STATCOM based Control and Analysis of De-Icer with Functionality using the Modular Multilevel DC

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Abstract- Deicing of overhead transmission lines are necessary to prevent damage to the transmission system and outages. In this paper, a modular multilevel DC de-icer (M2D2) is introduced, based on the structure of modular multilevel converter (MMC) with full-bridge submodules. The M2D2 exhibits a lot of salient features: high modularity, scalability, compactness, high efficiency, wide DC voltage range, and no harmonic filter requirements, etc. Moreover, during good weather, the M2D2 can be configured as a static synchronous compensator (STATCOM), providing reactive power support to the grid and alleviating power quality problems. Operating principle of the M2D2 is explained, harmonic features under phase-shifted carrier (PSC) modulation are analyzed, and selections of the phase-shifted angle are derived to achieve best harmonic performance. Control schemes for M2D2 are also developed, including control of de-icing current, capacitor voltages, and reactive power. Finally, experimental results, utilizing a downscaled prototype, confirm the validity of this topology and effectiveness of the proposed control strategies.

Keywords – De-Icer, M2D2, Static Synchronous Compensator (STATCOM), Phase Shift Carrier (PSC), Modular Multi-Level Converter (MMC)

I. INTRODUCTION

ICECOVERING on overhead transmission lines is of special concern in the cold regions. When weight of accumulated ice exceeds mechanical threshold of the transmission line or the tower, it will break the line or collapse the tower, which is a catastrophic damage, causing disruption of power transmission and leading to great economic loss. The 1998 ice storm caused severe damage to Hydro-Québec’s power transmission system. Most of the damage on overhead transmission lines was due to ice accumulation on conductors, causing towers to collapse (Figure). De-icing methods using techniques such as conductor heating or mechanical de-icing using a roller are possible for overhead lines ranging from 25 to 245 kV. However, such methods cannot be easily applied to lines with twin or quad conductors at rated voltages of 315 & 735 kV respectively. January, 2008 in Hunan, Guangdong and Guizhou provinces. The freezing rain that was seldom in history in Central China leaded the large scope of transmission lines frozen, in the hardest hit areas where the thickness of icing on some transmission lines were beyond the mechanical loading In addition, with more and more dc lines having been built during recently years, dc de-icing is becoming a new method. In the project various methods according to the characteristic of transmission line are introduced in details.

II. PROBLEM STATEMENT

A module multilevel DC de-icer (M2D2) is introduced, based on the structure of modular multilevel converter (MMC) with full-bridge submodules. An ICING OF POWER TRANSMISSION line during winter storms is persistent problem that causes outages and costs millions of dollars in repair expenses. In spite of these methods, other methods are proposed such as pulse electric heating deicing, corona discharge de-icing and infrared heating deicing etc. Deicing of overhead transmission lines are necessary to prevent damage to the transmission system and outages.

1) A.C. LINE DE-ICING

Most of the countries in the world use ac transmission as the main transmission system. So it is essential to melt the ice for the stability of the power grid. The main method described for de-icing the transmission line is described below.

A. Short- Circuit De-icing

Short-circuit de-icing is one of the most frequent methods which are in practice. During the melting period, short-circuit current needs to be huge enough so that accumulated ice melts, without exceeding the thermal limit of the conductor. According to the different categories of short-circuit faults, there are three categories of deicing: Besides, the feasibility of deicing is determined by the power device to supply the required de-icing current. According to reference, using 220kV to
melt 500kV transmission lines requires more than 1000Mvar reactive power and using 500kV to melt 500kV transmission lines needs more than 2000Mvar. For the 500kV transmission lines this method is unfeasible because the reactive power energy is limited.

B. Power Flow De-icing

Power flow de-icing is that method in which increasing the load current of the transmission lines by adjusting the grids power flow without adding any deicer. After the ice disaster of 1998 in north eastern America, Hydro-Québec developed a de-icing strategy for 120~315kV lines. A computer program has been developed to simulate the ice buildup on conductors and melting the ice using the heat generated by the currents flowing in the conductors. Using simulation tools, different network configurations can be tested and the best sequence of de-icing method can be applied to reduce the ice buildup over the network By using other ways to change the power flow of loop network, the results are very limited except the way to cut load. However the loop network has strong supply capabilities, it is necessary to cut two or more lines to change the power flow.

C. Phase-Shifting Transformer De-icing

Using the phase-shifting transformer as a deicer for the transmission lines has become quite popular because it can be generally used without interfering with service to the lines. Phase-shift transformer can cause an active power circle—one line transmits forward and the other line transmits reverse. So the increased forward transmission current and its value is equal to the phase-shifting current in addition with load current. Which causes circulating current to flow over a transmission line to de-ice it? Circulating current depends on the line impedance and the degree of phase shift. Under the normal operating conditions this method has the icing conductor melt by adjusting the circulating current of the double circuit transmission lines.

2) D.C. LINE DEICING

At present, to melt accumulated ice from dc transmission line, direct current de-icing method is widely used. Because of the control characteristic of HVDC, altering control mode is usually used to melt ice. There are four ways of de-icing methods based on the switching of control modes.

A. Parallel Mode De-icing

Two thyristor converters connected in parallel is the simplest and the most effective de-icing method. With this, the value of direct current increase up to twice of its level without exceeding the capacity limit of converter. The schematic diagram of bipolar converter in parallel is shown in Figure 2. Using two thyristor bridges in parallel is the natural configuration of the circuit in deicer mode and can provide larger de-icing current timely. For example, the nominal current rating in deicer mode is 7.2kA, defined at an ambient temperature of +10°C. This current rating is beyond the capacity of a singleconverter bridge based on present HVDC technology. With two converter bridges connected in parallel, the required direct current per bridge can easily be met, each operating at a nominal current rating of 3.6kA.

B. Low-Load Anti-icing

Using this method to produce the de-icing current, the amount of power source needs to be considered in order to get larger current while consuming less power source. The theory of low-load anti-icing is that the power of two polar flows in the opposite directions: one polar flows forward while the other one reverse. By adjusting the power flow direction of one polar, anti-icing current can be easily produced. As the less power source is required, this method causes little influence on the ac system.

III. THE PROPOSED AGENT-BASED SOLUTION

The MMC with full-bridge SMs for DC ice melting is named Modular Multilevel DC De-icer (M2D2). The M2D2 is a very promising de-icing solution as it has a lot of advantages over the traditional LCC de-icer, such as easier design; modular structure; simpler assembling; elimination of the harmonic filters, reactive supporting capacitors, and the input transformers; much improved voltage and current waveforms; better controllability from zero to full DC voltages;
smaller size; more flexible; scalable and transportable

Circuit Configuration Fig. 1 shows the circuit configuration of a modular multilevel DC de-icer (M2D2). It contains two sets of star-configured arms, in which N full-bridge submodules (SMs) are cascaded to constitute each arm. AC terminals of M2D2 are connected to the distribution grid, whereas the DC terminals are connected to the overhead transmission lines which need to be de-iced, through a set of DC disconnections (M1~M4). The inductors L, sitting between the upper and lower arms, provides voltage buffering among the upper arm, the lower arm, and the AC grid. In the M2D2, neither the line-frequency transformers nor the low-order harmonic filters are required, which makes the equipment small, light, and compact.

Moreover, the strictly modular design leads to reduced installation cost and easy maintenance. And high scalability allows a simple adjustment to meet different voltage ratings by increasing or reducing the number of SMs. De-Icer Mode: In ‘de-icer mode’, the M2D2 provides a controlled, high current, DC power source that feeds the resistive load of the line. This operation is similar to the MMC rectifier station in the VSC-HVDC transmission, except that the controlled variable here is not the DC voltage, but the DC current.

Modular Multi-Level Converter (MMC)
First proposed for HVDC applications in 2003 by Marquardt and first used commercially in the Trans Bay Cable project in San Francisco, the Modular Multi-Level Converter (MMC) is now becoming the most common type of voltage-source converter for HVDC.

Like the two-level converter and the six-pulse line-commutated converter, a MMC consists of six valves, each connecting one AC terminal to one DC terminal. However, where each valve of the two-level converter is effectively a high-voltage controlled switch consisting of a large number of IGBTs connected in series, each valve of a MMC is a separate controllable voltage source in its own right. Each MMC valve consists of a number of independent converter submodules, each containing its own storage capacitor. In the most common form of the circuit, the half-bridge variant, each submodule contains two IGBTs connected in series across the capacitor, with the midpoint connection and one of the two capacitor terminals brought out as external connections. Depending on which of the two IGBTs in each submodule is turned on, the capacitor is either bypassed or connected into the circuit. Each submodule therefore acts as an independent two-level converter generating a voltage of either 0 or \(U_{sm}\) (where \(U_{sm}\) is the submodule capacitor voltage).

Static Synchronous Compensator (Statcom):
A static synchronous compensator (STATCOM), also known as a static synchronous condenser (STATCOM), is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices. It is inherently modular and electable. Usually a
STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. There are however, other uses, the most common use is for voltage stability. A STATCOM is a voltage source converter (VSC)-based device, with the voltage source behind a reactor. The voltage source is created from a DC capacitor and therefore a STATCOM has very little active power capability. However, its active power capability can be increased if a suitable energy storage device is connected across the DC capacitor. The reactive power at the terminals of the STATCOM depends on the amplitude of the voltage source. For example, if the terminal voltage of the VSC is higher than the AC voltage at the point of connection, the STATCOM generates reactive current; conversely, when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power. The response time of a STATCOM is shorter than that of a static VAR compensator (SVC), mainly due to the fast switching times provided by the IGBTs of the voltage source converter. The STATCOM also provides better reactive power support at low AC voltages than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage (as the current can be maintained at the rated value even down to low AC voltage). One of the many devices under the FACTS family, a STATCOM is a regulating device which can be used to regulate the flow of reactive power in the system independent of other system parameters. STATCOM has no long term energy support on the dc side and it cannot exchange real power with the ac system. In the transmission systems, STATCOMs primarily handle only fundamental reactive power exchange and provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins and to damp out the system oscillations due to these disturbances.

ADVANTAGES

The M2D2 exhibits a lot of advantages:

- High modularity,
- Scalability,
- Compactness,
- High efficiency,
- Wide DC voltage range,
- No harmonic filter requirements,
- The M2D2 can be configured as a static synchronous compensator (STATCOM), providing reactive power support to the grid and alleviating power quality problems.

IV. SIMULATION SETUP AND RESULTS

An ICING OF POWER TRANSMISSION line during winter storms is persistent problem that causes outages and costs millions of dollars in repair expenses. Ice accumulated on conductor in transmission line can cause severe damage to the network.
SIMULATION OUTPUT
SIMULINK DESIGN

INPUT VOLTAGE AND CURRENT

M2D2 VOLTAGE AND CURRENT

OUTPUT VOLTAGE AND CURRENT:

V. CONCLUSION

Ice accumulated on transmission lines can cause severe damage to the lines and towers. In this paper, a modular multilevel DC de-icer (M2D2) is introduced which is very promising and can melt the ice effectively. Benefits of this topology includes: modularity, scalability, high efficiency, good voltage and current waveform quality, no requirement of transformers and filters, wide range of DC voltage availability from zero to full voltages. Moreover, when not being used as a de-icer, the M2D2 can function as an STATCOM providing reactive power support to the AC grid. Operating principles of M2D2 are described, harmonic features under PSC modulation are analyzed, and control strategies are proposed to ensure its stable operation. Validity of the M2D2 and effectiveness of the proposed methods have been confirmed experimentally.

REFERENCES


