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Loss Evaluation Considerations for Utility Synchronous Condenser Applications

P.E. MARKEN, A.C. DEPOIAN
GE Grid Solutions
USA

SUMMARY

Synchronous Condensers have experienced resurgence in popularity with transmission utilities in the last decade. While they provide unique benefits to the transmission grid such as increased short circuit current and can be desirable for a number of reasons, they are somewhat unfamiliar to many transmission utilities. Specifications used in acquiring the purchase of synchronous condensers vary widely in the handling of losses. Some give no consideration to losses at all and seem to assume that all synchronous condensers will have a similar loss profile. The loss profile can vary considerably among different machine designs depending, for instance, on the type and design of lamination steel, the number of poles, and the type of cooling system. In addition, the number of units and their method of operation can also have a significant effect on the overall station losses, depending on the application.

Equipment manufacturers have design choices that affect the loss performance of the machine. If no loss evaluation is given, price competition will tend to force the manufacturer to produce the equipment as inexpensively as possible. This typically results in greater losses, the cost of which is ultimately passed on to ratepayers. However, when there are well defined loss evaluation criteria including operating conditions with weighting at multiple points, a manufacturer can optimize the design to provide the lowest lifecycle cost balancing the cost of capital and losses.

This paper will provide the reader with a basic familiarity of the different losses involved with a synchronous condenser in a transmission utility application. A comparison of machine types is covered as well as some examples of how different operating methods can have an effect on the system losses. The reader will be able to produce a more knowledgeable specification with regard to losses in a synchronous condenser system for a transmission utility. While this paper specifically addresses synchronous condenser installations, many of the principles are universally applicable to all equipment installations. While real cases and calculations were used to develop values shown in charts and tables, in some cases the values have been intentionally skewed to protect proprietary information. However, the authors believe that the presented values are realistic.

paul.marken@ieee.org

KEYWORDS

Losses, Synchronous Condenser, Transmission Utility

OBSERVATIONS

In their work for a major manufacturer the authors have had the opportunity to see many, if not all, specifications for synchronous condensers applied to support the power transmission grid in North America. One area that varies greatly in these specifications is the loss evaluation. In some cases there is no mention of losses or a loss evaluation. Five examples are shown below taken from actual experiences and illustrate some of the variation seen.

Table 1 below shows the loss conditions of Utility A. Utility A was interested in a multiple unit installation. Most of their weighting factor is on a case where there is no reactive power output. This is not right or wrong but is given as an example of what made sense for this utility. The odd thing about this evaluation was that it was specified at maximum outdoor ambient temperature. Since the system seldom operates at this high temperature, either an average or typical outdoor temperature might have been more appropriate.

Mvar at HV Bus	Weighting Factor	Comment
25% Capacitive	0.05	Equipment fully capable but operating at low output (all units in service)
0*	0.60	* System on line and running but at low reactive output (2 units in service)
0	0.30	System off-line but ready to start
100% Inductive	0.05	Equipment at 100% of its inductive output rating (all units in service)

Table 1
Utility A Operating Conditions for Loss Calculations

Utility B did not list any information about losses in their specification. During the bid phase a question was raised about losses. The Utility responded with a sample transformer specification that did include a loss evaluation. The bidders were directed to follow the transformer example and provide no-load and load losses. A transformer of course is unable to have inductive or capacitive output. It is unknown how the response of the bidders compared to one another. One might assume full capacitive and zero output were the loss points provided.

Utility C, when asked about losses, stated ‘we do not have a method to evaluate synchronous condenser losses.’

Utility D provided information as shown in Table 2. The operating conditions are well defined; however, the evaluation was at the highest ambient temperature and the lowest operating voltage. Similar to the mention above regarding Utility A, it is questionable that the seventy percent of the time at zero output will really be at maximum temperature and minimum system voltage. A more accurate evaluation depicting the true expected losses would describe a less extreme voltage and temperature.

Operating Point	Description	Percentage of time at Operating Point
Point 1	Max Mvar, Inductive	5%
Point 2	0 Mvar	70%
Point 3	120 Mvar, Capacitive	20%
Point 4	225 Mvar, Capacitive	5%

Table 2
Utility D Operating Conditions for Loss Calculations

Utility E provided an equation for Total Variable Losses and selected a typical average temperature and normal voltage conditions for this evaluation. Total Variable Losses = ((Losses at +150Mvar) * 0.03) + ((Losses at +30 Mvar) * 0.93) + ((Losses at -75Mvar) * 0.02)

As can be seen from these examples there is wide variation in the treatment of losses. It is interesting to note that some utilities have no means to consider losses and have no intention to. This could be a holdover from days past when generation and transmission utilities were the same entity. Money was made by generating and selling watts, and transmission was just a necessary part of delivering those watts to market. The losses were not considered as the customer metering point was the place where revenue was measured. Many utilities in those days did not fret over losses in the transmission system as there was little to be done about it.

While not the topic of this paper, it has been suggested that transmission utilities are encouraged by regulators to optimize their capital spending. If the same regulators do not require a loss evaluation, or the transmission utility does not choose to justify possibly higher capital costs to obtain lower losses, a well-planned loss evaluation may not occur. As transmission utilities install more equipment, such as capacitors, FACTS controllers, or synchronous condensers, it may be prudent in the long run to consider losses.

SYNCHONOUS CONDENSER LOSSES

The losses involved in a synchronous condenser installation are composed of several elements. These include not only the rotating machine but also the transformer, cooling system, other auxiliaries, and even the AC system components. Some losses will vary with the system output (I^2R losses) while others remain relatively constant any time the system is online, principally friction, windage and core (magnetizing) losses. The losses will also vary with ambient temperature. This makes for a tricky answer to the question of 'what percent losses does a synchronous condenser have'? Losses at full capacitive output can be very different from losses when idling. Many machines are put in place for a dynamic response and therefore spend much of the time idling. Figure 1 shows a typical loss curve of a synchronous condenser system, including all auxiliaries and AC components, plotted in percent loss against per unit output. While the magnitude of losses does vary considerably with different designs, the typical curve shape is displayed.

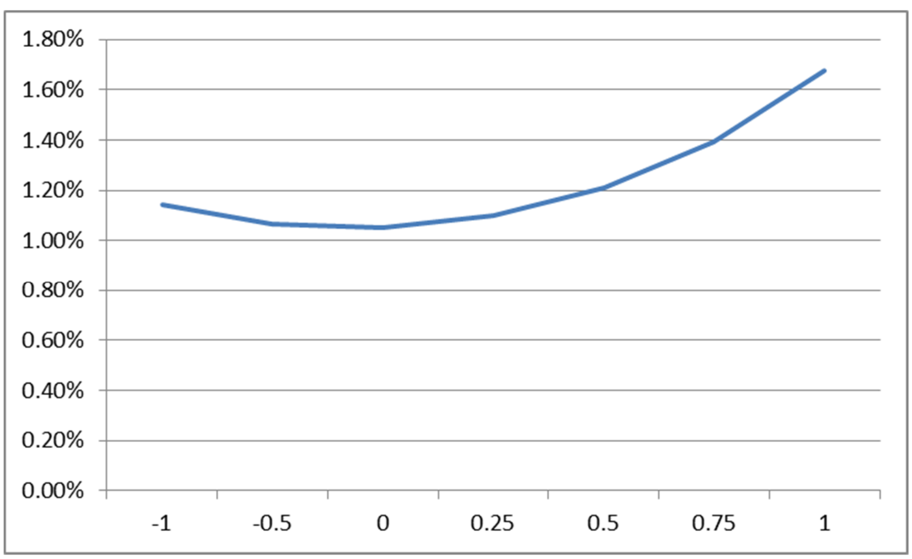

Figure 1
Typical Curve of Synchronous Condenser Losses

The majority of the total system losses come from the machine itself. The transformer, bus duct, cooling system, lube oil system, exciter, and controls combined are still a fraction of the losses of the synchronous machine. Figure 2 shows the breakdown of machine losses and auxiliary losses at two different ambient temperature points for a similar machine.

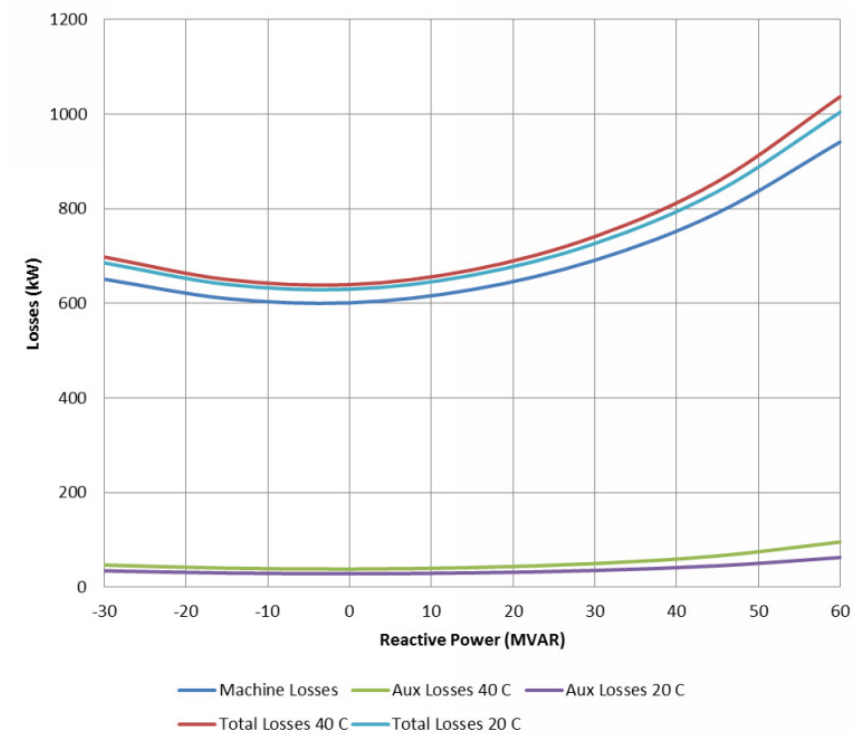

Figure 2
Synchronous Machine and Auxiliary Losses in a Synchronous Condenser System

The major portion of the no-load (zero Mvar) synchronous machine losses are friction, windage and core losses. Copper (load) losses in the above example are about a quarter of the machine losses at high output levels and very small when the machine is at idle (zero Mvar).

SMART CHOICES

Losses in the transmission grid are just as real as losses anywhere else in the system. The cost of transmitting electricity is passed on to the ratepayer in one form or another. It is possible to consider options and minimize these costs. One aspect of these costs is losses.

When a manufacturer bids on a specification, the goal is to create the lowest priced offering that fully complies with the specification. If no loss evaluation is included, the machine will be made as inexpensively as possible, and will tend to have the highest losses. Core steel is a good example of the cost verses losses trade off. By using different core steel, the core losses in the machine can be reduced. A more efficient core steel costs a little more. Over the life of the machine, the savings from the lower losses far outweigh the initial machine cost increase. It may be wise to consider increasing the capital cost budget up front and having a more efficient asset. Including a loss evaluation is a simple way to incorporate this choice.

Fifty years ago manufacturers had dedicated designs for synchronous condensers. Today, most base a synchronous condenser design on either a synchronous generator or a synchronous motor. Generators and motors typically operate loaded most of their life, so designs tend to be optimized for high load conditions. Synchronous condenser life is the opposite, as most of the time they operate at very low load (low Mvar) conditions. The buyer should consider this when determining the loss evaluation.

The normal mode of operation is a very important consideration. In the examples above, Utilities A and D wisely recognized that their machines would normally be operating near zero reactive power output, and their evaluation took this into account. It was also evident to the manufacturers that this was the case, making friction, windage, and core steel losses more important than copper losses during high output conditions.

An interesting aspect to consider is the friction and windage losses. There are a few options to reduce these losses, though neither has yet gained widespread acceptance in transmission applications. One option is the use of hydrogen versus air in the machine. Hydrogen cooled machines have much lower windage losses as the rotor is turning in a much lighter gas. The use of hydrogen cooled generators is common and the majority of older synchronous condensers were hydrogen cooled. However, transmission utilities seem reluctant to install new hydrogen-cooled synchronous condensers. Another option is to increase the number of poles in a machine. A six-pole machine has lower overall losses due to the reduced friction and windage losses. Figure 3 shows an example of the losses of a four-pole (blue) and a six-pole (red) synchronous condenser. At the point where the machine is idling the six-pole machine has 20% less losses. Different manufacturers may also have other methods to optimize losses.

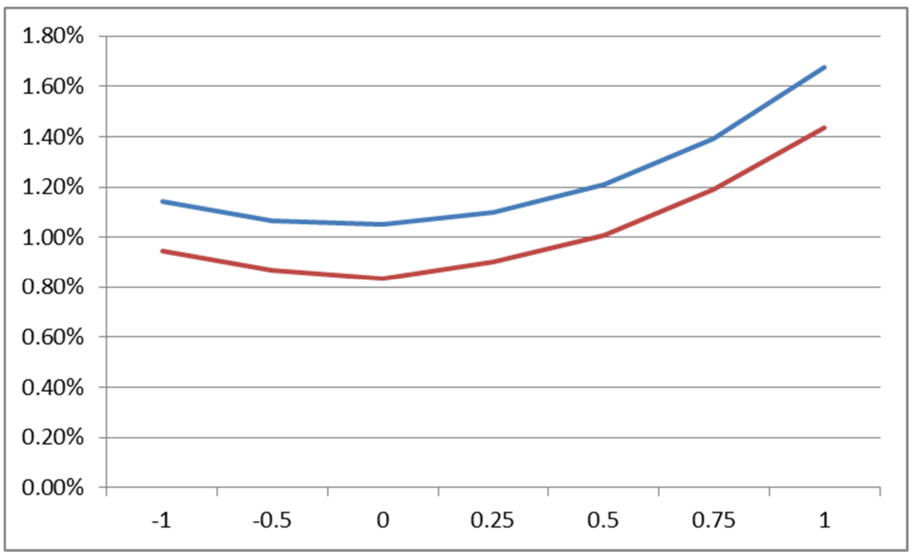

Figure 3
4-Pole (blue) and 6-Pole (red) Synchronous Condenser Losses

Another consideration for the overall synchronous condenser site installation is the number of machines. While the cheapest up-front capital cost is typically a single large machine, multiple smaller machines do result in some benefits. Aside from the redundancy and availability advantages, the load profile may allow for advantages in losses too. Consider the simple example of a single 225Mvar machine compared with three 75Mvar machines. If it is known that the full 225Mvar are only needed during part of the year, one or even two of the three smaller machines could be stopped when they are not needed. It is not an unusual situation that the full rating of the desired installation is needed only a small percentage of the year during peak load conditions. Table 3 shows an actual example of such an evaluation. Two different larger machines were compared with three smaller machines. The evaluation also compared leaving the three machines running verses turning off units when the capacity was not needed. As the table shows, the spread among the various options is valued in millions of dollars.

HV Bus Mvar	Weight	Each 6-pole machine	Three 6-pole Machines	One 2-pole Machine Design A	One 2-pole machine Design B	Three 6-pole Machines, switched	
		Losses [kW] each	Total	Losses [kW]	Losses [kW]	Total	On?
-90	5%	615	1845	1900	2238	1845	3
0	70%	515	1545	1824	2100	515	1
120	20%	740	2220	2116	2453	1480	2
225	5%	1131	3393	2921	2975	3393	3
	Weighted Total		1787	1941	2221	918	
	At $13,000/kW		$ 23,236,200	$ 25,233,650	$ 28,876,250	$ 11,939,200	

Table 3
Comparison of Losses of Single Units Versus Three Smaller Units

Figure 4 shows the kilowatt losses at different operating points of the four different options. While operating at maximum capacitive output, the three machine options appear to be the worst option from a loss standpoint. A utility evaluating only the losses at maximum output would miss that fact that while idling, the three units have lower losses. Figure 5 shows the weighted cost using the expected time at each operating point. The three, smaller, six-pole units have the lower loss evaluation cost. By switching off units that are not required, an additional $11 million evaluation difference can be realized.

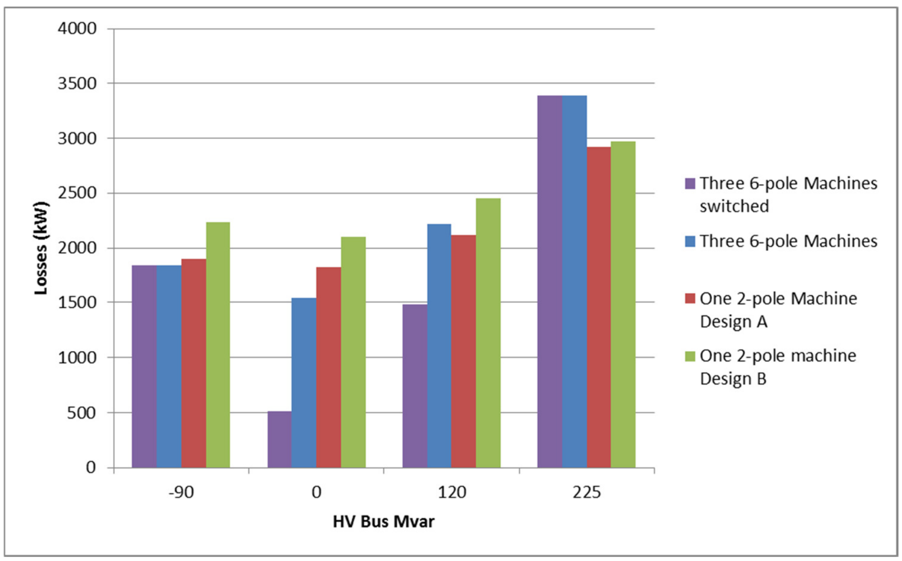

Figure 4
Losses in kW for the 4 Options at Different Operating Points

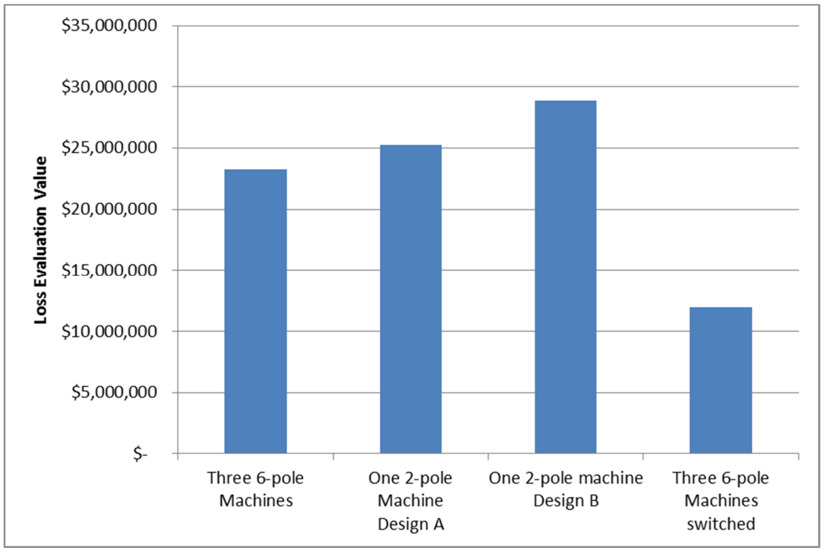

Figure 5
Loss Evaluation Values

CONCLUSIONS

Synchronous condensers are seeing resurgence in transmission grid applications. This device is not always familiar to transmission utilities, and some are not accustomed to considering the losses of such a device. The cost of losses over the life of the asset can be very significant, costing more than the up-front capital cost in some cases. Consideration can be given to how the machine will operate and under what conditions. Including a loss evaluation that takes into account the expected operating points can result in manufacturers bidding an overall system that can be significantly more efficient to operate over the life of the asset. Clearly defining the operating points and conditions are important. Understanding how much time the system will operate under which condition is key. By including a formula that reflects realistic conditions and making it part of the bid evaluation, utilities can lower losses in the transmission system and purchase a system that has a lower lifecycle cost, which is beneficial to the ratepayers.

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