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Synchronous Condenser for Integration of Wind Generation in Texas Panhandle Area

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SUMMARY

Transmission systems have historically relied on conventional power plants utilizing classical synchronous machines to provide the strong grid characteristics of stiff voltage and frequency. The synchronous machine provides a massive short-circuit power due to its physical construction as well as high contribution to grid inertia through the entire drive train of the power plant.

The integration of increasing amounts of renewable energy sources (RES) in transmission systems is increasing the share of inverter-based generation, (i.e. generation from solar photovoltaics and wind) connected to the grid. This transformation is weakening the transmission system by reducing short-circuit power and inertial support due to the inherent characteristics of the newly introduced inverter-based generation.

In order to cope with the transformation occurring in the transmission systems, transmission system operators (TSOs) must find proper measures to guarantee grid stability and reliability under increasing levels of RES integration. This task is especially challenging for isolated or remote areas of transmission systems, such as the Texas Panhandle in ERCOT's system.

This paper summarizes the planning effort undertaken by ERCOT in order to develop a suitable solution to ensure grid stability with the increasing wind generation in the Texas Panhandle area which is located at the periphery of the transmission system and lacks support from conventional synchronous generation resources. ERCOT recommended the installation of two synchronous condensers at Alibates and Tule Canyon substations to increase system strength and improve grid stability.

The paper continues in explaining the main equipment and characteristics of the selected solution and highlights the major actions needed to deliver the requirements set by ERCOT.

KEYWORDS

Synchronous Condenser, Renewable Generation, Weak grid

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INTRODUCTION

Renewable energy sources (RES) have become the fastest growing energy source by newly installed capacity resulting in a dramatic change in the generation mix for transmission system operators (TSOs) around the world. The Electric Reliability Council of Texas (ERCOT) has witnessed this change in their system – at certain times, more than half of the system load has been served by wind generation. Integration of RES is a priority and a concern for many TSOs nowadays. To maintain the reliability of the evolving grid, one needs to understand the impact of high RES penetration on the behavior of the transmission system.

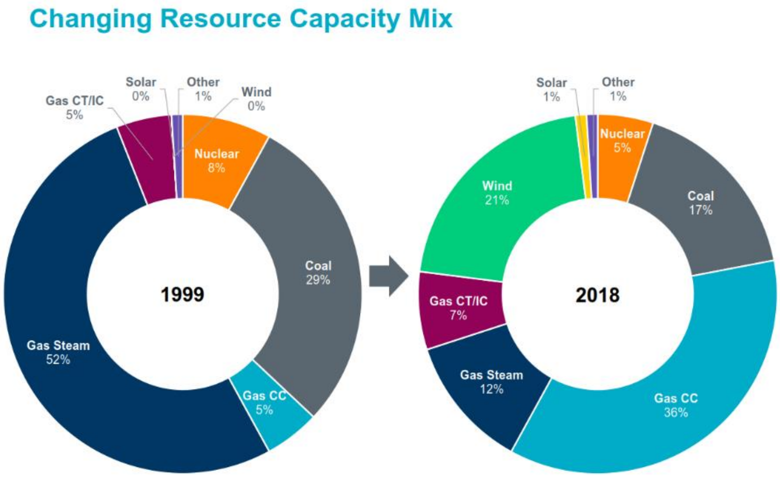

Figure 1: Changing Resource Capacity Mix in ERCOT [10]

Conventional power generation, and consequently the dynamic behavior of the transmission system has been dominated by directly connected large synchronous machines. The physical properties of the machine itself, such as the amount of mechanical inertia and electrical parameters, play the largest role in determining its fast-transient behavior. However, most of the RES, specifically, wind and solar photovoltaic, are connected to the transmission system via an inverter. The physical properties of inverter just limit its capability, but it is an implemented control strategy, that dictates the electrical dynamic behavior during disturbances. Inverters are controlled to operate as current sources that are “grid following” which require an existing AC transmission system to be able to synchronize and reliably operate. Moreover, most manufacturers’ algorithms assume the existing transmission system will provide a strong, stable voltage and frequency at the point of interconnection. This is a valid assumption for many transmission systems around the world where there are still plenty of large synchronous generators that provide sufficient system inertia and short circuit power for reliable inverter operation.

However, operational challenges associated with a lack of inertia or low short circuit power may become apparent when synchronous machines are displaced by RES, especially in smaller island transmission systems or remote parts of a system. The Texas Panhandle in the United States is a perfect example. It is one of the windiest areas in the state and has the highest capacity factor wind profile (Figure 2). In the recent years, multiple large-scale wind plants have been developed there. However, this part of the ERCOT system is remote from large load centers and synchronous generators.

Several studies have been carried out to identify the issues that occur in a weak system with high penetration of RES, also referred to as inverter-based generation [1,2]. Wind plant tripping, voltage violations and unstable behavior were also observed in the studies for the Panhandle area. No further increase of the wind generation would be allowed without infrastructural upgrades [3]. Although a STATCOM is generally an optimal solution to improve voltage violation issues [4], in the extreme case of virtually no local synchronous machines, it still offers significant improvements but would not be a complete solution.

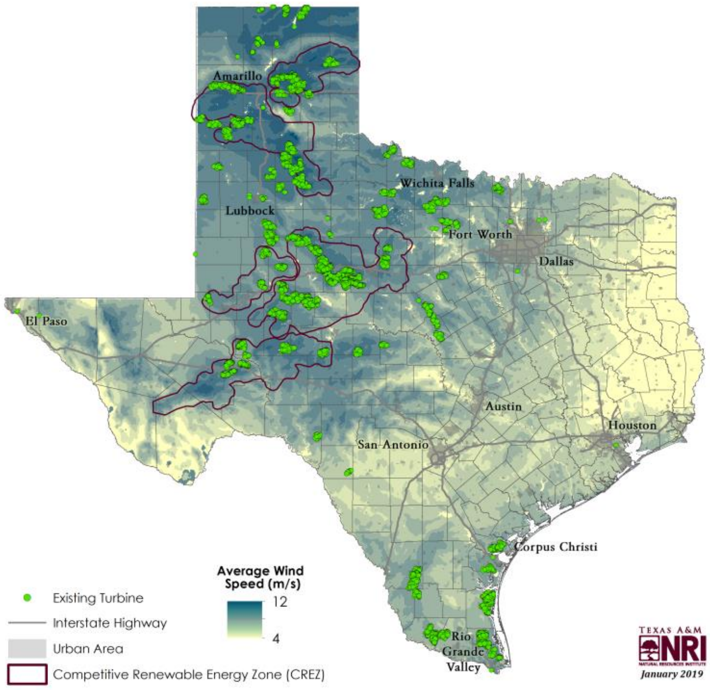

Figure 2: Wind turbine locations in Texas [11]

As with any synchronous machine, a synchronous condenser inherently improves the inertia of the system and short circuit power. It is becoming a popular choice for many network planners to address weak system issues [5]. When strategically located, a synchronous condenser contributes to the short circuit power and provides a stable AC voltage source. The system inertia also benefits from the additional spinning mass of the rotor or additional flywheel if required.

PLANNING FOR A RELIABLE GRID WITH HIGH PENETRATION OF WIND

As ERCOT studied increasing amounts of wind generation resources connected to the Panhandle area of the ERCOT system [6], potential reliability issues associated with the operation of inverter-based resources under low system strength conditions were identified. ERCOT used weighted short circuit ratio (WSCR) calculations as an index for quantifying and evaluating system strength [7] in the Panhandle. To ensure sufficient system strength for reliable operation, ERCOT proposed and implemented WSCR limits in the Panhandle. The validity of proposed WSCR limits in the Panhandle has been confirmed by both traditional dynamic stability studies and by detailed EMT studies [8].

In 2015, ERCOT recommended the installation of two synchronous condensers in the Panhandle. Synchronous condensers were specified primarily to increase fault current levels in the Panhandle thereby increasing the calculated WSCR and effectively improving system strength. Each synchronous condenser was to provide at least 1,050 Ampere (A) of three-phase fault current to the 345 kV system; it was assumed that this would correspond to approximately 150 MVAr of reactive capacity for each synchronous condenser. ERCOT studies showed that the addition of the synchronous condensers allowed wind generation exports from the Panhandle to increase by approximately 470 MW; the reduction in projected curtailments created sufficient production cost savings to satisfy ERCOT economic criteria.

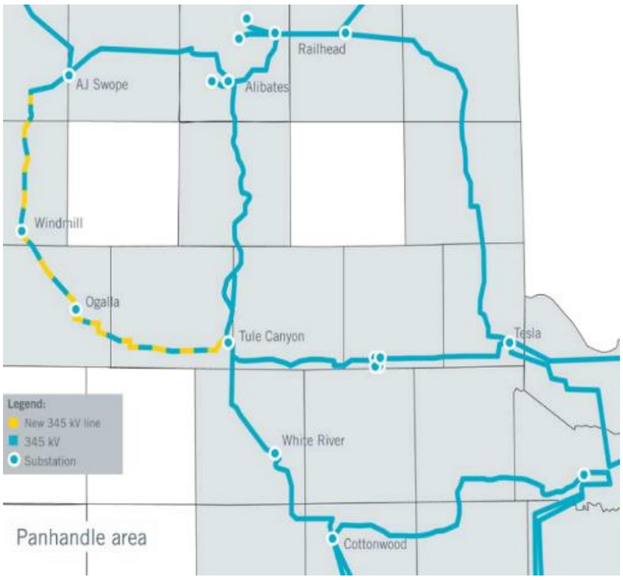

Figure 3: Structure of electrical power system in Panhandle Area [10]

Consideration was given to improving performance with respect to voltage support and transient response while also providing adequate system strength support when selecting synchronous condenser locations at Alibates and Tule Canyon. Other synchronous condenser locations may have provided higher increases with respect to the WSCR limit, but less voltage support overall so that voltage stability constraints would become more binding.

Although the installation of synchronous condensers improves system strength and allow reliable operation of higher amounts of inverter-based generation, ERCOT studies [9] have additionally shown that synchronous condenser solutions may introduce additional challenges. For example, synchronous condensers are susceptible to classical inter-area oscillations and angular separation when there are large power transfers over long distances across the network – conditions that are commonly associated with the integration of large amounts of renewable (inverter-based) generation that are often connected to remote areas of the transmission system.

SYNCHRONOUS CONDENSER SYSTEM

Functionally, a synchronous condenser is simply a synchronous machine that is brought up to speed by a startup system, excited and synchronized via a generator circuit breaker. All main components are shown on the single line diagram in the Figure 4.

The configuration of a typical synchronous condenser installation mirrors that of an electrical power plant design. In fact, many power plants could be either operated as or converted into a synchronous condenser. However, in most cases, the installation of a new condenser is a preferred solution. The weak grid conditions and lack of reactive power are very local problems. It is therefore crucial to define an optimal connection point for the synchronous condenser that would maximize its benefits to the entire transmission system. An old power plant converted into a synchronous condenser is often in the wrong place in the transmission system and cannot provide optimal support with respect to system strength. Moreover, lower operating expenses due to the unstaffed operation, lower risks and optimized losses often outweigh higher capital expenses associated with a new installation. A new greenfield installation allows a tailor-made design that often meets the specification requirement in the most economic manner.

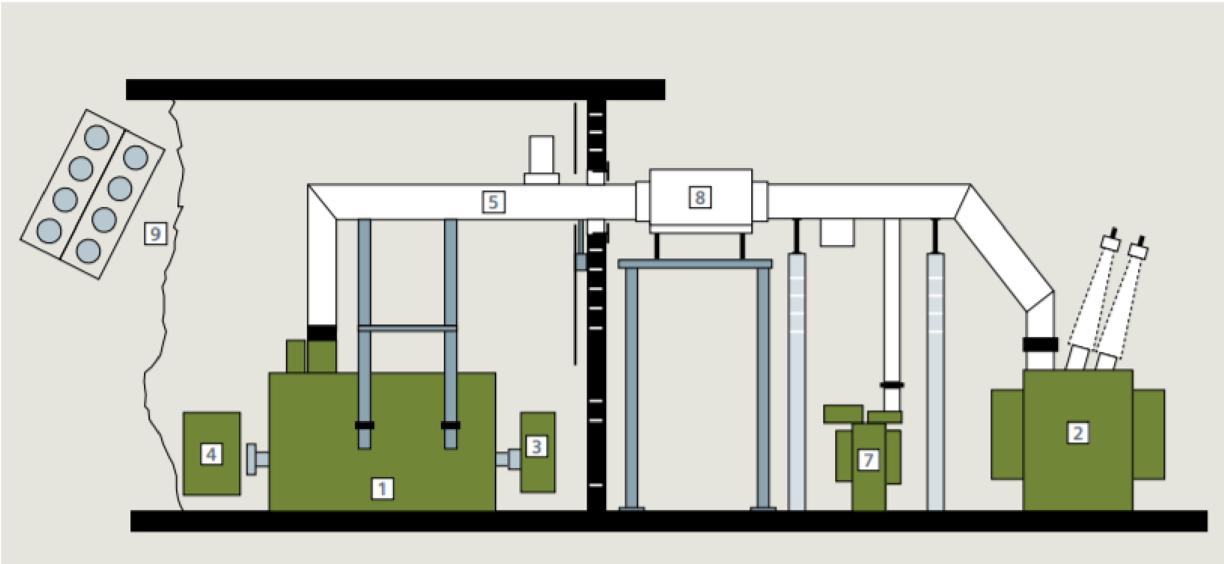

Figure 4: 1-Synchronous generator 2-Generator step-up transformer 3-Static/brushless excitation 4-Pony motor/starting frequency converter 5-Isolated phase bus duct 6-Control and protection system 7-Auxiliary transformer 8-Generator circuit breaker 9-Optional external coolers

SYNCHRONOUS CONDENSER DESIGN

The main requirements for synchronous condensers at the Alibates and Tule Canyon substations were (i) the capability to provide +150/-75 MVAr as well as (ii) a minimum 1050A of short circuit current to the 345kV substation bus. The primary considerations were the short circuit and low voltage ride through capabilities. These two requirements determine the choice of synchronous machine and step-up transformer.

Figure 5: Synchronous condenser installation with a pony motor

The red envelope on the Figure 6 shows the required reactive power capability - +150/-75 MVAr at 345kV considering the +/-5% voltage variation. This requirement directly translates into reactive power requirements at the machine terminals (red envelope on the Figure 7). Considering the inductive manner of the step-up transformer impedance, the machine must cover a larger range on the Volt/VAr characteristic. As shown on the Figure 7, the nameplate machine rating is +175/-125MVAr for +/-10% voltage variation range. The wide range of the machine operating voltage allows a design without a need of an on-load tap changer in the step-up transformer which increases reliability and reduces operational complexity.

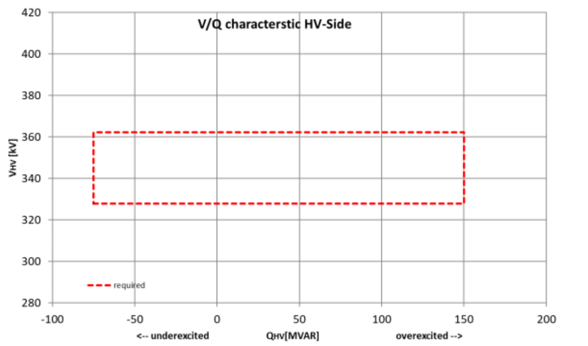

Figure 6: Required reactive power capability at 345kV

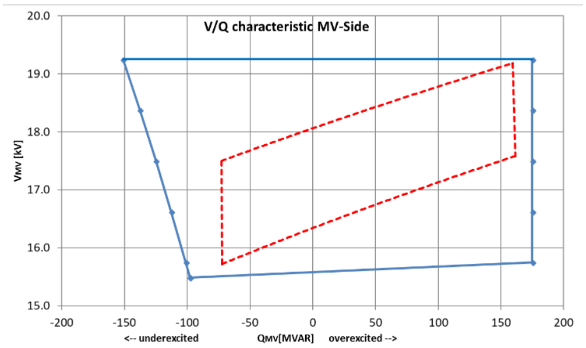

Figure 7: Red: Required reactive power capability translated to generator terminals; blue: generator reactive power capability

The nameplate machine rating indicates the continuous available MVAr output of the machine. For the same type of the machine, it varies depending on the ambient temperature and type of cooling system. The same machine installed in a hot region would have less available MVAr than in a colder region. It is therefore important to specify the design ambient temperature that should be considered in order to avoid unnecessary over-dimensioning of the equipment. The maximum output could be reduced in the periods when actual temperature exceeds the design criteria.

As discussed in previous section, the main motivation for new synchronous condenser installation is often not the MVAr rating, but short circuit current contribution. Continuous reactive power output might be considered as a useful by-product to the main contribution. The value of the short circuit current contribution depends on the sub-transient impedance of the machine (X''_d) and transformer impedance (X_t), as per IEEE C37.010-1999

$$I = \frac{E}{jX''_d + jX_t}$$

Since the short circuit current contribution quantifies the positive effect of the condenser, it is often desirable to maximize it. To do so requires a small sub-transient impedance (X''_d) and transformer impedance (X_t). Considering all manufacturing tolerances, the minimum short-circuit current contribution on the high-voltage side of the unit is $I_S = 1.606\ kA$, that far exceeds the minimum required value and therefore provides additional support to the grid strength.

One lesson learned is that the specification of fault contribution for a synchronous condenser is not as simple as is seems. The fault contribution should be specified at the transmission network connection bus because the impact of the step-up transformer needs to be considered in addition to the machine design. Further care is needed in defining the specific assumptions used to achieve the desired fault contribution. For example, the specification should clearly indicate what machine impedance should be used to achieve the desired fault contribution: Sub-transient reactance (X”d) or transient reactance (X’d), saturated or unsaturated values, etc.

The excitation system for the synchronous condenser was chosen to be brushless. The brushless excitation system has an important advantage of reducing maintenance time. Also, its power supply is not affected by grid voltage fluctuations and is therefore able to supply full excitation current even during severe faults in the grid. Since the exciter unit is not able to deliver AC output voltage via the rectifier without rotation, the use of brushless excitation requires a starting motor as a startup system. The starting motor is designed to accelerate the rotor to synchronizing speed during a start-up sequence. During shut down sequence, it is used to brake the rotor in a controllable manner. Considering the fact, that condensers are usually installed in a weaker part of the grid, Direct-On-Line start is unacceptable, due to the large voltage transients.

Since every outage of the condenser would directly translate into reduction of the maximum allowed power export, special attention must be paid to the design of the system. In order to achieve high availability requirements, adequate redundancy in cooling system auxiliary supply, control and protection systems was defined.

CONCLUSION

Transmission systems globally are enduring an unprecedented transformation through the displacement of the backbone of the AC transmission system, the synchronous machine, by inverter-based generation associated with renewable energy resources (RES). The transformation is causing a weakening of the fundamental characteristics of the transmission network, (i.e. voltage and frequency). The impacts of this transformation have been experienced in transmission systems such as the Texas Panhandle within the ERCOT grid. ERCOT considered the installation of synchronous condensers as transmission upgrades to ensure a stable and reliable transmission system while delivering increasing amounts of wind generation.

Two synchronous condensers were installed at Alibates and Tule Canyon substations to enhance the short-circuit power, hence elevating the grid strength metric, WSCR. Additionally, the synchronous condensers will provide local voltage support and contribute to the inertia of the grid due to their rotating mass. The design of the synchronous condenser installation equipment should be done accurately in order to deliver the required performance at the transmission level especially by tuning the short-circuit impedance of the step-up transformer and the sub-transient impedance of the synchronous machine.

The introduction of the synchronous condensers at Alibates and Tule Canyon have enabled ERCOT to increase wind generation in the Panhandle area by approximately 470 MW. If the synchronous condensers are in maintenance, the wind generation will be curtailed as necessary to avoid any adverse consequences.

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