Obtaining power quality grid-code compliance for a wind farm

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Grid-code compliance was recently achieved for a wind farm in the Eastern Cape, after the installation of active harmonic filtering (AHF) to mitigate plant generated harmonic emissions. This is one of the largest installations of its kind in the world. Some of the requirements and technical challenges overcome are highlighted in this article.

The 132 MW wind farm, comprising of sixty 2,3 MW wind turbines, went into commercial operation after being granted temporary exemption on the harmonic current emissions from the plant into the network. After fine tuning the wind turbine inverters, it was still required to mitigate high levels of current emissions at the second and fifth harmonic orders. This was measured at the point of coupling to the 132 kV network.

A 2700 A (at 400 V) Merus A2 active harmonic filter was supplied and installed by RWW Engineering to fulfill the harmonic cancellation requirements and achieve compliance to the South African Grid Code for renewable power plants (RPP). Grid-code compliance recordings and confirmation studies for the project were performed by ADAee.

Regulations and standards

Renewable power plants wishing to connect to the South African national grid must comply with regulatory specifications as set out by the national energy regulator. The relevant power quality (PQ) parameters are defined in the grid code. For this plant, the category C (20 MVA and larger) provisions are applicable. The latest update is Revision 3, dated August 2019. In addition, the specific limits for each of the defined parameters are also contractually agreed and assigned to each individual RPP. Several further guidelines and standards support the above specification and ensure a standardised approach in collecting and analysing data from operations, including standards and guidelines as per various NRS, IEC and Cigré papers.

Case study of wind farm challenges and solutions

Control systems to interface at various bus voltage levels

The point of connection (POC) for the WF (the point at which full PQ compliance must be demonstrated) is on the national grid at a 132 kV bus voltage level (Figure 1). The permanently installed highly accurate metering PTs and CTs are used to record voltage and current trends. These recordings effectively determine harmonic voltages, harmonic currents, flicker, resonance sensitivity and voltage unbalance conformance to the contractual limits.

The plant itself collects power at the 33 kV level from the wind turbines. Therefore, there is a need for a step-up transformer between the internal wind farm level at 33 kV and the grid at 132 kV. Flicker compliance is determined from this internal 33 kV voltage level with the transformer impedance used as a buffer between plant generated and grid related flicker content.

The wind turbine generators provide power at a nominal 690 V level. This voltage is transformed from 690 V to the distribution 33 kV via transformers local to each wind turbine. The Merus A2 active harmonic filter generates the compensation currents at 400V and is connected to the 33 kV network via a 5000 kVA, 400 V/33 kV three-winding transformer.

Effectively this translates the seemingly modest level of harmonic current mitigation requirement at grid level to very high levels of injected harmonic current at the 400 V level. For example, the need for a mere 5,5 A of harmonic current compensation at grid 132 kV level equates to more than 1815 A of harmonic current injection required at 400 V.

Control systems to interface at various bus voltage levels

The wind farm in question previously achieved compliance to all PQ parameters according to agreed limits with the national energy regulator, other than current harmonic emissions at the second and fifth harmonic orders. These emissions were in the region of 5,5 A at 132 kV. Various proven methodologies were undertaken prior to implementing the active filter to ascertain whether these harmonic currents were indeed coming from the RPP or whether the RPP was absorbing these harmonics from the grid network. After exhaustive testing, simulation and online plant controller modifications, it was proven that the second and fifth harmonic currents were mostly being generated within the RPP and exported to the grid network.

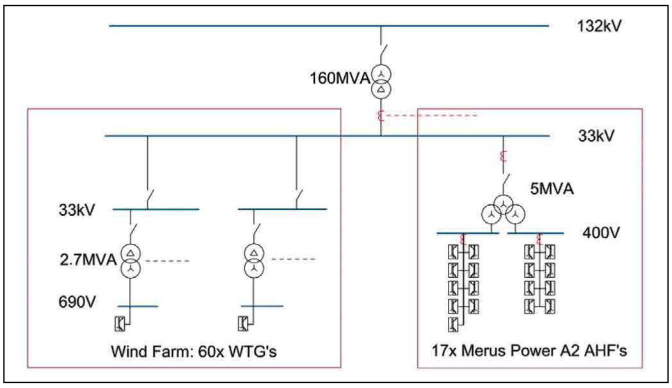

Figure 1: High level SLD wind farm with Merus A2 active harmonic filters

These findings were verified by the national energy regulator which oversees the compliance of all the RPPs. Therefore, the RPP was liable to reduce these harmonic levels to within acceptable limits, within a certain time frame.

Mitigation solution alternatives

Mitigating harmonic content on a supply line can be achieved via various methods. For example, a passive harmonic filter can be designed which involves capacitance and inductance elements, tuned towards the harmonic current frequency to be trapped and dissipated, rather than to be let through to the grid. Consideration should be given to unwanted resonance conditions at nearby harmonic orders. Passive harmonic filtration is the industry standard throughout the world for harmonic generators, such as mining and commercial operations, which have very well documented and steady state harmonic emissions. It is generally easy and relatively cheap to implement passive harmonic filters, as these filters are made from discrete components (capacitors and inductors). These filters also have some fundamental frequency losses. These operating losses reduce the kWh output of the wind farm accordingly.

Over the lifetime of the wind farm, these losses would accumulate into a large monetary value, which would be much greater than the initial cost and operating losses of an active type filtering system. In this case, these passive filters were not an option, as the harmonics in question were too close to the fundamental frequency (second) and were constantly changing based on the output of the RPP (based on wind speed).

The operating losses calculated were high and the RPP also has very strict resonance compliance conditions which limited the implementation of passive harmonic filtration equipment. Passive harmonic filters also take up a significant amount of space due to their required safety clearances. Many RPP's do not have the real estate available for a passive filtering solution with multiple steps catering for each harmonic order.

The second option for harmonic mitigation would be via active harmonic filters, whereby offending harmonic currents are cancelled or reduced via injection of inverse harmonic currents in real time. This is an attractive solution if the offending harmonic currents are at multiple harmonic orders, if the orders may vary over time, or include very low harmonic orders (second) to be mitigated.

Active harmonic filters further reduce the probability of further resonance conditions (as per passive filters) and can also be configured for a closed loop control. The closed loop control solution is based on the real-time measurement of harmonic content by the AHF, followed by the real time generation and injection of cancelling harmonic current.

An additional advantage of an active harmonic filtering solution over a passive one is modularity. Passive filters are typically designed so that there is one filter per harmonic frequency. This means that if there is a failure in any of the filter's components, that harmonic frequency is left unmitigated until the filter is repaired. Should the harmonic emissions change over time due to system impedance changes by the grid operator, passive filters would need to be physically reconfigured and some of the inductance or capacitance values would need to be replaced. Due to the long lead time of the passive filtering components, this could take up to six months.

Figure 2: New protection and control panel implemented

An active harmonic filtering system is modular, as can be seen from Figure 1. This means that if there was a fault in one active filter module, the system loses only that portion of its compensation capacity since the active filter modules used in this case each have an independent controller. The active harmonic filter compensation currents and harmonic orders can also be changed in real time by the client.

Transformer design parameters

With the active harmonic filter delivering harmonic cancellation at 400 V, a step-up transformer is required for interfacing towards higher plant 33 kV voltage levels. Due to harmonic content, such a transformer is bound to be suitably rated (i.e., suitable K-factor) and have a means for dealing with heat generation due to skin-effect harmonic current flow (at the internal transformer conductors). The losses from this transformer should also be very low to enable the maximum amount of harmonic current to pass through the winding. Therefore, the impedance should be as low as practically possible (Z% <= 3,5%).

There should also be no phase shift over the transformer and as such the requirement was for a star-star step up 5000 kVAR 400 V/33 kV transformer. The transformer should also be capable of operating at high loading continuously. Another aspect in transformer dimensioning is the harmonic voltage distortion at the 400 V bus. When the active harmonic filter modules inject harmonic current through a transformer, there is a voltage drop over the transformer at that frequency. Hence, the proper design must ensure that the total harmonic distortion at the 400 V bus is kept to a level which does not disturb the operation of any electronics connected to that bus.

Finally, the short circuit current at 400 V level needs to be considered. Splitting the 400 V side to two separate busbars limits the short circuit currents on those busses, which makes the protection design easier.

Protection design parameters

The protection system implemented should follow the client's existing bay control and protection scheme. This includes the integration into an existing differential protection envelope and the implementation of main and backup protection. SCADA elements should also follow the existing client system configuration. In this case, the client has a Schweitzer Engineering Laboratories (SEL) bay control, differential and protection scheme. Therefore, a SEL-787 protection relay was used as the main protection with a second SEL-751 used as backup protection. A new outdoor 40,5 kV circuit breaker was installed to switch and protect the transformer and the Merus A2 active harmonic filters.

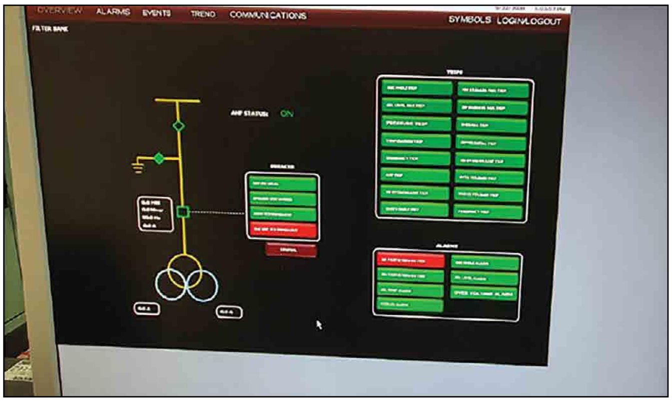

Figure 3: New client SCADA screens implemented

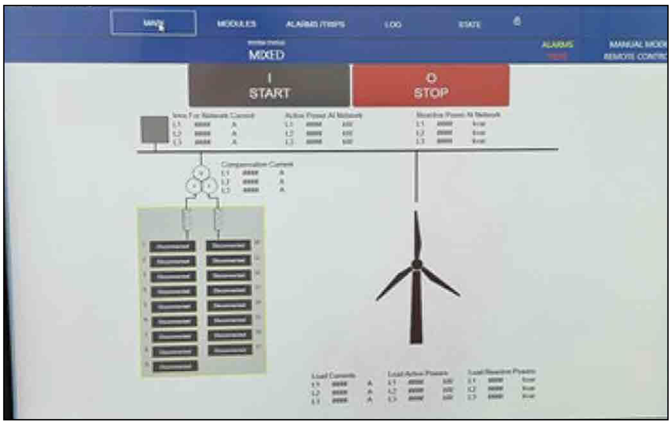

Figure 4: AHF SCADA screens implemented

Figure 5: Active harmonic filter and step-up transformer installation

Filter configuration

For this specific project, a relatively high level of harmonic current mitigation was required, making this one of the largest installations for this application in the world. Sizing requirements were determined to be at 2700 A at 400 V. This required the use of 17 x 160 A Merus A2 active harmonic filter modules. All the filter modules and control hardware were installed into a dedicated modified container, properly air conditioned and located in the existing HV switchyard. Real-time communication was installed to enable monitoring and remote adjustments of the control parameters as required. The control parameters and tuning of the filter modules can be made in real time from any operator who has access to the secure communication network. It is not required to switch off and isolate the system for any control changes to be made and any changes will take effect immediately.

The system is scalable and can react in real time to any RPP or network changes that occur. This is a great benefit over passive harmonic filters which are fixed in their tuning point and require large infrastructure changes, which have a long lead time for any modifications to the filtering parameters.

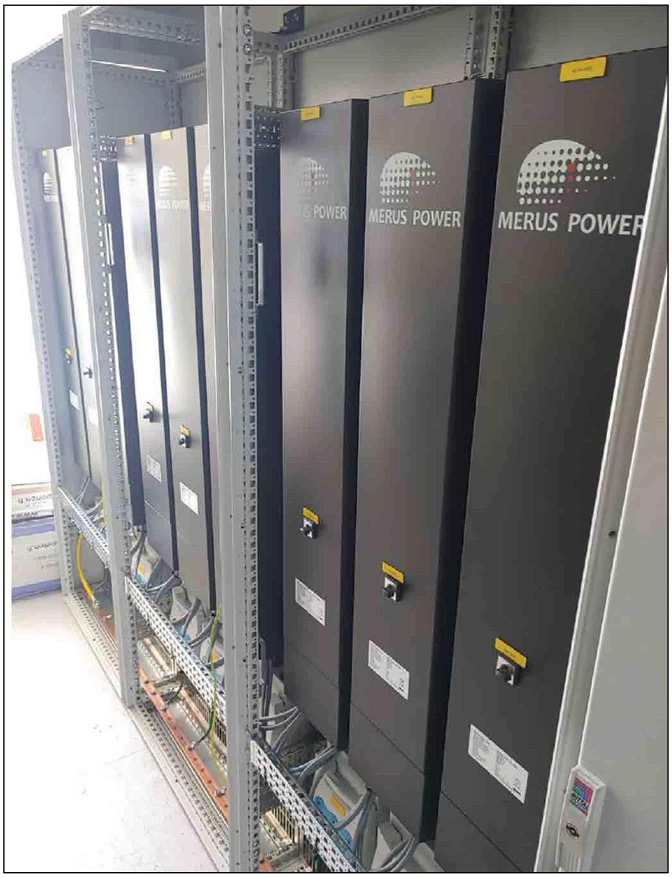

Figure 6: Merus A2 active harmonic filter modules

Active harmonic filter design

The active harmonic filtering solution was constructed from modular units. The OEM of these filtering modules is Merus Power Dynamics OY. They are a specialist power quality and harmonic filtering company based in Finland. RWW Engineering is the South African partner to Merus Power Dynamics OY.

The AHF modules were installed into enclosures and fitted into the converted container. The container was fully insulated from external temperature variations and cooled via bulk air conditioning. RWW Engineering completed all the required site integration including the civil works, mechanical installation, electrical installation, SCADA development, protection integration, switchgear and other requirements.

The filter modules are designed using a three level IGBT switching philosophy which increases the resolution, reduces the losses and audible noise and has greatly improved functionality compared to standard active filters on the market. Each module has its own touch screen where the local operator can modify the compensation requirements and parameters.

The entire system is also networked to Merus Power directly for them to check and maintain all parameters. The end client also has access for their own operators and maintenance personnel. Each active harmonic filter module is individually protected via fuses and the entire system is protected by group fuses. Each module also has other internal protections against overcurrent, over and undervoltage, overtemperature and so on.

Since the modules are actively controlled, they automatically limit their output current to the maximum allowed current, unlike passive filters which absorb harmonic currents without any control. If due to some transient event the module current exceeds the maximum allowed limit, the IGBTs can be shut down within a few microseconds to prevent damage to them or other internal components. The overtemperature control limits each module's output current linearly if a threshold temperature is exceeded. The aim is to find a current level which keeps the temperatures below the allowed limit.

The active harmonic filters can be programmed to automatically start up after a trip. For example, if there was a transient on the HV grid and the active filters were tripped from overvoltage, they would automatically start up once the voltage was restored back to the acceptable level. This automatic feature also has a limit on how many times a trip can happen before the module is locked and user action is required to restart it.

The modules can also easily be repurposed into a Static Compensator (STATCOM) should this be a requirement with regards to low voltage ride-through (LVRT) on a wind plant. If needed, they could also be configured to balance asymmetrical currents at the connection point.

Current transformer requirements

The correct selection of current transformers is paramount to optimal performance of the active harmonic filters. Frequency response, burden, transfer ratios and physical sizes should all be carefully considered. The measurement of the high order harmonic currents required the implementation of a specially manufactured metering CT with a high metering accuracy. This CT was installed around the bushing of the main 132 kV/33 kV RPP transformer. It also has a special core construction to accurately measure the harmonic currents that the plant is emitting into the system.

Figure 7: Special metering CT application

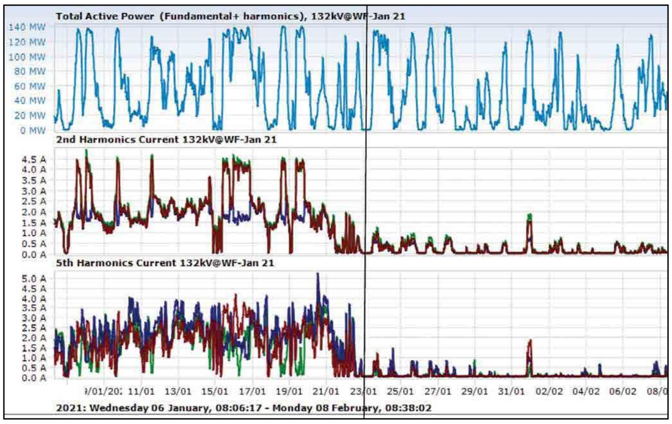

Figure 8: Second and fifth order harmonic current trend in relation to total active power: pre- and post Merus A2 active harmonic filter installation

Results

Figure 8 shows the results of the active harmonic filter installation for harmonic current mitigation. Trend data to the left of the horizontal marker indicates second and fifth harmonic order trending prior to the switch-on period. Being set up for targeting the second and fifth orders, the resulting mitigation can be clearly seen to the right of the marker line. The latter does conform to the limits set by the regulator for grid-code compliance.

Summary

This article provides a brief introduction into the requirements and solution for harmonic mitigation at a large wind farm in South Africa. It is shown that the use of an active harmonic filter is a viable solution and is often the only solution, due to ease of scalability and limited risk of introducing further resonance into the system. The wind farm is now fully compliant with all power quality parameters, including harmonic current emissions. ■

Reference

1. Grid Connection Code for Renewable Power Plants (RPPs) connected to the Electricity Transmission System (TS) or the Distribution System (DS) in South Africa, Version 3.0, August 2019.

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