CO-ORDINATION OF PARALLEL AC-DC SYSTEMS FOR OPTIMUM PERFORMANCE

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Summary

In December 1999, the world's first commercial HVDC-Light will be put into operation on the Swedish island of Gotland. This new concept of DC technology, incorporating the latest advances of power electronic devices, DC cables, together with a great flexibility of control, entails the beginning of a new era of HVDC. Thanks to the introduction of HVDC-Light, the possibility of large-scale wind power generation on the island has become a reality.

In the last years, the great wind potential on Gotland has led to fast expansion of wind power plants. However, the large proportion of asynchronous generation has led to problems such as flicker, voltage instability, inappropriate power flows, as well as problems of improper operation of protection equipment, among others. The intensive demand of wind power installations calls for enlargement of system capacity, without disregarding the power quality aspects.

Several alternatives were considered, being HVDC-Light chosen for its technical and economical viability, and environmental compatibility. The capacity of HVDC-Light for fast independent active and reactive power control, as well as protection functions for the AC system integrated in the converter equipment, provides important benefits regarding power quality and successful and reliable system operation.

In this paper, a description of how the possibilities of control of HVDC-Light have been utilised in the Gotland project, to co-ordinate the parallel AC-DC system with large proportion of embedded wind power generation, will be presented.

Introduction

The Swedish island of Gotland, situated in the middle of the Baltic Sea, had been earlier scenario of the world's first large scale HVDC link, which interconnects the Island with the Swedish mainland. This, using firstly mercury arc converters, was taken into commercial operation in 1954, and upgraded in 1970 by using thyristor valves. In the last years, the high wind potential on the island coast, has led to a fast expansion of the wind power generation capacity, up to levels which can equal the total system load. The generation of wind power in the distribution system has given rise to a number of power quality problems, which impeded the possibility of further connections of wind power if no upgrading was realized. The increasing demand of wind power installation called for enlargement of system capacity, without disregarding the aspects of power quality. Several alternatives were considered, being HVDC-Light the only technically and economically viable.

HVDC-Light offers possibility of fast independent active and reactive power control, as well as protection functions for the AC system integrated in the converter equipment, among others. However, in order to achieve a successful operation, the DC system must be co-ordinated with the existing AC network, special control strategies must be developed when considering specific problems of wind power generation. With this aim, the project has been a close co-operation between the designer, Vattenfall and the local utility Gotlands Energiverk (GEAB).

Results of simulation with detailed computer models showed from an early stage the great potential of this solution and the radical improvement on the power quality reached if the capabilities of HVDC-Light are adequately utilized. A model of HVDC-Light and the AC grid, together with the wind power stations, loads and HVDC link to the mainland, has been used. The studies performed have been an important tool to find out the control strategy and parameters for optimal co-ordination and performance with the AC system.

1. The Gotland distribution system

The network on Gotland is owned by GEAB, subsidiary of Vattenfall. The electric system can be regarded as an island net, even if it is connected to the mainland of Sweden via conventional HVDC link. It consists of approximately 300 km 70 kV overhead lines, 100 km 30 kV and 2000 km 10 kV lines. The island consumes around 900 GWh electricity per year, most of which is supplied from the mainland through the HVDC link, at a peak load of 170 MW. An important cement factory is installed and consumes 40 % of the energy on the island. 55 MW wind power are installed today, of which 38 MW are located in the southern tip of the island where the system is weakest and near the thermal limits at full power operation.

Figure 1 shows a simplified scheme of the system and the HVDC-Light connection in parallel to the AC network. The converter stations at Näs and Bäcks are connected to the 70 kV system by the HVDC-Light transformers. At Näs, a three-winding transformer in series provides the connection to the 30 kV net. Mainly wind power stations, together with some small load are connected to the 30 kV and 10 kV windings. The short circuit power in the 30 kV side is around 75 MVA. When the wind power production (WPP) in Näs reaches 50 MW, the line voltage will be upgraded to 70 kV (see discontinuous line), increasing the short circuit capacity of the AC network to 230 MVA, and providing 30 MW further capacity for wind power.

2. The HVDC-Light transmission system

As shown in Figure 1, the Gotland HVDC-Light will be installed in parallel with the existing 30 kV line. It consists of two forced-commutated voltage source converter (VSC) stations, which include AC filters, transformers, cooling system and other auxiliary equipment, and the ± 80 kV DC cable with a length of 70 km. The converter stations are rated at 65 MVA. By using Pulse-Width-Modulation (PWM), the amplitude and phase angle of the fundamental component of the converter AC output voltage can be controlled simultaneously, thereby the independent active and reactive power control is achieved. The DC system is capable of transferring the active power in both directions from 0 to 50 MW, and each station is capable of supplying the reactive power from –40 to +40 Mvar. The capability of supplying variable reactive power makes it possible for each converter station to function as an Static Var Compensator (SVC) and thus control the bus bar voltage at the same time when the active power is transferred.

Regarding the losses in the HVDC-Light, one characteristic which differs from an AC transmission is that a part of the total losses is independent of active and reactive power flow, and it is mainly determined by the DC voltage level for a given switching frequency. If the DC voltage is constant, the relative losses at low active power flow will be higher in the DC system compared with the AC alternative. This drawback is expected to pass away in the future when the semiconductor devices are further improved. At present, the countermeasures adopted in Gotland project are based on reduction the DC voltage set point without reducing the reactive current control capability, by using tap changer in the transformer, or switch-off the DC link, as will be discussed in 3.3.

3. The control and operation principle

3.1 Converter station control

As an integrated power transmission system, the control of active power in the converter stations should be co-ordinated. The co-ordination of active power control between the stations is realised by designating one converter controlling the DC side voltage whereas the other converter controls the active power. A constant DC voltage control will result in an automatic balance of active power flow between the stations. In the Gotland project, the Bäcks station is chosen to control the DC side voltage normally, whereas the Näs converter station controls the active power. However, it is possible for each converter station to change from the active power control to the DC voltage control, and vice versa.

The HVDC-Light is designed to operate without tele-communication between the two converter stations. Under severe operation conditions such as AC faults in the network close to Bäcks station, the Näs station will automatically adjust the power order in such a way that the voltage of the common DC link is under the control by using local information, for instance, the measured DC voltage.

In addition to the active power or DC voltage control, each station counts also with an AC voltage as well as a flicker control. The AC voltage control keeps the primary side voltage of the transformer to a predetermined set reference value. The flicker control, which works in parallel with the AC voltage control, eliminates voltage fluctuations mainly due to the tower shadow effect from the windmills. By using adjustable compounding impedance, it is possible to choose the desired bus, where the voltage fluctuations must be minimised. At Näs station, where the number of customers is few, it is especially convenient to use this compounding function, since better flicker reduction can be achieved at the bus where more customers are connected (See Fig. 2).

3.2 Master control: SCADA system

The reference values (set points) for the active power at the Näs station and for the AC voltage at both stations are provided by a SCADA system, in function of the WPP and system load level. These set points, which are calculated and sent periodically to the stations, determine the steady state active and reactive power flow in the network. In this application, the criteria of power loss reduction have been considered at determining the reference values. On the other hand, the Master control is designed to ensure a safe grid operation without dependency of availability of the SCADA system.

An algorithm based on power flow calculations has been implemented in order to obtain the desired operation point in function of WPP and load levels. This method, developed originally to calculate the losses originated by wind power, has been incorporated in the SCADA system for obtaining the optimum power flow in real time. The program uses data of all loads in the distribution stations, productions, capacitor batteries, as well as the main breakers in the 70 kV network.

The Master control is especially interesting when the configuration of the network is altered due to tripping of 70 kV lines, when some parts of the system might become overloaded. An adjustment of the operation point of the HVDC-Light converter might avoid further AC line disconnections.

3.3 Operation principle

Normally the HVDC-Light delivers the active power from wind farm at Näs to Bäcks with a maximum of 50 MW. When the WPP is close to zero, the active power may be transmitted from Bäcks to Näs with a maximum of 17 MW. When the WPP is under the load capability of the existing AC line, the DC transmission may be switched off. In this case, the Näs station is continuously active to ensure voltage stability and flicker control, while Bäcks station is in standby-mode. However, when a voltage drop is detected, the Bäcks station is automatically de-blocked within a few milliseconds to assist with reactive power. In many cases, the reactive support from the Bäcks station can avoid tripping of the big industrial loads in the north of the island (see section 1) during faults. Figure 3 shows the simulation results of a three-phase short-circuit at a 10 kV substation in the north of Gotland, previously and after the HVDC-Light connection. It can be seen how an important reduction of voltage drop during the fault is achieved in the AC network when HVDC –Light is incorporated.

4. Network protection: Disconnection of Wind Power Production

The 10 kV switchyard control is totally integrated with the HVDC-Light control making it possible to operate the four wind power breakers on essentially any signal within the HVDC-Light control. The functions of the switchyard control are programmed in the same computer as that of the HVDC-Light control. The main advantage of this solution is that the design of new functions can be realised more easily, and the delay-time can be reduced. At the same time, it helps planning the management, for example by using information of breaker status. The analysis of faults becomes also easier with the use of a *Transient Fault Recorder,* which automatically records measurements from the AC and DC systems at detection of abnormal event. The tap changer controller can be governed by the SCADA system.

The strategy of the wind power disconnection function is foreseen to avoid disconnection as many times as possible at disturbances. WPP units are only disconnected when sure indications are at hand that the units eventually will trip themselves on their own protections. Tripping all or part of the WPP units in an early stage reduces the stresses on lines and network equipment.

4.1 HVDC-Light permanent blocking

Permanent blocking and opening of the AC breaker are ordered at severe faults that affect the HVDC-Light main circuit components. These are an indication that WPP shall be disconnected. The initial active power through the DC cable determines how many of the four WPP breakers shall be operated.

4.2 Tripping of AC line breaker

When one of the breakers on the parallel AC line is opened, the HVDC-Light station in Näs will operate as an island network without connection to the rest of the AC system. In that case, WPP disconnection must be ordered by HVDC-Light control.

4.3 AC line over current protection

The active power overshoot through the AC from the WPP after large voltage drops is one example where the use of AC line over current protection is required. In such cases, the over current protection of the AC line will order WPP disconnection in the Näs1 switchyard. The overload protection disconnects 10 kV lines in sequence of time, even though, normally, disconnection can be avoided.

4.4 Other protections

Even under/over voltage protections and over/under frequency protections are used to disconnect windmills in the 10 kV switchyard. Normally the windmills have equipment to disconnect for over and under voltage and frequency although, in this case, it is redundant in the switchyard.

5. Short-circuit currents

The presence of WPP alters the normal short circuit conditions in the network and disturbs the shape of fault current, which makes it difficult for the operation of the over current protection with the desired selectivity. The effect of HVDC-Light under a fault is an increase of the fault current level as well as a stabilisation of the voltage, and therefore, of the current shape. These two factors are beneficial for operating the system with the planned selectivity.

5.1 Contribution from HVDC-Light

Simulation of a three-phase short circuit applied close to the Näs station with and without HVDC-Light shows a higher short circuit current in the first case, at no WPP (See Fig. 4). The HVDC-Light contribution is due to the presence of voltage regulators in the converter stations, which order an increase of reactive current, up to the capacity limit, under a voltage drop in the AC system. The contribution to the short circuit current decreases with the distance to the fault, and the pre-fault active power transmitted through the link. When HVDC-Light is connected, the short circuit current is approximately constant during the fault at no wind power production (WPP).

5.2 Contribution from wind power production

With WPP the sub transient short circuit current can considerably higher than without WPP, depending on the location of the fault and the level of WPP connected. Without voltage control, the current decreases with the time down to same or lower value than without WPP, due to the behaviour of the asynchronous generators and capacitors. The voltage control of HVDC-Light helps stabilising the voltage during the fault and therefore the fault current, which is beneficial for the protection operation.

5.3 Protection settings philosophy

Due to the high level of WPP, it is difficult to fulfil the selectivity demands at all production levels, with the normal over current protection used for the distribution system. However, it has to be ensured that the protection will operate, by setting them to the minimum values of the short circuit currents. By means of computer simulations of short circuits, the proper protection settings have been analysed.

6. Next steps of development. Frequency control mode for island operation

When one of the breakers on the AC line is opened, it is still possible to continue transferring WPP through the DC line. This can be achieved by shifting control mode from active power to frequency control. Although the frequency control mode is available, it is not in operation at commissioning.

7. Conclusions

In December 1999, the world's first commercial HVDC-Light will be put into operation on the Swedish island of Gotland. Before incorporation of HVDC-Light, the great proportion of asynchronous generation led to problems of power quality and inefficient network operation. Thanks to the introduction of HVDC-Light, the enlargement of wind power generation capacity on the island has become possible. The capacity of HVDC-Light for fast independent active and reactive power control, as well as protection functions for the AC system integrated in the converter equipment, provides enormous benefits regarding power quality, and successful and reliable system operation. Computer simulations of the Gotland grid together with HVDC-light showed from an early stage the benefits of this solution. The continued results of the extensive network studies during the Gotland project confirm the great potential of HVDC-Light technique, especially regarding connection of large-scale embedded generation in weak distribution systems.

References

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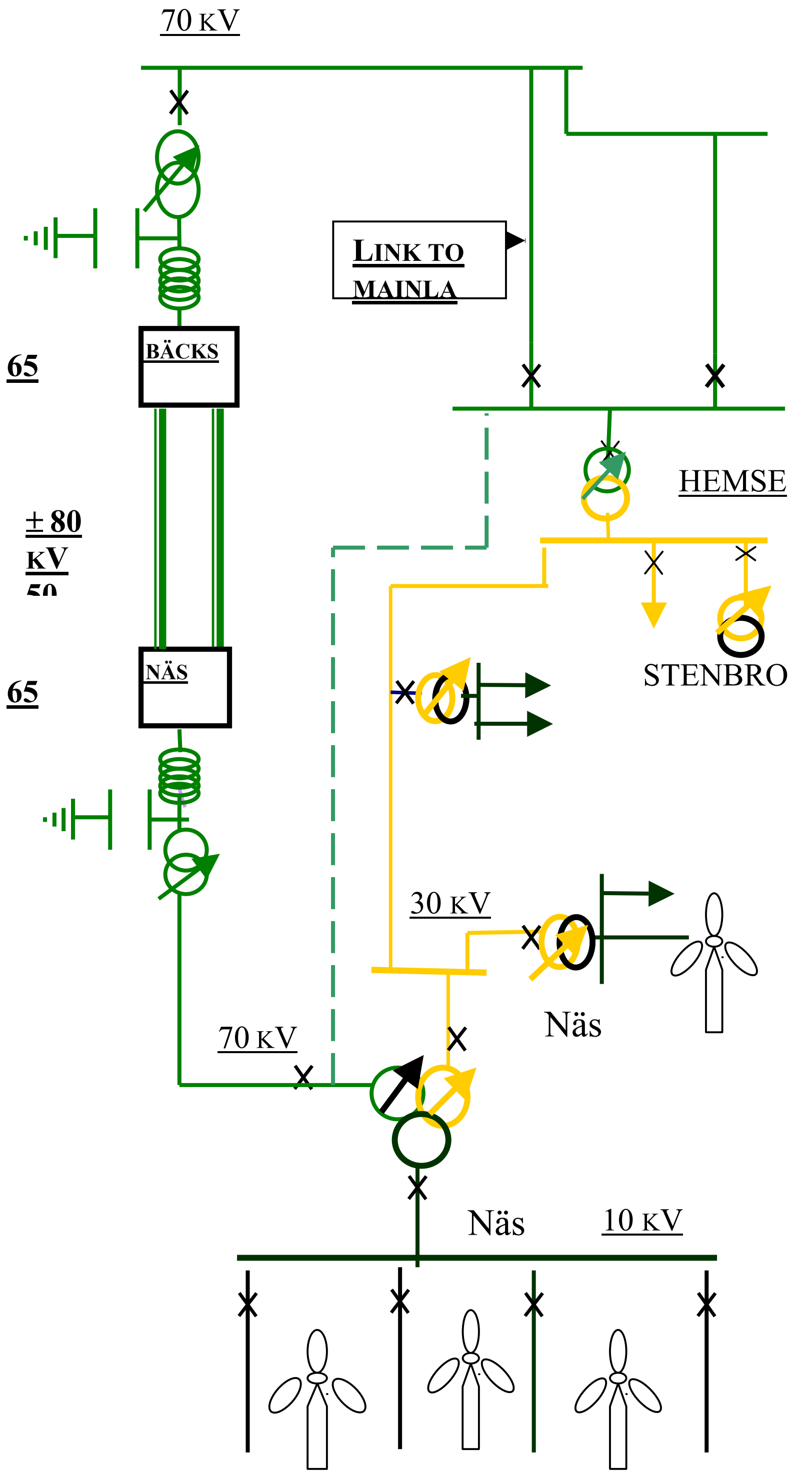

FIGURE 1. ***SIMPLIFIED SCHEME OF THE AC NETWORK WITH HVDC-LIGHT CONNECTION***

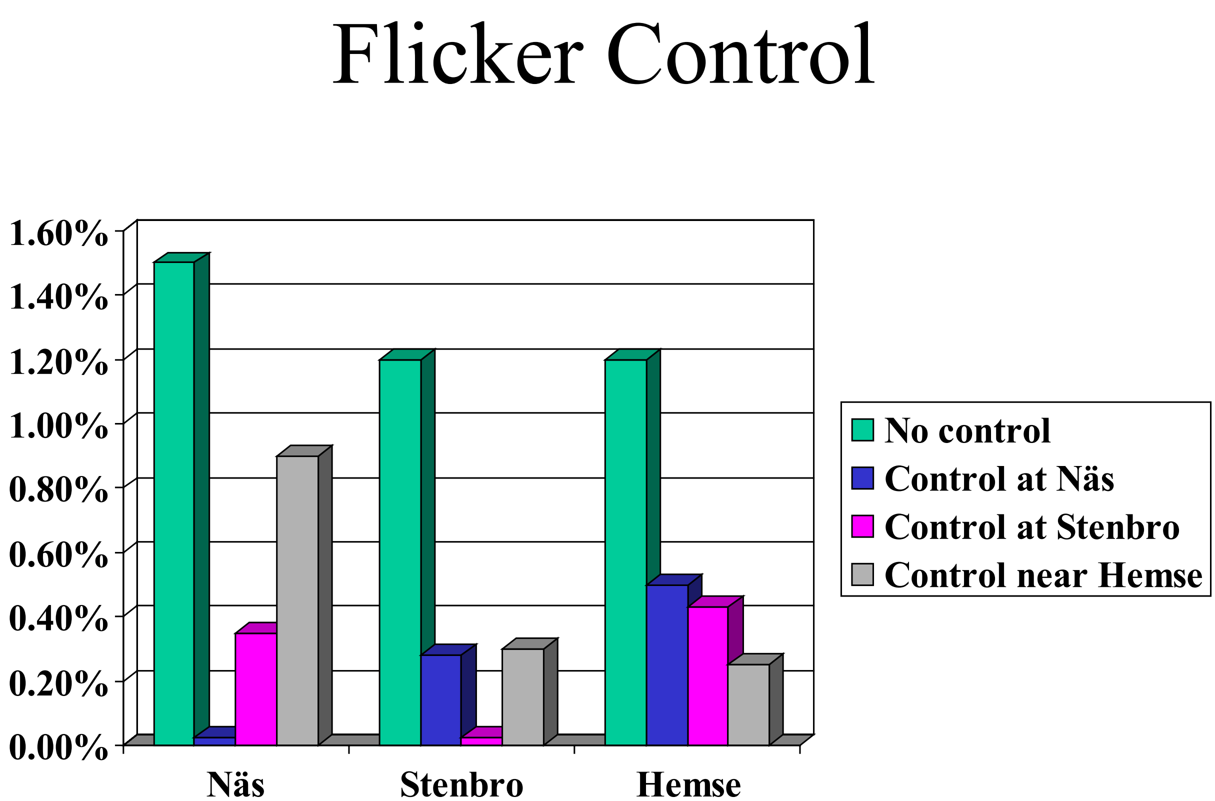

Figure 2. *Effect of the flicker control and compounding function*

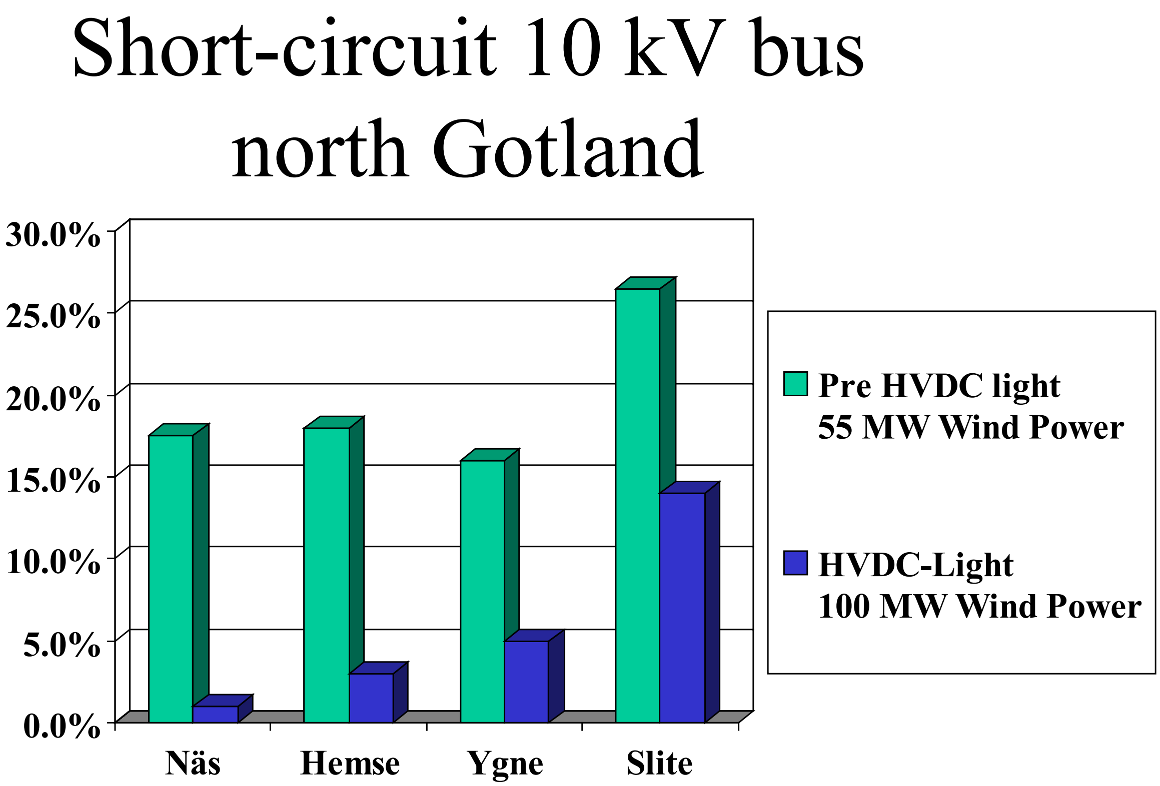

Figure 3. *Voltage drop during obtained previous and after HVDC-Light connection during a short circuit in the AC network.*

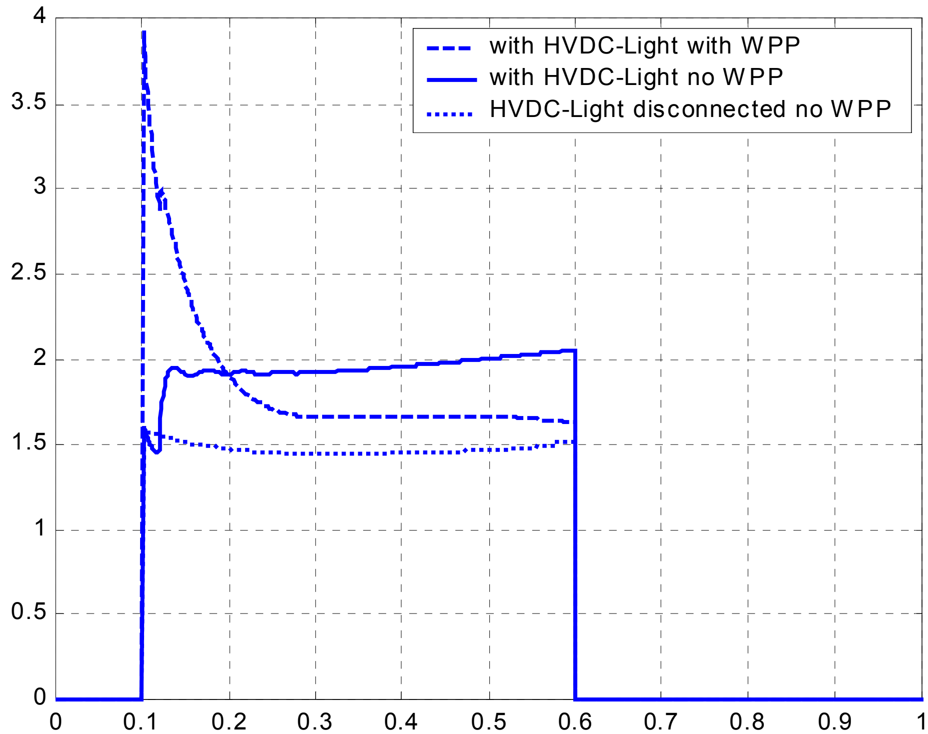

FIGURE 4. ***EFFECT OF HVDC-LIGHT AND WPP ON THE FAULT CURRENT DURING SHORT CIRCUIT AT NÄS***