy amount stored in energy-limited resources.

UDS Unit dispatch system (UDS) is MISO's 5-minute real-time energy and ancillary service co-optimization clearing engine.

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