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Detected problems in Wind Farms electrical network and operation improvement. Advanced WTG dedicated protection and control systems

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ABSTRACT

Wind farms consist of many turbines and technologies, often spread across a large geographic area and typically sited in harsh environments. It is essential to guarantee the stability and consistency of the performance of each wind turbine, by optimizing the protection and control systems of generators. On the other hand, the stable and consistent performance of each wind power generator is the most critical factor to wind farm developers for recovering the initial investment in a short period of time.

During the last decade, the technology in wind energy has been developed rapidly, which constantly increases the requirements in the installations that generates new needs for Medium Voltage switchgear and associated protection and automation functions. The constant evolution on the field of protection and automation allows us to solve these problems on a technological and cost effective way.

The paper identifies some of the problems and the enhancement possibilities detected during the last years and defines their solutions:

- MTBF improvement → Self–powered protection systems
- Discriminate internal and external faults to accelerate the former → Directional overcurrent protection
- Increase of the nominal power of the WTGs and selectivity→ Inrush current filtering
- Grid Code compliance (voltage dips and Reactive Power control) →Sequential reconnection of the WTGs
- Variety of engineering state of art → Standardised protection solutions independent from the earthing system
- Remote control and monitoring of the MV variables → Oscillography and event recording for fault analysing, current, voltage and power measuring and IP communications.
- Changes on the protection philosophy due to climatic facts → Different protection settings to be changed automatically

New developments in the field of protection and control devices allow us to implement the functions required for solving the above issues in compact systems, which does not affect the current dimensions of these devices. Furthermore, these new developments focus on Plug&Play solutions for getting a more competitive system, in terms of CAPEX & OPEX, COMMISSIONING savings included.

Field deployment of the described functions is already in progress in different wind farms around the world, in countries as different as U.K., Spain, Thailand, Jamaica, U.S.A. or Belgium, for example.

INTRODUCTION

The continuous evolution and improvement in the field of Wind Generation have caused a high increase on the needs and demands on all the components involved on the perfect performance of the WTG.

One of the key elements for this performance is the interconnection of the WTG with the Medium Voltage (hereinafter MV) network, composed by gas insulated switchgear, protection relays and automation, control devices, such as RTUs (Remote Terminal Units), power supply units and communications devices.

MAIN OBJECTIVE

The clear objective of these new systems is to continuously optimize the performance and energy generation of WTGs, improving the reliability and grid service capacity, maintaining always the maximum level of protection against electrical faults while increasing the total amount of working hours of the WTG.

REQUIREMENTS OF THE NEW GENERATION OF WTGs

For some years the transformer installed in the WTG was protected by a simple self-powered overcurrent relay installed on manually operated switchgear.

After years of expertise, the increase on the power of the generator and several new features required for a perfect behaviour of the WTG have led to a more complex electrical protection and control system.

The know-how throughout the years has produced the following list of requirements for protection and control units. The need of improvement on protection and control units is justified as they are needed for an optimal performing of the WTG in terms of generation, design and investment.

Compact devices: Even if the increase of the power of WTGs is clear, the requirement for compact solutions that save physical space is still on. This leads to decrease the volume of devices like MV switchgear, and accordingly, every device involved in the management of the latter needs to reduce its dimensions as much as possible.

MV switchgear with integrated Protection & Control devices inside a WTG.

Self-powered protections: The electrical protection of the WTG cannot be left in hands of an auxiliary powered relay in order to ensure a non-stop protection. Any failure of the power supply system would imply either the stop of the turbine or what is worse, a non-protected generation scenario. Self-powered protection relays maintain the WTG under protection whenever the turbine is connected to the MV network, including the energizing process, while other devices of the WTG are still in the powering up process.

Increase of the nominal power of WTGs: The constant increase on the nominal power of

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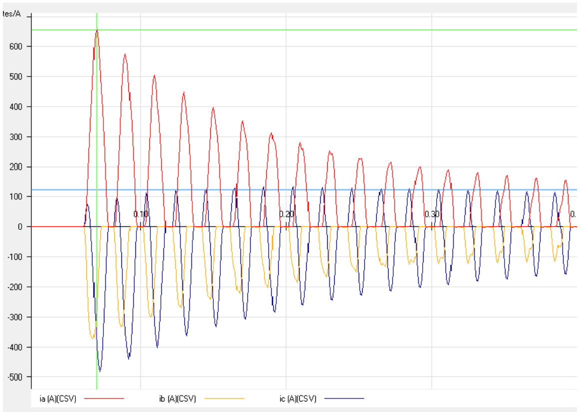
WTGs implies not only the need of more complex protection functions in some cases (such as overvoltage or over/under frequency if the WTG is connected directly to the network), but also the need to avoid tripping due to harmonics at the energizing moment.



Current/time diagram for the inrush current in the energizing of a 3.7 MVA trasformer at 20 kV. The nominal current of this transformer is 107 A, but the graphic shows that at the first moment the current reaches a peak of 650 A and that the attenuation of the wave takes 0.5 s until it reaches the nominal value.

The traditional way to avoid this event is to delay the trip and set the overcurrent protection between six and ten times the nominal current (the higher the power of the transformer the lower the relation between peak and nominal currents). The second part of the problem involves neutral overcurrent, as the unbalance on the current of the three phases can cause a trip from this function, which is normally solved by the same method.

But the increasing complexity of WTGs and the need of sharp selectivity in windfarms demand more sophisticated solutions that do not jeopardise neither the selectivity nor the protection of the WTG. The peak current values are higher for more powerful WTGs and this becomes a problem to set the overcurrent protection eight or ten times over the nominal value to coordinate with the complete protection system of the windfarm.

The best way to avoid tripping due to inrush current is to detect that the measured current includes an important percentage of second harmonic component regarding the fundamental 50 or 60 Hz wave. This feature should be included in protection and control relays for the protection of WTGs for the sake of a selective well-coordinated but safe protection.

Bidirectional overcurrent protection: In the event of a fault inside the WTG, in the step-up transformer or the generator, the flux of the current is incoming into the WTG. In this case it is clear that the fault must be cleared as fast as possible to avoid damage to the WTG.

Opposite, for faults occurred outside the WTG, implies that the direction of the current flux is going out of the WTG. In this case the relay should not trip, as the relay installed in the head of the line should be the one to take this action. Clearly two different sort of faults require different solutions (timing for the trip) while standard overcurrent relays are not able to perform in that way. The use of standard overcurrent relays implies a time delay born from the compromise of the needs of both situations, not being optimal for any. As stated, a fault inside the WTG must be tripped instantaneously while the trip due to an external fault must be delayed for selectivity reasons.

The solution to improve the performance is a bidirectional overcurrent relay that can detect the direction of the current and trip on different settings (current pickup and time delay) for each direction/kind of fault.

Grid Code compliance: Grid Codes differ from country to country and in some cases can be very sharp regarding the voltage dips that the WTG must bear without disconnecting or cause when it energizes the transformer.

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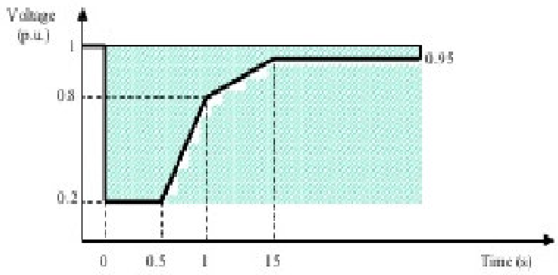
Simple undervoltage relays can trip the circuit breaker with no reason when facing a voltage dip. More developed relays can be set with different thresholds and time delay or inverse time curves to follow the requirements of the network operator.



Voltage dip diagram as per Spanish P.O.12.3 which defines the answer to be given to voltage dips by wind generators

At the moment of energizing any transformer there is a transitory peak of current consumption (inrush current) and subsequently, a voltage dip is caused at the connection point. This phenomenon can provoke problems on the network, mainly in weak networks, when connecting too many transformers (WTGs) at the same time. A known criterion is that the voltage dip caused by the connection of WTGs must be lower than 3% of the nominal voltage of the network.

The only solution in these cases is to connect the WTGs sequentially, in small groups instead of in a complete array. This connection scheme can be performed manually by an operator or automatically by a PLC or Control device. The advantages of the automated solution are clear and in this system the control device will detect the voltage presence/absence on the MV line and disconnect or reconnect accordingly the WTG after a set time, different for each WTG.

Measure of the generation of each WTG: Knowing the production at the outgoing of the generator, in LV, before the step-up transformer, can be enough for the control of the WTG, but the measurement of electrical variable at the MV connection point of each WTG provides more detailed and exact information in terms of exported energy. Current, Voltage and Power measurements sent to the SCADA system allow the operator to handle all the information needed to optimize the energy production, including diagnosis capabilities such as transformer aging.

Harsh climatic performance: The worldwide deployment and constant search for best wind locations has brought wind farms to be installed in really harsh environment locations, such as desserts, tundra or offshore.

Any device to be installed in WTGs must be able to work on these conditions at least as far as the WTG. Very low temperature (-40ºC) performance or salty atmosphere installation are some or the requirements to be fulfilled by any protection and control device for WTGs.

Construction of an offshore WTG

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Remote Control & Operation: Remote access to the Intelligent Electronic Devices (EIDs) installed in WTGs can provide very useful data to the SCADA.

The real status of the switchgear or local alarms are important data to be known by the SCADA, as well as the measurements of Voltage, Current, Power and Energy at the connection point and the remote operation of the switchgear.

MV switchgear with integrated Protection & Control relays connected to the communications network to perform remote control and monitoring of the switchgear inside a WTG.

All this information can be gathered and sent to the SCADA by Protection and Control relays if connected to the communications network of the Wind Farm.

Moreover, in case of faults, a remote access to the relay's event log and fault records, allows to clarify the reason and decide whether a remote closing order can be sent and continue producing energy.

Integration and Data exchange with other devices: Modern MV installations become smarter with the use of several Protection and Control devices that perform different tasks. The standard intercommunication among these devices is a must that can only be accomplished with the use of standard protocols such as IEC-61850. The use of GOOSE messages among different WTGs will allow them to take decisions, achieve interlocks or change features using the information provided by other devices located in nearby WTGs.

Insulation health monitoring: The use of Partial Discharges monitoring allows to detect insulation fails before they become a real problem and hence, a fault. This kind of predictive maintenance can save money avoiding non-expected production stops.

Real cable terminal configuration error (central cable) detected during energizing of the WTG. This kind of errors can be discovered by Partial Discharges monitoring prior to energizing.

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Moreover, Partial Discharges monitoring can also be used during the commissioning to detect non-correct installation facts, such as cable connections, before energizing the wind farm.

ADVANCED WTG DEDICATED PROTECTION AND CONTROL SYSTEMS

All the points seen before have led protection and control relays to a new generation of devices dedicated to WTG protection. The use of standard feeder protection relays is no longer a solution due to the lack of specialization in standard devices that cannot answer to the real needs of WTG Protection and Control.

Compact and robust Protection & Control Solution:

- <u>Compact relays:</u> Reduced dimensions of WTGs imply that the space assigned to each function is limited. Therefore, increasing the size of the components to allow new functionality is not an option and modern Protection & Control relays must keep the size of older ones even if performing enhanced functions.

Protection and control relay integrated on gas insulated circuit breaker cubicle.

One of the most interesting points, taking into account the dimensions of the WTG, is to avoid the use of control boxes. Compact protection relays designed together with switchgear can be mounted directly on special compartments of the latter, designed for this use.

- <u>Standard relay model:</u> The same relay family is to be used in all the installations for the sake of a standard engineering. This allows to apply the same kind of device all around the world independently of the earthing method or the different WTG.

- <u>Improved MTBF:</u> In order to improve the total amount of working hours of the WTG the constant running of some devices is compulsory. Protection relays must be on for the WTG to keep producing, so any external fact that can leave the relays out of order must be avoided.

The use of self-powered protection relays allows to reduce non-production gaps to enhance the MTBF of the WTG. On the other hand, the need for self-powered protections must not stop the relay to perform control or automation tasks, so, an auxiliary power supply source becomes necessary to power up a secondary set of units on the device.

As stated on the previous point, all device must fulfil also with harsh climatic requirements in order not to fail and maintain the MTBF of the WTG. Thus, robust and failsafe protections are mandatory to optimise the performance of WTGs.

- <u>Harsh climatic conditions:</u> Windfarms are located worldwide often under severe climatic conditions, either due to extreme temperature or to the environmental conditions, like in offshore windfarms.

All protection and control devices integrated in WTGs have therefore to work under these circumstances without fail. So, temperature ranges from -40ºC to 60ºC are needed to ensure the functioning all over the world, while harsh condition performance has to be taken into account in offshore or seashore locations.

- Factory installed & tested solution: When protection relays and accessories such as current transformers are installed in field, the risk of installation errors increases resulting on longer delays and higher costs.

On the contrary, if relays are installed in factory, not only installation times are reduced in the basis of a serial manufacturing method, but also the protections can be set from factory and a full battery of tests can be performed decreasing the checklist to be carried out in field and hence, saving time and money and improving the quality of these tasks (due to complete tools set in factory, better working conditions, etc.).

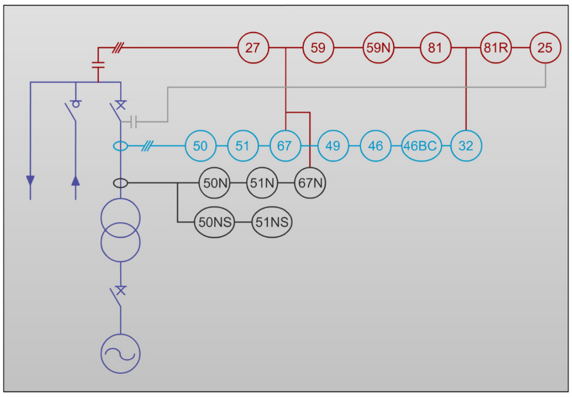
Enhanced protection and control features:

- Self-powered protection: Being independent from external power supply ensures that the WTG remains protected every moment the WTG is producing, from the energizing moment on. In this situation, not only the protection is ensured, but also the production is maintained on the event of a fail in the power supply unit, not needing to stop the generator for this kind of fails.

- Scalable models: Protection, control and automation requirements in WTGs can differ from project to project due to the nominal power of the WTGs, added to the point that Wind farms are spread all around the world with different grid requirements. The result is that often different protection and control philosophies need to be implemented, but keeping as much as possible the defined standardization.

The best option to cope with this issue is the possibility to enhance the standard protection relay defined for the most of the projects with more functionality into a higher level device. The task must be fulfilled maintaining the main characteristics of the standard relay, that is, keeping the engineering and human interface as similar to the standard as possible. The key, is that the same family of devices is always used for an easier and faster project development.

- Dedicated Protection CPU: The use of two separate CPUs allows the protection CPU not to be overloaded by remote control, automation or communications, for instance. The advantage is clear, as the protection unit can be dedicated to the main task and even work on self-powered function as secondary tasks can be performed throughout external auxiliary power supply.



ANSI device numbers for protection functions used for WTGs protection. Starting from well known overcurrent fucntions (50/51, 50N/51N) and increasing to directional overcurrent (67) voltage (27, 59) or frequency (81) protection, among others.

On the other hand, once protection units have been deployed in a separate CPU, control functions can be performed with no restriction on their own CPU with auxiliary power supply.

Reliability:

- Programmable logical automation: Old fashioned automatisms based on hard wiring do not ensure totally the safety of workers. Instead, when automation is programmed in the internal logic of a relay, the program can include much more inputs, such as interlocks after manual operation, for example. The latter situation can

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dramatically enhance the safety of the user, disabling the automation after every operation not made directly by the logic under automation terms, while the opposite may put in danger the worker if the automations operate unexpectedly.

- Standardized solution: The advantages of standardized solutions are clear, as factory delivery times are reduced due to the repetitive engineering. Moreover, the use of standardized solutions reduces field commissioning time as settings and testing procedures can be repeated.

- Partial Discharges monitoring: A complete compatibility of protection relays with Partial Discharges monitoring is requested to be able to perform an optimal and periodical maintenance task to prevent damages due to the ageing of the installation.

On the other hand, the use of Partial Discharge monitoring before the energizing can help to solve problems that can only be detected with installations in service (like wrong terminal configuring or wrong cable connections). The new generation of relays must be ready to be integrated in the Partial Discharge monitoring system as one of the main tools.

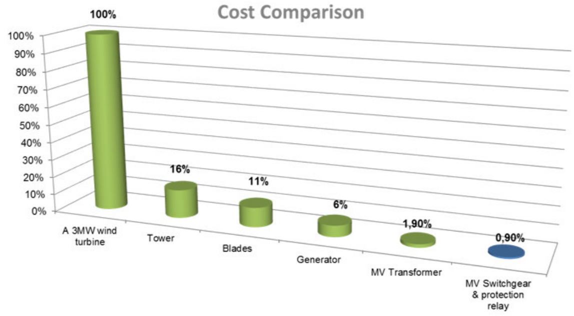
CONCLUSIONS

The use of standard feeder protection relays is no longer a competitive solution for the protection of WTGs as the evolving technology demands solutions to historically detected problems.

New features for WTGs require more powerful relays that can cope with the technological evolution and provide complete solutions to ensure the safety of the WTGs while keeping low the MTBF of the whole turbine.

Moreover, while some of the new features can be considered as enhancements for the WTG, some others are among the requirements of the grid code or safety requirements that must be fulfilled.

The cost of MV switchgear (including protection devices) regarding the WTG is comparatively a low investment (0.9% of the total investment of the WTG), as shown on the following chart.



The chart shows the percentcost of different items in a 3 MW WTG: Tower 16%, Blades 11%, Generator 6%, MV transformer 1,90% and MV Switchgear + Protection & Control relay 0,90%

As shown above, the investment required on a device that provides higher safety for personnel and equipment, as well as longer working hours for the whole WTG implies a clear benefit for the complete system while adding limited extra cost.

REFERENCES

1. Evolution and development of medium voltage switchgear for special wind farm applications. José Maria Torres, Iñaki Blanco. CIRED 2011
2. My vision. Andoni Iturrizaga. Wind PES Issue 18, 2011
3. How much does a wind turbine cost?, www.renewablesfirst.co.uk

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