BACK

IN DEPTH

DC system of systems

The future of power grids? *06/08/2013 - 4.22 pm*

HVDC MESHED GRIDS
NETWORK MANAGEMENT PROTECTION & CONTROL

The complex systems observed in the social organisations of the natural world could hold the key to stable plug-and-play DC grids that use control functions on different timescales and system levels to integrate the energy from wind and other renewable energy sources.

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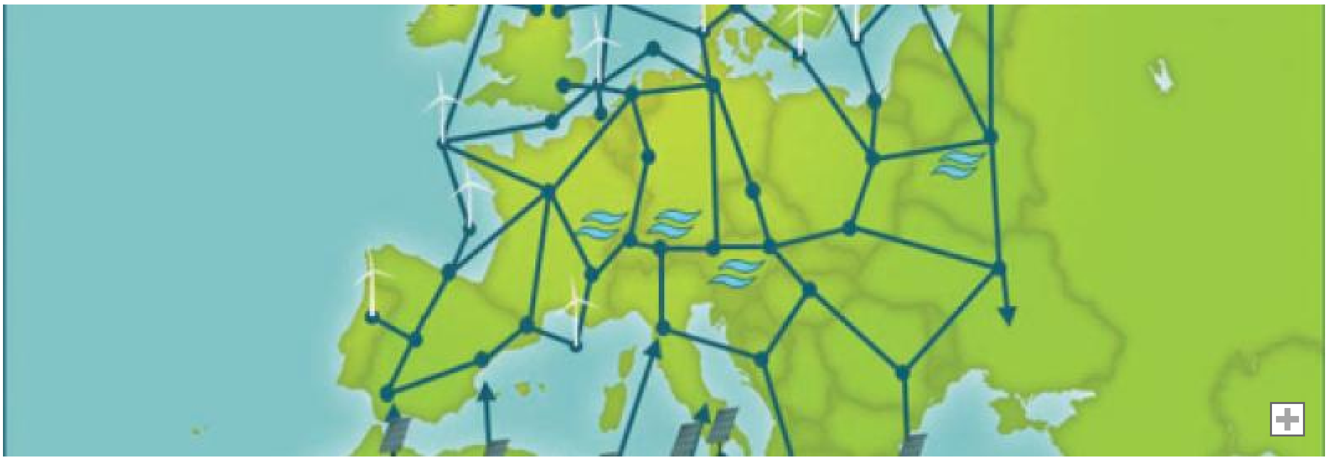
AC networks are operating ever closer to their limits. The warning signs are there. In 2003, blackouts cost the US economy $6 billion. They were held responsible for four deaths in Italy. The power failures across Western Europe in 2006 caused by a transmission line shutdown in Germany underlined the risks of outages crossing national boundaries. During this latter event, the European transmission network was split into three islands at different frequencies. In the 2 hours it took to resynchronise, some 15 million people were affected, and some 17,000 MW of power generation had to be curtailed (1). Yet a certain school of thought contends that blackouts are natural network behaviour. “It’s like a pyramid of sand that reaches a certain height before it collapses, because that’s the nature of sand,” explains Smart Grid Research Manager Dr Abdelkrim Benchaib. Can “natural” be “good”, though, when the lights go out on livelihoods and economies?

There have been serious attempts to develop blackout prevention strategies (2), but blackouts and brownouts still occur and will continue to do so. Prevention is merely containment. “Sooner or later the variety and complexity of loads and operations will breach AC network limits,” asserts Benchaib. The European Commission’s energy trends show an exponential rise in energy demand from 2,800 TWh per year today to nearly 4,000 TWh by 2030. Electricity is the fastest rising demand – up 58 % by 2030 and accounting for nearly 25 % of the total energy demand. Higher production will require stronger protection, particularly as more and more renewable energy sources (RES) flow into the grid.Total gross RES power generation – under 500 TWh in 2009– will reach almost 1,400 TWh by 2030. Ultimately, only a grid with a far higher power transmission capacity will be able to cope with burgeoning consumption, production and protection.

(1) Source: Union for the Coordination of Transmission of Electricity (UCTE).
(2) "Alstom presents the Blackout Team", Alstom 360° Video, Issue 55, March 2012.



1 __With Supergrid, no need for grid codes to be overprotective

For now, transmission system operators (TSOs) ensure grid stability with grid codes. Wind power operators, for example, must comply with codes for anti-islanding, power factor control, and no-trip low voltage ride-through. However, more numerous and tighter codes constrain the large-scale grid integration of RES, and calls from the IEC for greater inertial response will compound matters. More efficient means of transmitting energy must be used. One solution gathering momentum in the R&D community is the HVDC "Supergrid".

DC networks use interconnections and rapid support for variations in capacity: no need to synchronise. Most significantly, a network of interconnecting DC grids would carry electricity thousands of miles from distant sources – wind farms in the North Sea, geothermal sources in Iceland, solar power in the Sahara – to areas of highest demand. Such is the concept developed by the Friends of the Supergrid (FOSG). In addition to the top-down HVDC superhighway concept, the transmission system would also incorporate bottom-up, consumer-driven MV smart grids for charging electric vehicles, public transport systems, data centres, etc. The DC grid would overlay the existing AC grid, like a national motorway system connects to smaller local road systems. At the heart of the thinking behind the HVDC Supergrid is, precisely, the notion of "system of systems", whereby a Europe-wide network would link with national grids and so on, drilling down to the synchronous generators.

Operating diagram for trains-Mediterranean lines

2__Systems of systems

“Systems of systems were informally developed by AC grid engineers,” explains Benchaib. “Today we’re formalising the concept in DC grids. It is an active example of ‘thinking globally and acting locally’.” This brings to mind the theory of complex systems. In a school of fish, for example, each fish keeps a certain distance and follows the fish in front. The result is that each fish acts like the whole school, while the whole school acts like an individual fish. “Systems of systems are naturally occurring forms of organisation,” states Benchaib. “They will underpin the 2030 transmission grid in which control will be distributed amongst the nodes.”

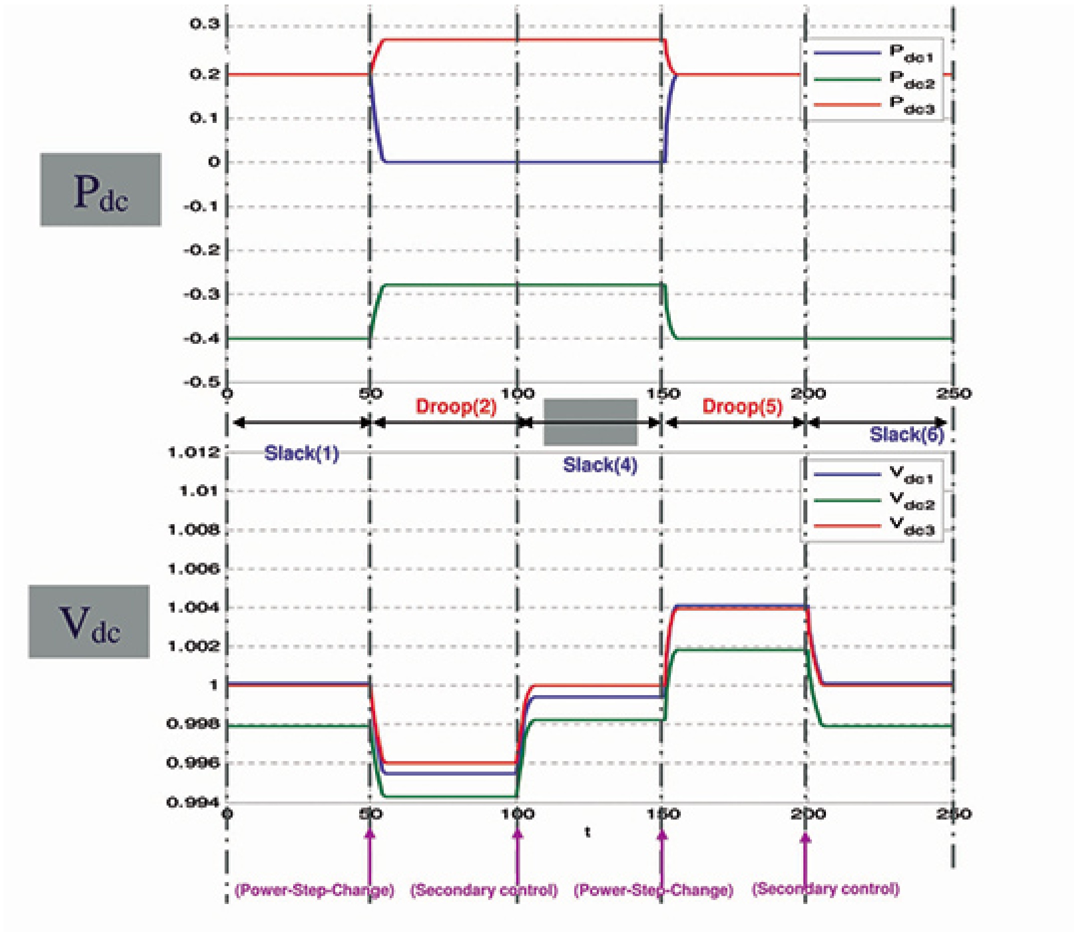
Distributed control will enable adjustments at different hierarchical levels and at different timescales to take place across the entire network. Indeed, a key component of systems of systems thinking is the notion of scale. Flexibility comes from the ability to switch from long timescales and large space scales to small ones, then back again. Again taking the example of the school of fish, should one or more individual fish quit the school, there is no effect on the school or its pattern of movement. All of which points to the tantalizing prospect of plug and play. “It should be possible to add a load to a system or to remove it without destabilising the system in the DC power network of 2030,” states Benchaib. AC networks, of course, have that plug-and-play capability, developed piecemeal over the years. However, with mass RES their control systems are unlikely to be able to cope. To enable plug-and-play behaviour in a multi-terminal DC (MTDC) system that integrates offshore wind farms, Benchaib and his research team are exploring primary, secondary and even tertiary control functions. They operate on different timescales and at different system levels to ensure grid stability. Primary control represents the variation of the power/current injection set-points caused by disturbances in the system. This is different from the local controller of the (AC/DC) converter, the role of which is to track any set-points. In the “system of systems” approach, a solution with different timescales has been adopted.

The time dynamic response of the primary control should therefore be slower (longer timescale) than the controller of the converter, which is around a few milliseconds. This primary control “time constant” will not depend only on the reactivity of the converter but also on the power injection ability of all connected nodes (production, storage, loads, etc.), which theoretically should be from a few hundred milliseconds to a few seconds, as for AC systems. Primary control is global but distributed. A primary control strategy that has proved itself in AC grids is the so-called droop control technique. This could be applied for MTDC power grids. In such networks the distributed control will then employ the droop mechanism to regulate the DC voltages by adjusting the power (or current) injections from the converters.

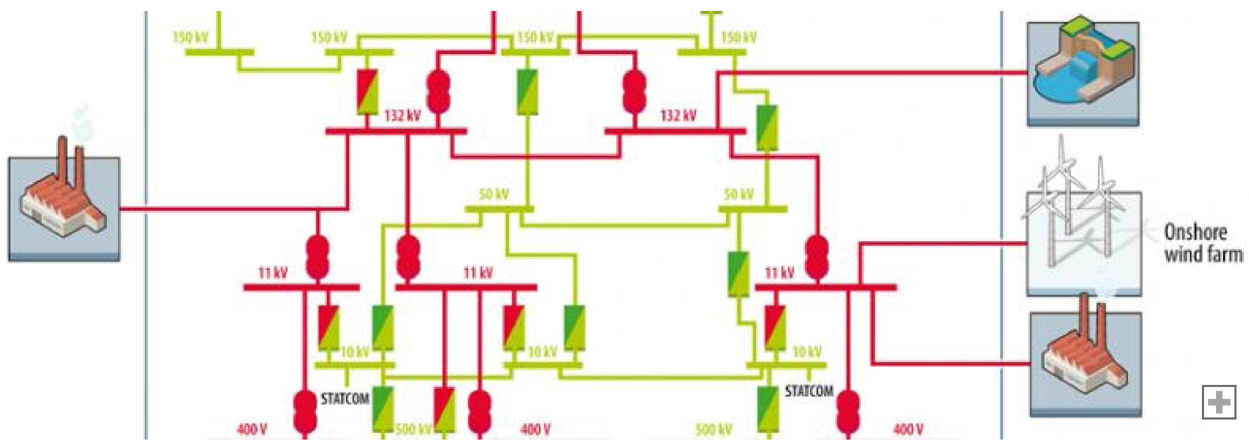
The converters simultaneously and individually inject the active power needed to restore balance to the MTDC grid. Thus, for the same voltage deviation two converters could inject different amounts of power. “Droop control is in each node. This is another example of ‘thinking globally, acting locally’ at work,” stresses Benchaib.
At a different and slower timescale, secondary control regulates the voltage deviation across the grid – or the next system up in the system of systems – on a timescale of several seconds. It uses master-slave strategies where one or more converters act as a slack bus (provide or absorb the power needed to achieve power balance within the DC grid), while other converters control their power exchange between the AC and DC systems. “The work we have put into formalising a system-of-systems approach for DC grids could usefully be applied to several other fields,” says Benchaib. “It’s a whole philosophy.”

Fault clearance speed: a system-wide challenge to HVDC grids
Unlike AC networks, which have been around for over a hundred years, HVDC grid technology is still in the making. Few of the principal protection systems from AC grids would work for DC grids, though the main requirements still hold. These are sensitivity (detection of all faults), selectivity (ability to isolate and trip only faulty parts), speed and reliability.

An issue that cuts system-wide across those criteria is the circuit breaker (CB) speed. CBs in AC systems typically clear a fault in 70-100 milliseconds (ms), including the fault detection time. However, DC networks have low impedance, so faults go deeper and faster. To be absolutely reliable, HVDC CBs should have completely cleared the fault current in less than 5 ms after the fault inception.
Communication speed is again a challenge in current differential protection, an AC protection system that is actually applicable to DC grids. “Alstom recently doubled the speed of its differential protection’s communication channel from 64 to a very fast 128 kbps. It reduces the fault detection time to less than 17 ms. However, that’s still far short of the 3-4 ms required to protect HVDC grids,” explains Dr Oleg Bagleybter, Programme Manager (Networks).
Backup protection solutions, where there is often an additional time lag, will demand even higher CB speed, and without backup there can be no reliability. New strategies are needed to integrate fault detection, discrimination and isolation for DC grids. A possible future solution may be the Alstom proposal of autonomous HVDC breaker operation, minimising breaker duty while also reducing the time the power interruption is “seen” by the interconnected AC systems.



Multi-terminal DC Grid Primary & secondary controls



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Dr Abdelkrim Benchaib
Smart Grid Research Manager

Dr Oleg Bagleybter
Programme Manager (Networks)

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