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B4-108

CIGRE 2012

Upgrading the Intermountain HVDC Project to handle 480 MW additional Wind Power

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SUMMARY

The Intermountain Power Project, Southern Transmission System (IPP STS) was built in the early 80's and commissioned in 1986 to bring power from a 1600 MW coal-fired generating plant in Utah to Southern California. The original project comprised of one bipole with 1600 MW ±500 kV continuous rating, meeting (N-1) reliability criteria. IPP STS had a very unique short-time overload rating allowing one pole to run at 2.3 p.u. current for few seconds before ramping down to operate continuously at 1.5 p.u. current (1200 MW power) should one pole trip [1].

To achieve this large overload on one pole all redundant cooling equipment for the transformers and the valves were used. The reactive consumption increased for the overloaded pole, but the full reactive power compensation for the bipole was available for that single pole.

Some of this overload capability was used in 1989 when the bipole was up-rated to 1920 MW.

To advance California's environmental policies, in 2005 Los Angeles initiated an aggressive renewable resource development program to reach a 20% renewable portfolio standard (RPS) by 2010 (which was later supplemented with 35% RPS by 2020 and 30% CO_2 reduction by 2030). One possible source for additional renewable resources was the wind power potential of southern Utah. To be able to bring such power into the Los Angeles area the IPP HVDC link provided a very interesting opportunity as well as a challenge.

Since each pole of the IPP STS was rated 1200 MW, continuous operation, there was a potential to have a bipole rating of 2400 MW resulting in a 480 MW capacity upgrade.

However, at 2400 MW rating, the (N-1) reliability criteria could not be met and still maintain the (N-1) redundancy criteria, as redundant A.C. filters and cooling for the valves and transformers were not available at this power level.

At the same time the project had been running for over 20 years and a control system upgrade before 30 operational years had already been planned. These two needs were combined and LADWP issued a request for proposal for a power and control system upgrade to take place before the end of 2010. The contract to perform these upgrades was awarded in December 2008.

The control concepts needed to integrate 480 MW of fluctuating wind power into an existing HVDC link and still maintain a large amount of bulk power transfer capability created many new challenges and special control features were developed to handle this efficiently.

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The dynamic performance issues of increasing the power transfer and adding new filters to an existing installation required extensive studies to be performed.

As always, when upgrading an HVDC link, the time needed to perform the installation and testing of the new equipment becomes an issue and in this case the outages could be limited to 3 weeks per pole, complemented by additional system tests in bipolar operation.

KEYWORDS

HVDC, Intermountain Power Project, IPP, Southern Transmission System, STS, LADWP

LOS ANGELES POWER SYSTEM BACKGROUND

LADWP Power System

The LADWP is the largest municipal utility in the United States serving over 4 million residents in Southern California with electricity and water. The LADWP service territory consists of 1,200 km^2 (465 square miles) that encompasses the entire City of Los Angeles and a portion of the Owens Valley, about 400 km north of Los Angeles.

The LADWP's maximum system peak demand is approximately 6,200 MW. Presently, LADWP has over 7,200 MW of generation capacity with annual energy production of approximately 25,000 GWh. In 2010 the LADWP's energy mix consisted of approximately coal (40%), natural gas (25%), large hydro (6%), nuclear (9%), and renewables (20%). Approximately 70% of this energy is produced outside the Los Angeles basin and imported to the city using LADWP's transmission system.

LADWP's internal system consists of natural gas-fired and hydroelectric power plants, including a large pump storage facility (over 1200MW capacity) and an extensive network of overhead and underground transmission lines ranging from 115 kV to 500 kV HVAC systems, including two large HVDC converter stations (over 5000MW total capacity).

The LADWP has an extensive transmission network extending over several states in the western United States that imports the majority of LADWP's energy needs.

As shown in Figure 1, the external system consists of long distance 500 kV HVAC and HVDC lines and coal-fired, nuclear and hydroelectric power plants. LADWP jointly or individually owns over 4,600 miles of HVAC and HVDC transmission lines.

Figure 1 LADWP's External System

STS Transmission

The STS line is a 785-km (488-mile) ±500 kV HVDC transmission line that connects two generating units in central Utah to the load centers in Southern California. The STS, originally rated at 1600 MW capacity, was upgraded to 1920 MW in 1989, and has now been further upgraded to 2400 MW as described in this paper.

LADWP RPS[1] and Transmission Development Plan

Most electric power providers in the United States have RPS policies or goals that define the level of renewable resource in percentage of their energy sales to their customers that they will be supplying to their electric customers at a given target date. LADWP's present RPS goal is 20% by 2010 and 33% by 2020. The 20% by 2010 goal is already met and LADWP is currently working on the 33% goal by 2020.

The LADWP plans to meet its RPS goals through the acquisition and development of various types of eligible renewable resources. This includes wind, geothermal, solar, and biomass (including landfill and digester gas power generation). Figure 2 depicts the various renewable resources that LADWP has potential access to. Depicted in Figure 2 are also the transmission components that are part of the development plan to support the delivery of renewable resources to the Los Angeles basin.

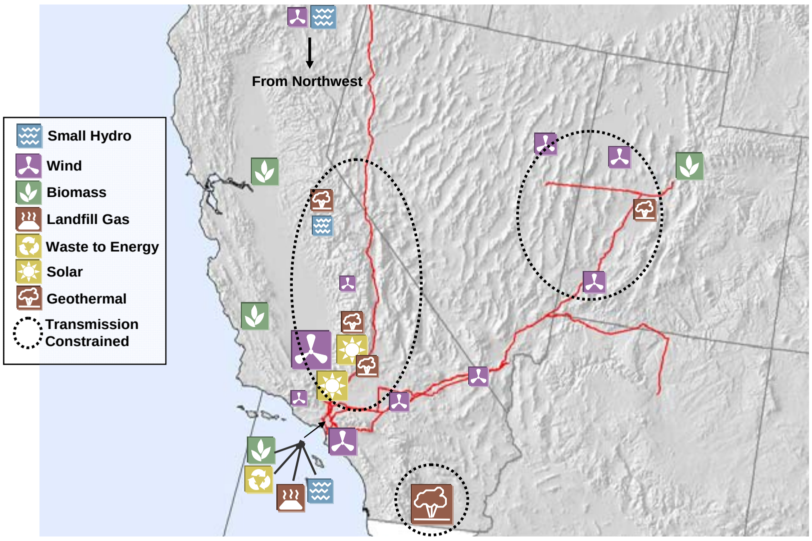

Figure 2 LADWP Renewable Development Plan

Wind resources development is a major component of LADWP's RPS program. Three key regions where the LADWP is engaged in the development of wind resources are the Tehachapi in Southern California, Southern Wyoming and Utah, and Mid Colombia River in the State of Washington. Barren Ridge Renewable Transmission Project (BRRTP), the STS Upgrade, and the Pacific DC Intertie (PDCI), respectively, are directly connected to these wind development activities. The focus of this paper is the integration of the wind resources in Utah to the STS Upgrade Project.

UPGRADE WORK SCOPE

When designing the original IPP HVDC link each pole had to be designed to allow it to take over the full power of the bipole (1600MW) in the event of a trip of one pole and stay at that level for several seconds before starting a 6 minute ramp down to the pole continuous rating see Figure 3 [1].

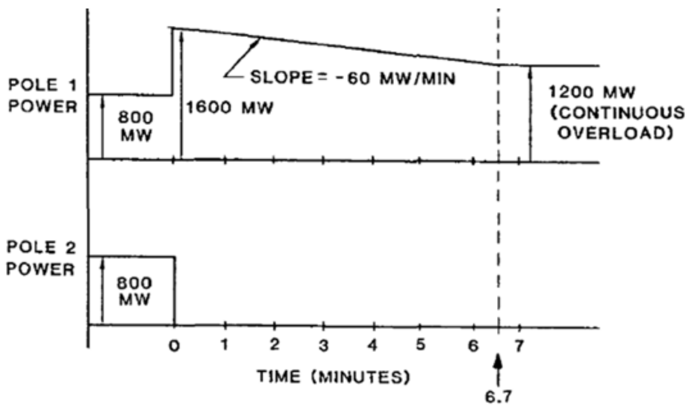

Figure 3 IPP System Response to a loss of a Pole when Operating in Bipolar Mode

This meant that all main-circuit equipment had to be rated to handle this extreme overload.

For the thyristor valves a 30 second

[1] Renewable Portfolio Standard

overload can almost be considered continuous so the thyristors, reactors and snubber parts of the valves had to be designed for 2.3 p.u. current. This meant that the cooling water temperature was maintained at a low level during normal operation to be prepared to handle a sudden doubling of the current.

The valve cooling system on the other hand can rely on the amount of water in the system and can be designed more for the continuous overload situation. The basic design was made to require 2 cooling towers per pole for normal operation and provided one additional, redundant, cooling tower. In the overload situation all three cooling towers could be used to achieve the required 50% increase in cooling capacity.

For the transformers an overload for 6 minutes means that it has to be designed for the high current, but from heating point of view the very long time constants of the transformers allows them to be designed only for the continuous overload. The original specification allowed the use of all fans and pumps in this operating condition.

The original overload was meant to be used for one pole going into overload at a time, which meant that the full set of filter-banks for the bipole could be used for the remaining pole. Now when trying to use the overload capability in both poles at the same time, this is no longer possible while maintaining the (N-1) reliability criteria. Therefore the original ac filter banks needed to be extended with one additional ac filter bank.

Thus a summary of the scope for the upgrade is:

- One additional filter-bank and some additional filter sub-banks in the existing
- One additional cooling tower for each pole and station
- New and larger heat exchangers in the cooling system
- Improved cooling arrangements (air deflectors) and additional monitoring for the transformers
- New control system including valve control

Valve and Valve Cooling upgrade

When going through the original design calculations and performing some complementary measurements in the running system, it was found that by adding a forth cooling tower for redundancy and replacing the aging heat exchangers with new and higher capacity units the temperature of the incoming water to the valve could be maintained at the level needed for the new and higher rating.

Thus the upgrades for the valve cooling system was fairly limited, but there was an additional request to replace all pneumatic valves and dampers with electrically operated, which added up to quite a large number of replacements and additions to the cooling system. In the end this meant that the cooling system work was one of the most critical aspects in the planning for the outage.

Transformer Upgrade

The original transformer design was made to allow for the continuous overload, but this condition was not expected to last for many days in any given year so the effect on transformer life-time did not have to be considered. The original specification also allowed the use of all fans and pumps during an overload, thus eliminating redundancy and tolerance for individual fan or pump failures.

Therefore it was necessary to improve the cooling arrangement for the transformers when increasing the rating. The full scale temperature measurements originally taken on one Adelanto unit in the factory, where they experimented and documented the effect of the distance to a fixed wall on the fan side of the transformers, proved very useful to this effort. From these series of measurements it was possible to predict that a 6 °C temperature reduction could be obtained if the re-circulation of hot air through the radiators could be eliminated.

This was achieved by designing and installing air deflectors in the form of aluminum sheets to force the hot air away from the radiator intakes.

As the transformers had been operating at high load for over 20 years without any failures it was possible that statistical end-of-life failures could start to appear in the coming years. Therefore a number of additional supervision devices were added to allow a closer watch of the conditions for the transformers. These included TEC[2] devices that look at current and temperature and track tap changer operations. Also traditional on-line gas detectors were added and devices for partial discharge measurement in the transformer bushings.

This is the first usage of an on-line PD measurement in an HVDC transformer so it will be interesting to follow this installation to see if this detection principle can be combined with the high amount of harmonics flowing through such a transformer.

Filter and Reactive Controls Upgrade

The IPP AC filter arrangement originally consisted of 3 filter-banks with 3-4 sub-banks in each.

To be able to maintain the N-1 criterion a 4th filter-bank was needed for the power upgrade. New filter studies also indicated the need for additional 5th harmonic filters and shunt banks and these new filters were distributed over both the new and the old filter-banks to provide a proper redundancy.

The result is a station with a very large number of filter-sub banks, shunt-banks and reactors. In Adelanto there are 17 switchable elements and in Intermountain 23.

To be able to control all these and always choose the best combination of filters, shunt-banks and reactors a very sophisticated Reactive Power Controller (RPC) is needed.

Because of the high calculation capacity of the Mach 2 computer units this was implemented as matrix calculations using function block diagrams in the redundant Bipole Power Controller (BPC).

There is also a need for several types of overvoltage protections that quickly remove filter and shunt banks if the transfer capability of the bipole is suddenly reduced.

New Controls and Protections

The control system for the original IPP HVDC link had a large number of unique and important features for its time such as redundant digital control systems, fully digital protections using single board computers and an alarm and monitoring system integrated in the HVDC controls.

This system could now be implemented in new control and protection computers improving the functionality and redundancy in the same control room and actually reusing some of the original control cubicles. The reuse of cubicles was implemented to save time during the outage as very few wires and cables needed to be moved in this way. The structure of the Mach 2 control system helped a lot here as it allows the I/O units to be placed where the appropriate cables are terminated and connects these units to the computers only by optical fibers. The advantages of this system approach for control and protection upgrades have been proven numerous times over the last 10 years [2] [3].

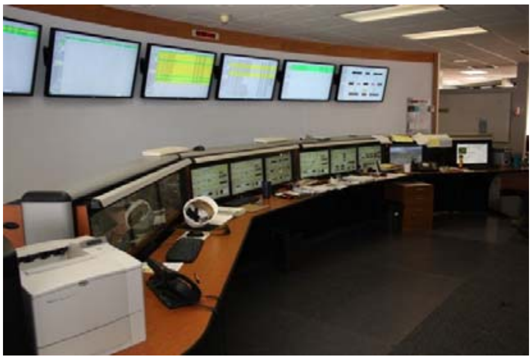

Figure 4 Operator Workstations in IPP

One of the more visible integrated functions is perhaps the integrated local SCADA system that makes it possible to remove the control desks and replace them with PC based Operator Workstations (OWS).

This system also allows the maintenance crews to bring an OWS in a laptop computer to the field where it connects through a wireless LAN. This allows the

[2] Transformer Electronic Control

maintenance personnel to have access to all the information that is available to operators in the control room. They can also access the server with the integrated circuit diagrams and activate these to monitor any signal in the whole station from any location.

Other functions that are integrated in a modern HVDC control system are the transient fault recorders (TFR sometimes also called digital fault recorder, DFR). With this function integrated the usual restrictions on the number of signals that can be recorded are removed. Because the TFR is integrated it will also, by default, be redundant.

A GPS[3] based line fault locator (LFL) was essential in this upgrade and was integrated in the bipole control computers. As there were filters for the power line carrier frequency bands included in the original installations these could be used to provide a good location for the measurement of the incoming waves by the integrated LFLs.

Redundant protection systems were provided for the AC filters and here the protection computers could be moved from a distributed AC Filter Relay house to the main control room to simplify maintenance. Instead only I/O units were placed in the remote building and connected to the protection computers with optical fibers.

The converter and pole protections including transformer differential and over-current protections were all implemented in the redundant pole protection computers.

SYSTEM INTEGRATION ISSUES

Utah Wind Integration with the STS HVDC Upgrade

Presently there is about 300 MW of wind power directly connected at the DC terminal substation at Intermountain. This amount is expected to increase to approximately 400 MW by the end of 2012. This is in addition to about 80 MW scheduled to IPP from Wyoming.

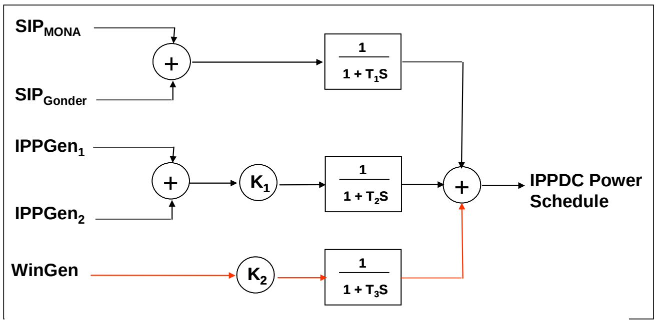

Figure 5: IPP DC Power Scheduler

The essential component of the integration of the wind generation at Intermountain requires dynamically scheduling the total wind output to Southern California. The design and implementation of such control system required key considerations that include inadvertent power flow to neighboring balancing authorities, voltage control, reactive power exchange, dynamic overvoltage, and system oscillations. One of the key controllers, known as the DC Power Schedule Calculator (DCPSC), that serves the dynamic scheduling function of the wind and coal generation at the rectifier end of the DC line is shown in Figure 5. Proper design and testing of this controller is important to avoid any system oscillation and stability issues.

The integration challenge of HVDC and wind generation is to develop the proper control functions and operating parameters to provide robust and stable system operations. The benefits gained with this application include:

- Allows full control of the wind power output with the HVDC power schedule
- Minimizes excessive voltage and reactive demand fluctuation within the converter stations
- Minimizes excessive operation of the converter transformer Load Tap Changer at the HVDC inverter station
- Controls the area-control-error at the IPP interconnection points to zero

[3] Global Positioning System

Contingency Arming System

In the IPP sending end there is a lot of generation connected, around 1900 MW from the thermal generators and up to 400 MW from wind generators. The AC connections to the converter station are not designed to be able to transfer this much power, not even during transient conditions.

In steady state the DCPSC as described above will take care of balancing the power and controls the amount of power transferred on the AC lines, but if there is a sudden drop in the HVDC power transfer capability, like when a pole is blocked or tripped, certain emergency actions need to be taken to make sure that the AC lines are not overloaded and their protections trip the lines.

Therefore a special contingency arming system (CAS) was included already in the original design [4]. This was implemented in a separate PLC[4] in the generator station but did not have any capability to be extended with the additional conditions for the wind farm.

Therefore it was decided to integrate and extend the CAS functionality into the HVDC controls when upgrading the control system. In this way both a much more powerful as well as a redundant CAS system could be designed, that will also have considerable expansion capabilities for the future.

CONSTRUCTION AND INSTALLATION

Project Schedule

The project was built and delivered on a quite accelerated schedule to allow finishing before the end of 2010. In total the project was handed over to operation around 24 months after order.

The 4th filter bank could be built in advance before any outage was required so that work could start as soon as material was delivered to site after roughly 16 months.

After the new filter-bank was installed it was taken into operation using temporary filter protections to allow the protections to be exchanged for one filter-bank at a time in the original banks.

Pole and Bipole Outage Requirements

When all filters had been converted to the new protections it was time to start rebuilding one pole at a time. To do this Pole 2 was taken out of operation and Pole 1 continued to operate in metallic return. This reduced the capacity of the IPP link to 1200 MW, but as this outage was coordinated with a maintenance stop of one of the Intermountain generators the 1200 MW capacity was sufficient to transfer the output from one generator as well as the output from the wind farm at that time.

Then followed a very busy period when the controls were replaced, new heat exchangers installed, the 4th cooling tower connected and all pneumatically operated valves in the cooling system replaced by electrically operated units. The air deflectors around the transformers and the additional supervision devices were installed and connected to the control system.

The complete installation was finished in around 2 weeks and then followed circuit testing (so called green lining) of all control and protection circuits.

After 3 weeks pole 2 was ready for testing and the output of the remaining generator was ramped down to allow for low power testing of pole 2. Then successive higher power levels were tested for pole 2 up to 1200 MW and after 3 weeks outage and testing pole 2 was ready to handle the power transfer and a similar operation of replacement and testing could be performed in pole 1.

When both poles were rebuilt and the basic pole testing of pole 1 was done it was time to move into system testing of the bipole.

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[4] Programmable Logic Controller

Commissioning and Testing

The system testing program was quite extensive incorporating such tests as pole blocking with compensation of the power transfer by the remaining pole. Staged DC line faults were conducted to verify the DC line protection and to calibrate the DC line fault locators.

After adjustments the LFL were able to indicate the faulted tower for both close to end fault locations and a mid-line fault. During these type of transient disturbances the sub synchronous oscillations and their damping was observed to verify that the new control system had been set up to provide the same positive damping in the sub synchronous region as the old.

The original IPP controls had shown a tendency to provide low damping for 90 Hz oscillations in the rectifier network at a couple of instances during the years. Therefore the new control system had been set up to always provide positive damping for oscillations in that frequency range.

A very interesting special test was arranged to verify this improved damping at 90 Hz. For this test the commissioning crew programmed a controllable 90 Hz oscillator into the current control system so the converter could be used to produce a very small 90 Hz current modulation. As soon as this could be measured the modulation was removed and the effect of the additional damping functions could be verified. This is a type of tests that would be very difficult to perform without a powerful block programmable control system.

CONCLUSIONS

The upgrade of the IPP HVDC link is a first example of how an existing HVDC link that was primarily designed for bulk power transfer can be successfully converted to also handle a substantial amount of highly fluctuating renewable wind power. With the large amount of wind farms being installed and planned around the world there will definitely be more examples were similar adaptations will also need to be performed.

The IPP upgrade also exhibits a clever way to utilize all the inherent overload capability to actually increase the rating of a 25 year old HVDC link by 25%.

This upgrade is also another example on how control and valve cooling upgrades can be done one pole at a time in just a few weeks and can thus provide confidence for owners of HVDC plants, planning similar upgrades in the future, that it can be done with very minimal losses of transfer capability.

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