Journey of a Renewable MegaWatt – from an Interconnection Request to Real-time Market Dispatch

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***Abstract*—Due to availability of a rich renewable resource and a favorable political climate, there has been tremendous growth of renewable generation in the Mid-continent ISO (MISO). MISO has significantly improved its processes around generator interconnection, transmission planning, system operations and markets to ensure reliable and efficient integration of bulk quantities of wind and solar power. This article presents the various aspects of System Planning and Operations at MISO that facilitate the journey of a renewable resource from a conceptual project to a viable, commercially operating generating facility in the MISO market.**

Keywords-renewable generation, system planning, system operations, energy market

I. Introduction

MISO is a not-for-profit, regional transmission organization with responsibility to ensure the reliability of the high-voltage electric transmission system and to deliver low-cost wholesale energy to consumers. The wholesale markets that MISO manages are the largest in North America in terms of geographical scope, as shown in Fig. 1 ahead, serving about 42 million people across all or parts of 15 states, stretching from the Canadian border to the Gulf of Mexico. They are also among the largest in the world as measured by transactional value, with more than US $25 billion in annual gross market charges [1]. Additionally, MISO also serves as the reliability coordinator for the Canadian province of Manitoba. Currently, the MISO market region contains about 66,000 miles of high-voltage transmission with an aggregate value of approximately US $38 billion, as well as 175,000 MW of electricity-generating capacity.

Majority of the MISO footprint is rich in wind energy resource as seen in Fig. 2 [2]. Recognizing this tremendous resource, many states in the MISO footprint have enacted Renewable Portfolio Standards (RPS), mandating load serving entities to supply a portion of their load using renewable energy [3]. Majority of the states are relying on wind energy to meet their RPS needs, but more recently even solar plants are being added to the mix, given that the MISO footprint has a fair amount of solar energy resource as well [4]. Therefore, driven by such regulatory policies and increasingly favorable economics, wind and solar power plants are being developed in the MISO footprint (as well as in other parts of the US) at an unprecedented rate.

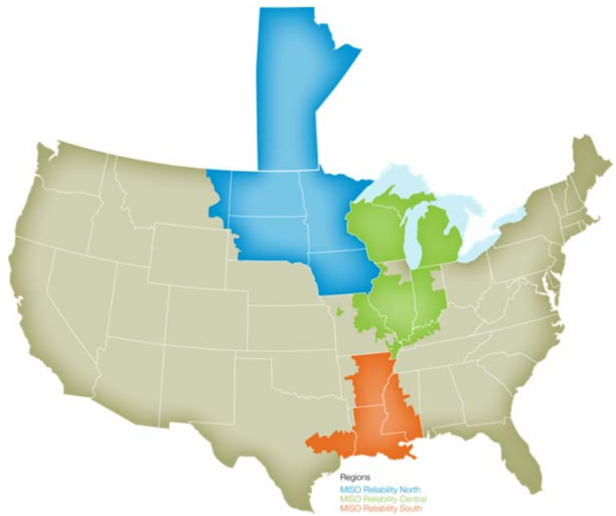

Figure 1. MISO footprint

Increased penetration of renewable generation has presented numerous challenges for transmission planning, system operations and market development [5-7]. The sheer volume and interdependencies of interconnection requests has made generation interconnection planning studies increasingly complex.

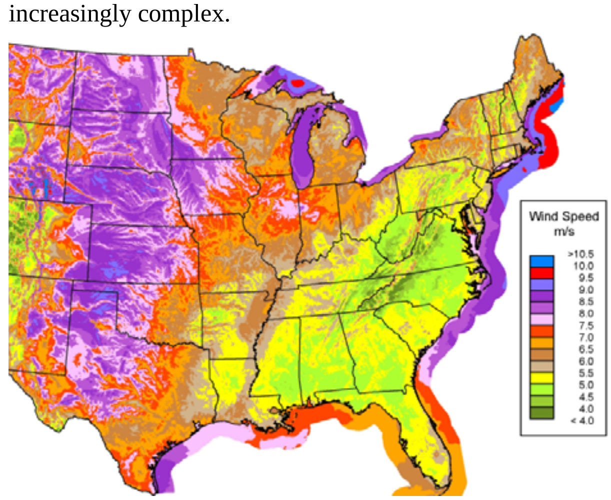

Figure 2. Rich wind energy resource in MISO footprint

Moreover, significant investments are needed to build the transmission infrastructure necessary to deliver power from these, often remotely located energy resources to the load centers – which has caused the overall transmission planning processes and cost-allocation mechanisms to be revised.

The need to manage the variability of these renewable resources – both in terms of quantity and timing of the output – has spurred development of innovative tools and technologies. Wind and solar forecasts are key inputs to ensuring reliability and efficiency of systems with high renewable penetration – and these renewable energy forecasting capabilities are steadily maturing. Increasing penetration of renewables has also driven market enhancements to effectively manage generation dispatch to maximize the utilization of these resources.

This paper discusses the efforts taken over the last decade or so at MISO to effectively integrate large quantities of renewable generation. Aspects of transmission planning and system operations that are instrumental in transforming a conceptual project into an actual, commercially operating renewable power plant are presented.

II. Generation Interconnection Process

As a RTO, MISO is responsible for regional transmission planning and for expansion of the transmission system to reliably accommodate proposed generation within its footprint. Before a new generator can interconnect to the transmission system, it is required to achieve a Generator Interconnection Agreement (GIA) through the MISO generator interconnection process. Generation interconnection procedures at MISO are based on a Federal Energy Regulatory Commission (FERC) approved tariff [8]. The GIA is a culmination of the planning and engineering studies performed to identify transmission improvements necessary to reliably accommodate the new generator on to the transmission system. The GIA is a three-party agreement - between the interconnection customer, the interconnecting transmission owner (TO) and the transmission provider (MISO), which documents the terms and conditions of the interconnection including the transmission upgrades necessary, their construction cost and schedule estimates, and any other stipulations on the interconnection service.

MISO has been inundated with requests for interconnecting proposed renewable generation over the last several years. Historically, among renewable generation, the queue has been dominated by wind generation, and more recently requests for solar generation have begun to make their presence felt as well. Fig. 3 below shows the cumulative MW of wind & solar requests in the queue over the last decade, as well as the percent of the total queue that is comprised of renewable, mostly wind generation. It is noteworthy, that until 2006 only about 20% of the queue comprised of proposals for renewable generation. With the enactment of the various renewable portfolio standards in 2007 within the MISO region [3], that percentage shot up to over 80%! In the years following the RPS mandates, the queue peaked out where over 90% of requests (in terms of MW) were for interconnecting renewable generation. Presumably, due to the glut in the amount of proposed renewable projects chasing a finite demand (as stipulated by the RPS requirements), as well as due to a continued decline in natural gas prices, MISO began to observe an increase in requests for proposals to interconnect new gas generation, with a corresponding slowing down of the requests for new renewable generation for a few years. However, recently MISO has seen a sharp increase in the requests for renewable generation, and this second peak is being driven by requests to interconnect new solar generation. Solar generation development is driven both by policy [3] as well as by the continued decline in costs for developing solar power plants [9], which are making them very competitive.

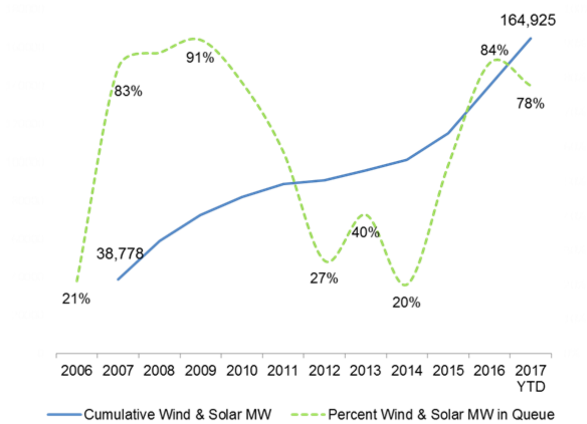

Figure 3. Wind and Solar Generation Interconnection requests over the last decade at MISO

Given the size of the queue, and with large amounts of proposed generation facing a constrained transmission system, processing these requests has been challenging. MISO has taken on numerous efforts to improve the cycle time for processing interconnection requests. MISO initially studied these under the FERC pro forma procedures enacted under the landmark Order 2003 [10], which standardized large generation interconnection procedures. Since then, MISO has worked to revise its interconnection tariff multiple times – the most significant one was the successful revision in 2008 [11], where MISO got FERC approval to transition the queue from a *"first-come, first-served"* paradigm (as stipulated by Order 2003) to a *"first-**ready**, first-served"* concept, with the readiness being two-fold: i) the transmission system being ready to accommodate the new generation, and ii) the developer being ready to actually build the generating facility, rather than to simply make an interconnection request. Interconnection customers that demonstrate readiness to build the project by meeting various technical and non-technical milestones are given priority regardless of queue position. Details are provided in [8].

Following are some of the broad issues with the Order 2003 approach which seemingly were preventing expeditious processing of interconnection requests, mostly renewables:

– Queue position being significantly valuable – provided flexibility to an earlier queued request, which translated into an unmanageable amount of uncertainty and risk to subsequently queued requests
– Lower cost of entry into the queue – was not a barrier for speculative requests to enter the queue which

increased uncertainty for serious projects

– No cost/penalty for suspension, resulting in large number (& MW) of projects being suspended which adversely impacted timelines and uncertainty for later queued generators
– High attrition driven primarily by the apparent oversupply of requests, causing rework, delays and uncertainty for subsequently queued projects

MISO's current process under the first-ready, first served approach has alleviated much of the concerns noted above. The process comprises of the following phases:

- **Pre-queue phase**: Accept interconnection request along with the corresponding study deposits and readiness milestones; and ensure that the customer is sufficiently educated about the overall interconnection process.
- **Application review phase**: Conduct scoping meeting between the interconnection customer, MISO and the impacted transmission owner(s) to ensure that the application is valid and ready to be processed.
- **Definitive Planning Phase**: This is the studies phase where the required planning and engineering studies are performed to identify transmission system upgrades necessary to accommodate the new generation, and their construction cost and schedule estimates. Studies typically include performing power flow, short-circuit and transient stability evaluations.
- **Generation Interconnection and Facilities Construction Agreements (GIA/FCA)**: The terms and conditions of the interconnection are negotiated during this phase of the process and are documented in three-party agreements. The GIA is between the interconnection customer and the interconnecting TO, whereas the FCA includes any impacted transmission owners other than the TO where the proposed generation is interconnecting.

Overall, the tariff timeline to complete the current process is around 500 days. Details of the process can be found at [12, 13]. Obtaining the generator interconnection agreement is the first step towards integrating renewables into the MISO system.

III. Transmission Planning & Cost-allocation

It goes without saying that interconnecting and integrating bulk quantities of renewable generation typically requires massive upgrades to the existing transmission system. While identifying the most cost-effective transmission solutions is challenging indeed, determining an equitable cost-allocation for these upgrades is even more challenging. Given that these assets would be in use for well over 30-40 years, ensuring over time that the costs are allocated commensurate with the beneficiaries is indeed critical.

MISO's transmission planning has evolved over the last decade or so, from being driven primarily by reliability needs to a value-based process focused on ensuring reliability as well as on minimizing the total cost of delivered power to consumers. This evolution of the process was necessary to plan for the renewable generation expected to be developed across the footprint to meet the RPS enacted by the various states within MISO. An estimate of renewable capacity necessary to meet the RPS mandates is in the range of 23,000-25,000 MW. While historically, transmission upgrades necessary for interconnection of new generation had been identified through the generation interconnection process, the amount of transmission necessary for interconnecting this large amount of new, renewable generation was expected to be massive. Planning for transmission upgrades for individual projects (or at best groups of projects expected to share transmission upgrades) would have been a much more onerous effort – and more importantly would have led to a more expensive, yet less efficient transmission solutions. Moreover, transmission upgrades of this scale (numerous EHV lines spread across the footprint) would naturally have multiple system benefits including reinforcing overall system reliability and improving market efficiency in addition to interconnecting the renewable generation. Therefore looking at the problem holistically, instead of consideration of individual interconnection requests was a prudent approach. Ref. [14] compares the various cost-allocation mechanisms at MISO and tries to articulate how the MVPs and their corresponding cost-allocation, is equitable compared to relying on cost-allocation rules governed by the GI tariff.

Fig. 4 below shows a graphical representation of MISO's value-based planning process [15, 16]. This process was instrumental in the development of the Multi-Value Project (MVP) portfolio, which comprised of 17 transmission projects costing around US $6 Billion, developed primarily to accommodate bulk quantities of renewable energy [17]. While having a robust transmission planning process is crucial, it is equally necessary to have a cost-allocation approach that seeks to allocate costs for new transmission projects commensurate with the spread of the project's benefits.

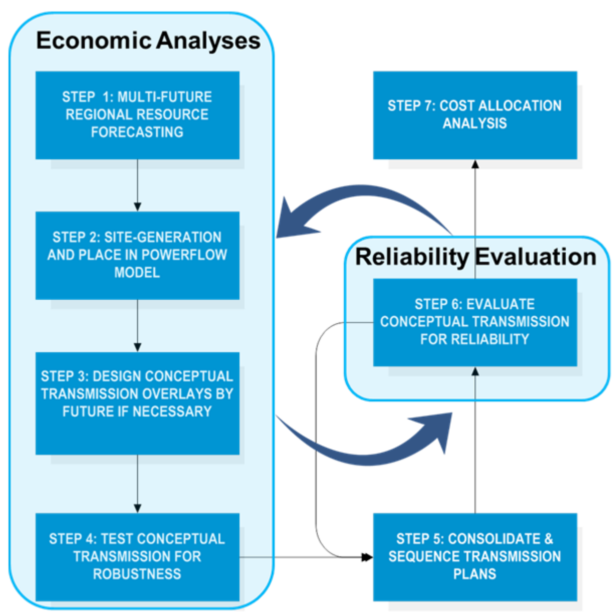

Figure 4. MISO's value based planning process

MISO's cost-allocation approach, which was instrumental in ensuring the approval of the MVP projects through its stakeholder process, classifies transmission projects into five different categories [15] based on the extent of benefits and costs, as shown in Fig. 5, and described ahead.

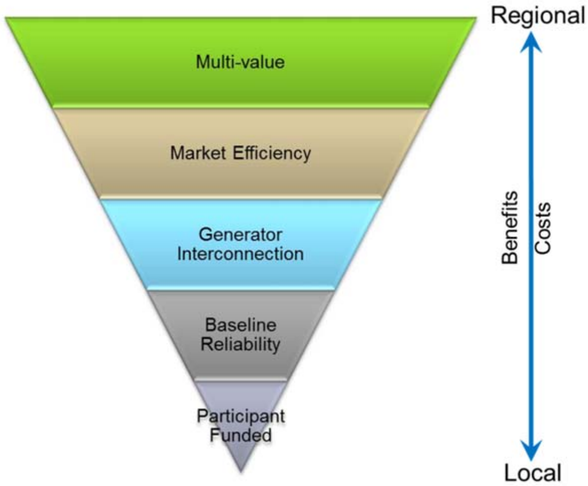

Figure 5. Cost-allocation categories for transmission projects

- **Multi Value Projects** address public policy drivers and/or provide widespread benefits across the footprint, and thus are cost-allocated across the footprint load.
- Economic benefits of **Market Efficiency Projects** spread farther beyond the local zone, and thus these projects are cost-allocated more broadly, based on observed benefits.
- **Generator Interconnection Projects** mitigate system impacts caused by new generation and are paid for primarily by Interconnection Customer
- **Baseline Reliability Projects** are driven by NERC reliability criteria and are paid for by the local zone, as majority of the benefits of such projects stay in the zone in which the reliability issue exists.
- **Participant funded projects** are paid for by the party proposing the project and address a specific, typically narrowly focused need.

Therefore in summary, from a transmission planning perspective, for efficient interconnection and delivery of large-scale renewable resources, robust generation interconnection, value-based transmission planning and equitable cost-allocation approaches are essential.

IV. System Operations with Renewable Generation

Broadly, integration of new generation into the transmission system can be viewed as a two part process:

1) Identification of the required network upgrades through the Planning process to reliably interconnect and deliver the proposed generation to load, and
2) Reliable operation of the generating facility upon achieving commercial operation.

The remaining portion of the article presents some of the operational considerations involved in dealing with renewable generation integration.

A. *Transition from Planning to Operations:*

Execution of the GIA obligates the generation developer to build the generating facility and the impacted transmission owner(s) to complete the necessary transmission system upgrades identified through the planning studies and agreed upon and documented in the GIA. As the generator approaches its commercial operation date, it triggers a hand-off process within MISO from Generation Interconnection Planning to Real-Time operations. MISO collaborates with the generation asset owner to get the generating facility registered in the MISO market and to obtain information needed for MISO to include the generation plant in the commercial (market) and network/EMS (reliability) models [18, 19]. Registration of the asset makes it eligible to participate in the MISO market. Additionally, this process also includes review of the need to perform operational planning studies, development of operating guides, coordination of generation testing, and ultimately the commercialization of the renewable energy asset.

More often than not, when a new generator is ready to start commercial operations in the market, the system conditions prevailing at that time are invariably quite different than those assumed during the interconnection planning studies. This situation is largely driven by the fact that typically wind and solar power plants can be built in a much shorter timeframe than the transmission necessary to reliably accommodate it. What this means is that most likely the wind/solar generation comes online without the necessary transmission in place (MISO allows this so long as there is commitment to build/fund the requisite upgrades). Moreover, even though the objectives are similar, the Planning and Operations paradigms are quite different – with Planning focused on ensuring reliability by identifying upgrades necessary to accommodate new generation, and Operations focused on reliably and efficiently operating the system with the new generation online, through operating mechanisms such as generation redispatch, transmission reconfigurations and curtailments. Therefore various operating studies are necessary to identify potential system limitations and corresponding solutions.

Operating studies are jointly performed by MISO and the Transmission Operators. Studies typically include thermal, voltage stability and dynamic transient stability. Various scenarios are studied to identify potential issues with different levels of energy transfer bias and generation dispatch patterns, including varying regional wind output levels. Any potential issues identified in the operational planning studies along with their proposed mitigation are documented in operating guides that are used by the system operators.

B. *Growing pains while incorporating wind in real-time market operations*

MISO faced numerous difficulties during the early days of wind generation being installed across its system as described ahead.

1) **Congestion management**: Fig. 6 ahead shows the growth of wind generation at MISO over the last 10 years (in GW by year). Values through 2016 are actuals,

and values for 2017 and beyond are estimates based on proposed projects in the generation interconnection queue and their status towards achieving a GIA.

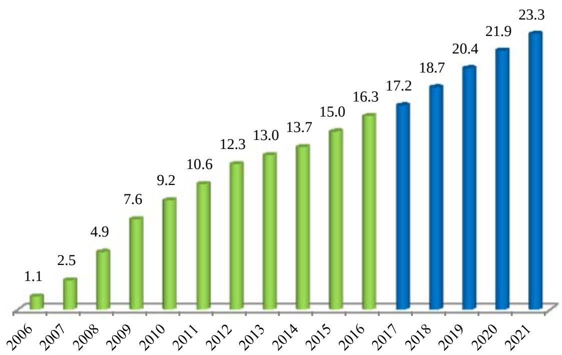

Figure 6. Growth of wind generation at MISO (in GW)

As is shown in Fig. 6., wind generation increased over 400% between 2007 and 2011, up to 10,000 MW. The rapid development of wind generation affected MISO's ability to effectively manage system congestion. Congestion was driven due to a rapid penetration of large quantities of wind generation in areas that historically had little generation. The development of wind generation outpaced the necessary transmission development as mentioned earlier which further exacerbated the situation. Since the market design at the time classified wind as an '*Intermittent Resource*' that could not be economically dispatched, in areas with high wind penetration, it was difficult for the Security Constrained Economic Dispatch (SCED) to manage congestion with limited dispatchable (traditional) resources. Therefore reliability coordinators needed to manually curtail wind resources adversely impacting constraints. Manual curtailment has several drawbacks. Since it is a manual process, it is extremely time consuming for the operators. It requires tracking of wind resources with firm versus non-firm transmission service to determine priority which is not straightforward. Manual curtailments cannot be accounted for in the automated SCED and thus lead to loss of price transparency. In general, manual curtailments are therefore onerous and less economically optimal than the automated SCED.

2) **Generation commitment**: The goal of the day-ahead unit commitment processes is to ensure that sufficient generation capacity is scheduled to meet the load and operating reserve requirements on the operating day. Using an accurate wind forecast in this process is therefore crucial to avoiding generation capacity emergencies. An incorrectly high or low wind forecast has the potential of resulting in a capacity insufficiency or surplus respectively, potentially causing emergency situations. In the early days of wind generation being developed on the MISO system, as wind forecasting capabilities were not that robust, there were frequent instances of surplus supply on the system, primarily caused due to an unanticipated over-generation from wind plants and the inability of conventional generation to reduce output below their "emergency minimum levels" due to emission constraints (and decommitment of such resources was not an option due to other constraints such as minimum down time etc.). Such events were clearly undesirable as not only did they wear out the generation, they also required MISO to declare emergency events which have adverse regulatory ramifications [20].
3) **Market impacts**: The MISO Market is a Locational Marginal Pricing (LMP) based energy market that utilizes a SCED algorithm to manage and mitigate transmission constraints. SCED mitigates constraints with the lowest cost solution based on energy offer prices. In the initial design, there was no ability or requirement for wind energy to provide an offer price in either the day-ahead or the real-time energy market. Wind energy was considered as an intermittent resource and a price taker with no ability to set the price at the injection point. When a transmission constraint is observed, SCED provides a lower LMP to incent the generation to reduce their output. However, in areas with high wind penetration, where the wind generation is contributing to the congestion, this lower LMP might still be higher than the actual production cost of wind energy. Consequently, no actual reduction of energy takes place, and the transmission system still remains constrained which may cause a system operating limit to be violated. In some instances, if no manual intervention is done, the LMP at the wind plant may turn negative (meaning which generators are paying to produce electricity). In theory, it should not be feasible for any generation to produce energy when the LMP is negative. However, there are often external factors (such as tax incentives etc.) that allow wind plants to generate energy even when the LMP is negative. In this scenario, manual curtailment of wind energy is needed to ensure system reliability. Negative LMPs were largely driven by:
   a. wind resources making negative price offers
   b. chronic congestion due to the transmission system not being upgraded to accommodate the wind
   c. unavailability of market mechanisms to control wind generation output to follow market dispatch signals.

Enhancements made to the MISO's wind forecasting capabilities and the market design that have largely resolved these issues are discussed ahead.

V. WIND GENERATION FORECASTING

In anticipation of large amounts of wind power generation expected to be built, MISO has been working to improve its wind forecasting capabilities for the last several years. There was recognition early on that most of the operational and economic discomfort caused by renewables was due to the inherent variability of the resource. In order to have a better handle on the timing and quantity of the resource output ahead of time, accurate forecasting was key. Such forecasts would allow the system operators to treat renewable, variable generation similar to how conventional, dispatchable generation is treated – and will greatly enhance renewable generation integration and utilization.

MISO has contracted with Energy & Meteo [21] as the wind & solar generation forecast vendor. Wind forecast provided by the vendor is based on Numerical Weather Prediction (NWP) models which use current weather conditions as input into mathematical models of the atmosphere to predict the weather. Four independent forecasts are produced from numerical weather prediction data obtained from:

- American Weather Service
- Canadian Weather Service
- European Weather Service
- German Weather Service

The independent forecasts are weighted by their historical performance and a combination of all four of the forecasts is used as the final MISO wind generation forecast. Fig. 7 below shows the individual and combined forecasts, compared to the measured output. It is observed that the combined forecast is more accurate than each of the individual forecasts. MISO forecasts wind output for each wind plant in its footprint. This forecast is developed for different timeframes with varying granularity [22]:

1) An hourly forecast is developed for seven days into the future and is used to establish expected wind output in unit commitment, transmission security planning, and near-term outage coordination processes.
2) A 5-minute interval forecast is developed for six hours into the future and is used to establish limits for maximum wind resource output in real-time economic dispatch.

The short-term forecast is continually fine-tuned using variances between forecasted and actual output. Measurements are captured every minute at each wind plant location. The weights used with the numerical weather prediction model are dynamically switched based on forecast performance over the most recent time horizon. The most accurate forecast is weighted the highest, which results in the most accurate overall forecast for the next 5-minute interval. Therefore every deviation of the forecast from the measured output is used to help “train” the forecasting engine. Additionally, if the output from a wind plant is curtailed due to transmission congestion, such deviations are appropriately excluded from the feedback used.

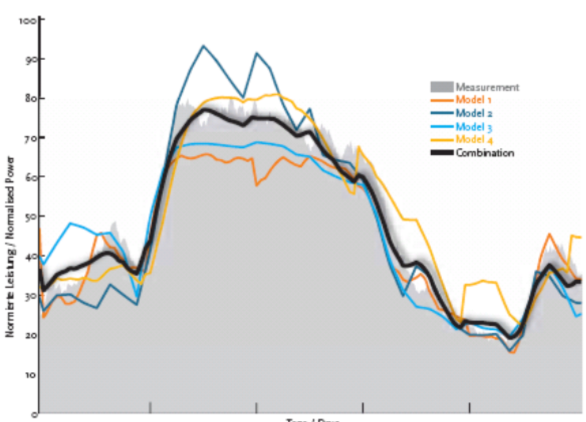

Figure 7. Using 4 independent forecasts improves forecast accuracy

Forecast accuracy is impacted by input data quality, extreme weather, and operational actions, such as:

1) Missing or incomplete input data which biases future forecast
2) Precipitation (snow, ice, freezing rain etc.), low temperatures beyond turbine operational limits or extremely high wind speeds causing reduced MW output due to turbine shut down
3) Wind curtailment due to transmission constraints
4) Market Participants not following dispatch signals

As shown in Figure 8 below, MISO continues to make improvements in its wind generation forecasting accuracy. For the last several years, accuracy of both the day-ahead and operating day (4-hour ahead) forecasts has been over 93% and continues to improve.

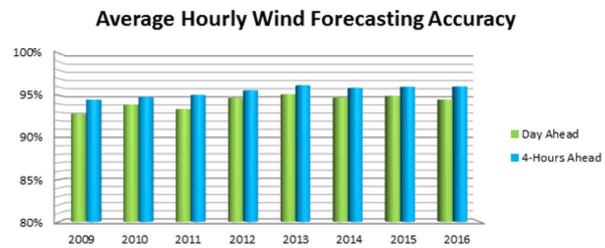

Figure 8. Improvement in wind generation forecast since 2009

Accurate wind forecasting has helped MISO considerably alleviate the issues noted in the earlier section around generation capacity emergencies as well as in managing congestion during real-time operations. It is also a key enabler of the *Dispatchable Intermittent Resource* (DIR) market product, which is described in the next section.

VI. Renewable Energy related Market Enhancements

In response to the difficulties MISO faced in the early days of wind development, and having developed reasonably accurate wind generation forecasts, MISO has developed a market product known as the DIR, which is a solution to make variable (wind, solar) resources closely mimic traditional generation operation. This product, as the name indicates, afforded MISO operators the ability to “dispatch” the wind/solar generation, which helped MISO resolve most of the congestion management and negative pricing issues noted earlier.

DIRs enable wind generation to be automatically dispatched down or up in real-time based on resource capability, offer price and system conditions. Having control over the output has significantly improved congestion management performance by reducing need for manual curtailments. Since DIRs are eligible to set prices in the energy market, it has improved market price performance as well. Lastly, again due to wind generation being more predictable and controllable, it reduces the system regulation burden due to wind variability in the dispatch time-frame. DIRs therefore have not only greatly enhanced congestion management and price formation, they have also enhanced utilization of variable generation in the market.

DIRs are treated very similar to traditional generation in the day-ahead and real-time markets as noted ahead:

- Same market timelines apply to DIR as other resources
- DIR offer parameters are similar to any other resource
- DIRs can self-schedule energy (self-schedule will be reduced if real-time MW capability is less)
- DIRs are expected to follow dispatch targets and set point instructions just like any other generator

Primary differences between DIRs and traditional generation are:
- DIRs are eligible to supply Energy, but not Operating Reserves (Regulating, Spinning, or Supplemental)
- Maximum output limit for the DIR is based on the forecast instead of the 'nameplate' capacity

An example is given ahead of how before the implementation of the DIR, the system was unable to fully leverage benefits of wind generation. Fig. 9 below shows the comparison between the 5-minute dispatch target for a wind resource and the corresponding actual output. The issue here is that the actual output at the beginning of the interval (say at XX:05), was used to establish a target for the subsequent 5-min interval (starting at XX:10). As is observed, and as is normally the case, wind output is highly variable and can change significantly in the five minute timeframe – as is being illustrated below – the target is much higher than the actual wind output. Therefore, the system was being dispatched with a low level of confidence in the wind outputs, which was potentially unreliable and definitely expensive, as, for example if wind output dropped off without warning, operators ended up having to start expensive units; conversely, if wind generation ramped up without warning operators ended up curtailing it if the transmission system couldn't accommodate it or other generation wasn't available to be redispatched.

In contrast to the above example, Figs. 10 and 11 ahead illustrate how with the DIR implementation there is much more control and confidence in the wind generation output. As noted earlier in the article, having a reasonably accurate, granular forecast is essential for DIRs to be successful**.**

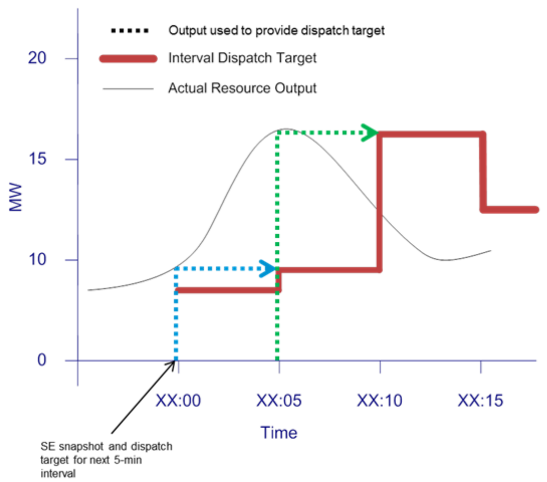

Figure 9. Illustrative example showing issues with wind dispatch prior to DIR implementation

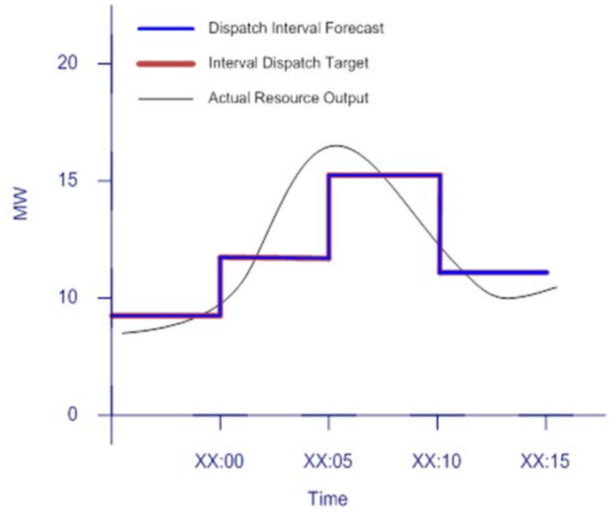

Figure 10. DIR following dispatch in an unconstrained system

Fig. 10 above shows a relatively straightforward example where the wind generation output is not constrained due to transmission congestion. As is observed, the dispatch target and the actual wind output both nicely follow the forecasted output. The case ahead, of a wind resource injecting into a constrained transmission system is probably more illustrative of the effectiveness and benefit of DIRs. Fig. 11 ahead illustrates how, even when the forecast shows higher output available, due to the congested transmission system, the dispatch engine sends a lower output target to the wind resource, and the wind resource then adjusts the output to a lower level, to match the target sent.

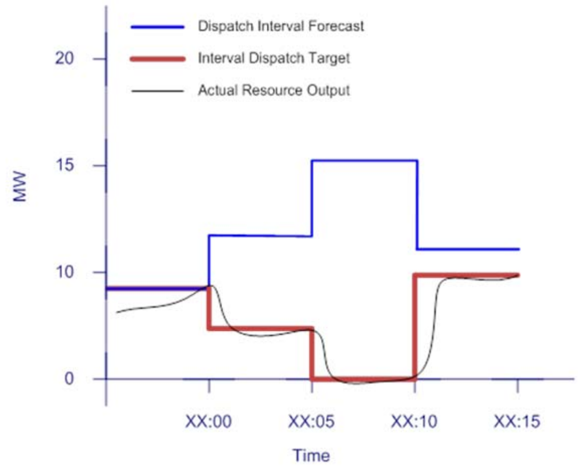

Figure 11. DIR following dispatch in a constrained system

In summary, improved wind forecasting capabilities and sophisticated market mechanisms have greatly enhanced MISO's ability to reliably and efficiently integrate renewable resources in to the footprint and maximize their utilization.

VII. CONCLUSIONS

The electric industry across the globe is at an exciting juncture, with majority of the systems looking at a significant evolution of the generation portfolio. Most of the change is driven by large-scale development of renewable generation, primarily wind and solar power. Integration of bulk quantities of renewables into transmission systems that have historically developed to serve load through traditional, thermal generation is quite challenging. This article presents various aspects of MISO's generation interconnection, transmission planning and system operations processes that facilitate the journey of a renewable resource from a conceptual project to a commercially operating generating facility. Due to enhancements such as the "*first-ready, first-served*" queue process, value based transmission planning and market products such as DIR, MISO is well-positioned to continue to efficiently and reliably integrate bulk quantities of renewable generation into its footprint.

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