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Effective Cost Evaluation and Interconnection of HVDC System Drive

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Abstract—*Electricity reform has been a component of India's economy since early 1990s. Most of India's power sector problems revolve around poor financial and technical conditions of the State Electricity Board (SCBS), vertically integrated utilities that own about 60% of generation and operate the distribution system. The initial stage of reform did not address the problem of SEB finances. In 1991 the government responded to a balance of payments crisis with a package of economic reform, which includes amending the electricity law to encourage Independent Power Producers (IPPs). The second stage of electricity reform involved experiment by individual states, with the intimate involvement of the World Bank and US, UK, Canadian, Japanese development agencies. In 1996 Orissa became the first state to unbundle its SEB and privatize generation and distribution. A third stage of reform is marked by passage of the Electricity Act (EA) of 2003, which seeks to replace the state experiment with a uniform national frame work. The performance of Indian power sector in last two decades of reform was surrounded with several problems on financial and technical fronts. Most of India's power sector problem circled around a poor techno-financial condition of the SEBs.*

This paper is intended to study the electricity pricing frame works, approaches and methodologies with the reference to bulk power or wholesale electricity market. It analyze the present electricity transmission pricing practices and its impact on development of wholesale electricity market. In this paper we analyze the present electricity transmission pricing practices in state of Madhaya Pradesh.

For machine learning and training frequency based annotations, common knowledge annotators and schema value annotators are being applied which are going to facilitate for correct annotation process. For annotation website pages shall be looked for content type, presentation style, data type, tag path and adjacencies of the contents.

Keywords:— *Data Annotation, Web Databases, data alignment, data filtering, frequency annotation, multimode text.*

1. INTRODUCTION

Beginning with a brief historical perspective on the development of High Voltage Direct Current (HVDC) transmission systems, this paper presents an overview of the status of HVDC systems in the world today. It then reviews the underlying technology of HVDC systems, and discusses the HVDC systems from a design, construction, operation and maintenance points of view. The paper then discusses the recent developments in HVDC technologies. The paper also presents an economic and financial comparison of

HVDC system with those of an AC system; and provides a brief review of reference installations of HVDC systems. The paper concludes with a brief set of guidelines for choosing HVDC systems in today's electricity system development.

In today electricity industry, in view of the liberalization and increased effects to conserve the environment, HVDC solutions have become more desirable for the following reasons:

- Environmental advantages
- Economical (cheapest solution)
- Asynchronous interconnections
- Power flow control

Added benefits to the transmission (stability, power quality etc.)

Historical Perspective on HVDC Transmission

It has been widely documented in the history of the electricity industry, that the first commercial electricity generated (by Thomas Alva Edison) was direct current (DC) electrical power. The first electricity transmission systems were also direct current systems. However, DC power at low voltage could not be transmitted over long distances, thus giving rise to high voltage alternating current (AC) electrical systems.

Nevertheless, with the development of high voltage valves, it was possible to once again transmit DC power at high voltages and over long distances, giving rise to HVDC transmission systems.

There are many different reasons as to why HVDC was chosen in the above projects. A few of the reasons in selected projects are:-

- In Itaipu, Brazil, HVDC was chosen to supply 50Hz power into a 60 Hz system; and to economically transmit large amount of hydro power (6300 MW) over large distances (800 km)
- In Leyte-Luzon Project in Philippines, HVDC was chosen to enable supply of bulk geothermal power across an island interconnection, and to improve stability to the Manila AC network
- In Rihand-Delhi Project in India, HVDC was chosen to transmit bulk (thermal) power (1500 MW) to Delhi, to ensure: minimum losses, least amount right-of-way, and better stability and control.
- In Garabi, an independent transmission project (ITP) transferring power from Argentina to Brazil, HVDC back-to-back system was chosen to ensure supply of 50 Hz bulk (1000MW) power to a 60 Hz system under a 20-year power supply contract.
- In Gotland, Sweden, HVDC was chosen to connect a newly developed wind power site to the main city of Visby, in consideration of the environmental sensitivity of the project area (an archaeological and tourist area) and improve power quality.
- In Queensland, Australia, HVDC was chosen in an ITP to interconnect two independent grids (of New South Wales and Queensland) to: enable electricity trading between the two systems (including change of direction of power flow); ensure very low environmental impact and reduce construction time.

Details about the above projects are provided elsewhere (under Details of Selected HVDC Applications).

The High Voltage Direct Current (HVDC) transmission system is a high power electronics technology used in electric power systems mainly due to its capability of transmitting large amount of power over long distances [1-2].

The HVDC transmission technology can be realized by using current source converters (CSCs) commutated thyristor switches, known as traditional HVDC or classic HVDC, or by using voltage source converters (VSC-based HVDC). Due to the rapid development of power electronic devices with turn-off capability and of DSPs, which are generating the appropriate firing patterns, the VSCs are getting more and more attractive for HVDC transmission [1-2]. A detailed comparison between CSCs and VSCs may be found in [1].

Usually, the VSCs are using insulated gate bipolar transistor (IGBT) valves and pulse width modulation (PWM) for creating the desired voltage wave form.

By analyzing the operation of both classic HVDC technology and VSC-based HVDC technology, the main difference between these two technologies can be highlighted: the controllability, which in the case of VSC-based HVDC technology is higher compared with the one of the earlier developed technology. Thereby, if VSCs are used instead of line-commutated CSCs several advantages can be stated, some of them being presented below:

VSC converter technology provides rapid and independent control of active and reactive power without needing extra compensating equipment [1-4];

- The commutation failures due to disturbances in the AC network can be reduced or even avoided [1,4];
- The VSC-HVDC system can be connected to a ”weak” AC network or to a network where no generation source is available, so the short circuit level is low [1-3];
- Self (forced) commutation with VSCs permits black start, which means that the VSC is used to synthesize a balanced set of three phase voltages as a virtual synchronous generator [3];
- In comparison with the classic HVDC transmission, the VSCs do not have any reactive power demand and moreover, they can control their reactive power to regulate the AC system voltage like a generator [2-3].

Because of its advantages, the VSC-based HVDC transmission suits very well in certain application such as: power supply to insular loads, offshore applications, underground/underwater cables transmission, urban in feed and asynchronous interconnection [1, 3-4].

The HVDC technology

The fundamental process that occurs in an HVDC system is the conversion of electrical current from AC to DC (rectifier) at the transmitting end and from DC to AC (inverter) at the receiving end. There are three ways of achieving conversion:

Natural Commutated Converters. Natural commutated converters are most used in the HVDC systems as of today. The component that enables this conversion process is the thyristor, which is a controllable semiconductor that can carry very high currents (4000 A) and is able to block very high voltages (up to 10 kV). By means of connecting the thyristors in series it is possible to build up a thyristor valve, which is able to operate at very high voltages (several hundred of kV).The thyristor valve is operated at net frequency (50 hz or 60 hz) and by means of a control angle it is possible to change the DC voltage level of the bridge. This ability is the way by which the transmitted power is controlled rapidly and efficiently.

Capacitor Commutated Converters (CCC). An improvement in the thyristor-based commutation, the CCC concept is characterized by the use of commutation capacitors inserted in series between the converter transformers and the thyristor valves. The commutation capacitors improve the commutation failure performance of the converters when connected to weak networks.

Forced Commutated Converters. This type of converters introduces a spectrum of advantages, e.g. feed of passive networks (without generation), independent control of active and reactive power, power quality. The valves of these converters are built up with semiconductors with the ability not only to turn -on but also to turn-off. They are known as VSC (Voltage Source Converters). Two types of semiconductors are normally used in the voltage source converters: the GTO (Gate Turn-Off Thyristor) or the IGBT (Insulated Gate Bipolar Transistor). Both of them have been in frequent use in industrial applications since early eighties. The VSC commutates with high frequency (not with the net frequency). The operation of the converter is achieved by Pulse Width Modulation (PWM). With PWM it is possible to create any phase3 angle and/ or amplitude (up to a certain limit) by changing the PWM pattern, which can be done almost instantaneously. Thus, PWM offers the possibility to control both active and reactive power independently. This makes the PWM Voltage Source Converter a close to ideal component in the transmission network. From a transmission network viewpoint, it acts as a motor or generator without mass that can control active and reactive power almost instantaneously.

2. HVDC SYSTEM MODEL IN SIMULINK

The HVDC system modelled, using the Simulink package, is based on a point-to-point DC transmission system. The DC system is a mono-polar, 12-pulse converter using two universal bridges connected in series, rated 1000 MW (2 kA, 500 kV) at the inverter. DC interconnection is used to transmit power from a 500 kV, 5000 MVA, 60 Hz network to 345 kV, 3 000 MVA, 50 Hz network. The converters are interconnected through a 300 km transmission line and 0.5 H smoothing reactor. The converter transformer (Wye grounded / Wye / Delta) is modeled with three phase transformer (three-Windings). The tap position is rather at a fixed position determined by a multiplication factor applied on the primary nominal voltage of the converter transformers (0.9 on rectifier side; 0.96 on inverter side).

The AC networks, both at the rectifier and inverter end, are modeled as infinite sources separated from their respective commutating buses by system impedances. The impedances are represented as L-R/L networks having the same damping at the fundamental and the third harmonic frequencies. The impedance angles of the receiving end and the sending end systems are selected to be 80 degrees. This is likely to be more representative in the case of resonance at low frequencies [6-7].

From the AC point of view, an HVDC converter acts as a source of harmonic current. From the DC point view, it is a source harmonic voltage. The order n of theses characteristic harmonics are related to the pulse number p of the converter configuration: $n = kp \pm 1$ for the AC current, and $n = kp$ for the direct voltage, k being any integer. In the example, $p = 12$, the injected harmonic are: 11, 13, 23, 25 on the AC side, and: 12, 24 on the DC side [8].

The automatic generation control (AGC) is a technical requirement for the proper operation of an interconnected power system.

Some intelligent controllers have been proposed to perform this act considering area interconnection with ac tie line [1]-[4].

Also fast-acting energy storage systems e.g. superconducting magnetic energy storage [5], battery energy storage [6], super capacitor bank [7] etc., can effectively damp electromechanical oscillations in a power system, because they provide storage capacity in addition to the kinetic energy of the generator rotors which can share sudden changes in power requirement. A little attention has been paid to use of HVDC transmission link as system interconnection. Majority of the work carried out earlier is centered on interconnected power systems considering the area interconnection with ac tie lines only. However, there has been a tremendous growth of the HVDC transmission system due to economic, environmental and performance advantages over the other alternatives. Hence it has been applied widely in operating a dc link in parallel with an HVAC link interconnecting control areas to get an improved system dynamic performance with greater stability margins under small disturbances in the system.

A favorable effect on system dynamic performance has been achieved considering such system interconnection. These studies are carried out considering the nominal system parameter values after linearization of the system about an operating condition.

the present paper a fuzzy logic based proportional integral (pi) controller is designed and implemented to analyze the dynamic performance of four area thermal power system, interconnected with HVAC/ HVDC parallel link taking parameter uncertainties into account. The simulation results are presented to show the effectiveness of the scheme.

3. EXISTING SYSTEM

In their paper "HVDC Application for Enhancing Power System Stability", Nguyen-Mau, K. Rudion, Z. A. Styczynski, the authors, the benefit of power system stability that occurs when applying the voltage source converter based high voltage direct current (VSC HVDC) is discussed. Due to the advantages of fast and decoupled active and reactive power control, VSC HVDC can be used to dampen the oscillation of the load angle of the generator after disturbance.

This paper deals with the application of VSC HVDC technology for enhancing the transient stability of a power system. The simulation results reveal that, due to the capability of fast and independent active and reactive power control, VSC HVDC can greatly improve the stability of a power network. This technology has high potential if it would be applied to the Vietnamese power system, which has some problems such as power swing dampening, overvoltage and interconnection with the neighboring countries.

The future works are the control strategies of VSC HVDC when it operates with the HVAC transmission line. The focus is how to co-ordinate the control strategies of VSC HVDC and the other controllers of synchronous generators such as governor and exciter. Moreover, the optimization of these controllers as mentioned above should be also studied. Additional benefits for the power system such as back start capability, frequency support, and voltage regulation of VSC HVDC should be studied in depth.

A Transient Protection Scheme for HVDC Transmission Line Xiaodong Zheng, Tai Nengling, Member, IEEE, Yang Guangliang, and Ding Haoyin IEEE Transactions on Power Delivery, VOL. 27, NO. 2, APRIL 2012, The relation between the parameters of dc transmission line and the variation of transient energy has been analyzed under various fault conditions in this paper. According to that, a new transient energy protective scheme is proposed. It is developed based on the distributed parameter line model in which the transient energy distribution over the line can be obtained from the voltage and current measurements at both terminals and the fault can be recognized from the calculated value simply. The test system is modeled based on the CIGRE benchmark and considered the distributed parameters of the dc transmission line. Comprehensive test studies show that the performance of transient energy protection scheme is encouraging.

It can not only identify internal fault and external faults correctly and quickly, but can also respond to the high ground resistance fault. Finally, two main factors, including fault resistance and transmission distance, that affect the performance of the protection are also discussed.

A novel transient energy protection method for the HVDC transmission line is proposed. The relation between the parameters of the dc transmission line and protection sensitivity has been deduced. Based on the test system, the different operation conditions and various faults are tested. Comprehensive test studies show that the performance of transient energy protection is satisfied. It cannot only identify the internal fault and external fault correctly and quickly, but can also respond to the high ground resistance fault. Two main factors that affect the performance of the protection are considered: fault resistance and transmission distance. And the relationships between the two factors and the sensitivity of transient energy protection have been deduced.

4. PROPOSED ALGORITHM

There three different long distance transmission technologies:

- High Voltage AC (HVAC)
- Hybrid High Voltage DC (HVDC)
- Bipolar HVDC

These can have different voltage stability and point of collapse.

These can be compared using different lengths of transmission lines and different contingency conditions.

Voltage stability in HVAC and HVDC systems has been traditionally studied for simple power system models. However, stability indices in the literature have been analyzed only for each individual technology. The conventional methods to determine the stability margin for a HVAC system are based on QV and PV curves. From those curves one can calculate steady state voltage stability indices, such as reactive power margin, point of collapse, as well as voltage stability factor. [1-2]

The impacts of HVAC and HVDC interconnections to the PoC of the system have been compared. From the simulation results based on the simplified Southern and Eastern Australian system the followings conclusions can be made:

In this particular system, the bipolar HVDC is found to be superior to the others and the hybrid HVDC is the worst option in terms of PoC no matter how long the transmission line was.

It should be noted that optimal placement of reactive power compensation can greatly improve the efficiency of both HVAC and HVDC systems, which has not been addressed in this paper.

Moreover, one potential advantage of the HVDC system is its capability to enhance the total system dynamic stability. A thorough study of optimal reactive power compensation and a comprehensive study of system voltage stability are thus needed and will be the subject of our future research.

In my research work proposal to provide a mechanism to interconnect the HVDC in efficient and low loss technique has been added. The work shall be implemented and tested using MATLAB.

5. RESULTS & DISCUSSION

There three different long distance transmission technologies:

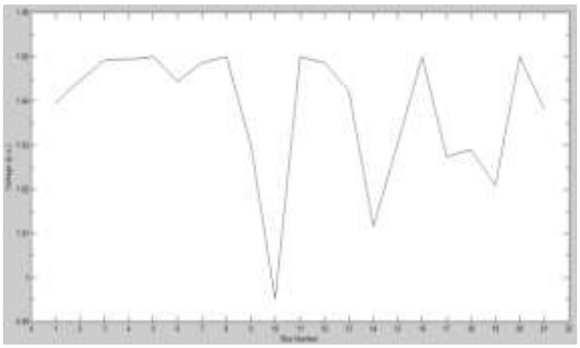

Figure 1: Analysis of Voltagesat Buses

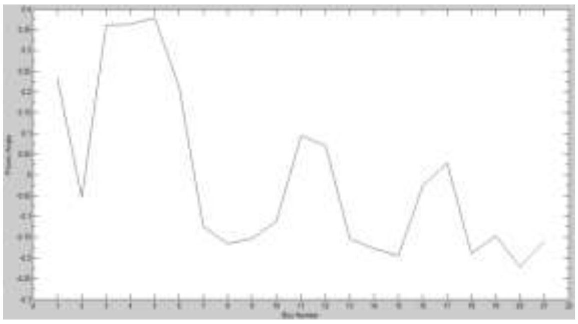

Figure 2: Analysis of Power Angle at Buses

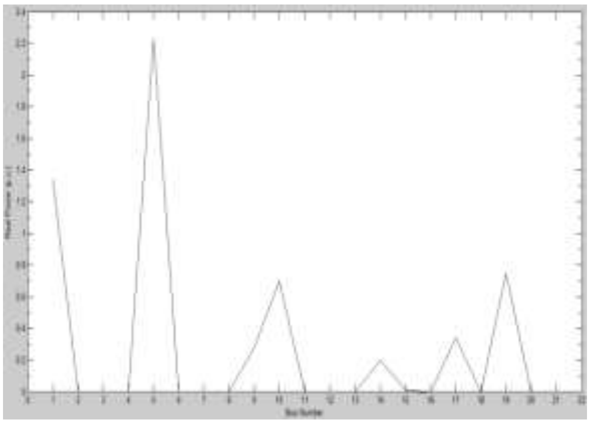

Figure 3: Analysis of Real Power at Buses

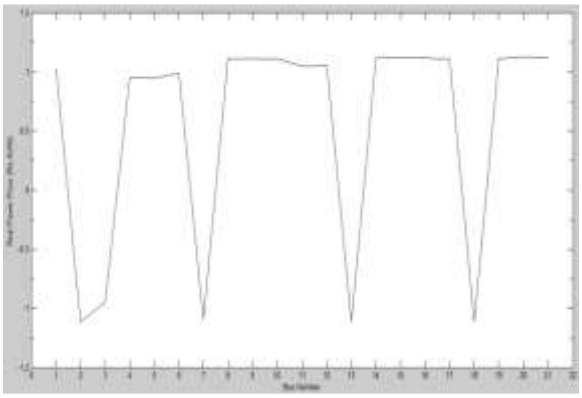

Figure 4: Analysis of Real Power Pricing at Buses

The configuration of IEEE-30 Bus system is shown in FigureA.1 (Appendix A-1). It consists of 6 generators and 41 transmission lines. The generator and demand data is shown in Table A.1.2. The upper and lower bounds (reactive power) for all generators i.e. G1, G2, G13, G22, G23 and G27 are 0.7<Qg<0.7. The voltages for all buses are bounded between 0.95 and 1.05. Also to study the effect of HVDC link, a dc link is assumed and connected between Bus 1 and Bus 30. The converter rating at buses is assumed to be 1.0 p.u.

The optimal real electricity nodal prices without and with HVDC link are computed and compared. The simulated results are obtained and comparison is shown in Table 1.

Table 1: Real Nodal Price ($/kWh)

S. No.	Without DC link	With DC Link
1	19.54	15.61
2	19.62	15.63
3	19.52	15.70
4	19.51	15.71
5	20.95	15.30
6	19.72	15.85
7	20.30	15.76
8	19.84	15.91
9	19.92	16.08
10	20.02	16.22
11	19.91	16.08
12	19.15	15.24
13	15.20	15.20
14	19.43	15.60
15	19.38	15.95
16	19.70	15.78
17	20.03	16.17
18	19.94	16.29
19	20.16	16.43
20	20.16	16.39
21	19.67	16.50
22	19.47	16.53
23	18.88	16.59
24	18.57	17.31
25	16.09	19.16
26	15.29	19.99
27	15.10	19.93
28	19.74	15.86
29	15.49	20.58
30	15.75	21.02

The result obtained by proposed methodology shows that the electricity nodal prices are considerably reduced at several buses with the incorporation of DC link in existing AC transmission system. Nodal prices at Bus No. 29 and Bus No. 30 are increased because these buses might be served by costly generators due to transmission congestion. Also with incorporation of DC link, the voltage profiles at few buses are within narrow range compared to without DC link due to decrease in power flow and voltage drop across few transmission lines.

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