Performance Analysis of Bipolar based HVDC and AC System for Ethiopia -Kenya

Aberra Jote, Saravanan Kandasamy

***Abstract*— Electrical power can be generated from renewable and non-renewable energy sources in the world. Ethiopia blessed by renewable energy sources in the East Africa. Ethiopia Electrical Power Corporation has been constructed huge clean renewable Energy for national as well as for neighboring countries. The potential to generate electric power from only hydro plant is 45,000 MW in Ethiopia. Currently generated power transmission takes place by High Voltage Alternate Current (HVAC) overhead systems to inside and outside of Ethiopia. This paper is to develop high voltage direct current (HVDC) technologies instead of HVAC system from Wolayta Sodo at Ethiopian side Suswa at Kenyan side. This HVDC link between Wolayta Sodo and Suswa, consisting of about 1,045 km of high voltage direct current ±500 kV, 2000MW capacity. The intention of this work is to develop bipolar HVDC overhead system and analyze the system performance with and without fault in AC side can be carried out using MATLAB/Simulink.**

Index Terms— **HVDC, Voltage source converter, Passive filter, Harmonics, Pulse width modulation**

I. INTRODUCTION

Now a day the number of interconnection with an existing power systems growing exponentially, it leads to decays the performance of the power network. The existing power systems are becoming harassed because of long distance electrical power transfer. The more stress in long distance electrical power transfer induces low frequency oscillations, and security problems. Over the years, many blackouts due to these low frequency oscillations have been reported [1]. The growth in existing power system demand reaches more than system capacity, giving rise to possibility of voltage instability. The voltage instability is often to voltage collapse because of large disturbance in the power network.

High Voltage Direct Current Transmission Systems (HVDC) is an attractive and reliable method for long distance power transfer [1-5]. For long distance transmission, developing countries like Ethiopia and Kenya are installing more HVDC systems for power capacity enhancement. Ethiopia and Kenya have the small electricity sectors with a power capacity of approximately 800 MW and 1100 MW respectively. The total energy consumption for these countries are lowest in the world about 40 kWh/yr in Ethiopia and 145 kW h in Kenya in spite of the obtainability of massive energy resources. Power deficiencies and irregularity of supply are common in both countries. The irregularity of power supplies is described by low voltage levels and voltage fluctuations beyond the tolerable levels, causing frequent blackouts.

Deficient standby power capacity to meet fluctuations in hydro power generation (in case of severe drought conditions) has also directed to unreliable power supply. So there is a need for to sustain costly backup in industries. This lack of reliable supply is contributing to reduced economic competitiveness. Ethiopia is well endowed with a huge hydro generation potential which is estimated at approximately 45,000 MW. In line with the country's energy policy, the Government intends to develop these indigenous resources for domestic consumption and export. The Government of Ethiopia is in the process of effecting power system interconnection with its neighboring countries as part of its export strategy and for mutual benefit. The Ethiopian - Kenya Power interconnection project involves establishing the power transmission facilities (power transmission line and substations) between Ethiopia and Kenya to export up to 2000 MW. The interconnecting transmission link between Ethiopia and Kenya is approximately 1045 km long [6]. In this research article, the performance analysis of this HVDC transmission line with and without disturbance in Kenya side can be carried out by MATLAB/Simulink.

II. PROPOSED MODEL DESCRIPTION

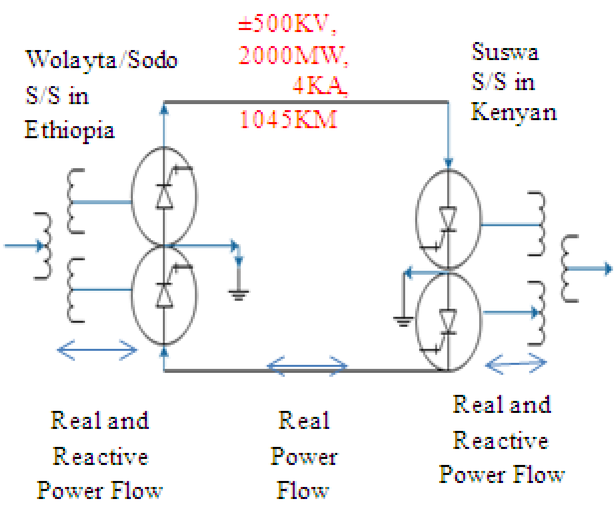

Fig.1. HVDC system based on VSC technology built with GTOs

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A 2000 MW, 500 kV, 4kA DC interconnection is used to transmit power from a 400 kV AC network. The rectifier and the inverter are 12-pulse converters using two 6-pulse thyristor bridges connected in series in Fig.1. The rectifier and the inverter are interconnected through a 1045 km distributed parameter overhead line. The transmission line between Ethiopia-Kenya is HVDC bipolar overhead lines. To construct HVDC overhead lines, the parameters like overall system reliability and construction costs should be considered. The proposed bipolar ±500 kV HVDC line will originate from HVDC rectifier substation Welayta Sodo in Ethiopia and terminate at other inverter substation at Suswa in Kenya. The total length of the proposed transmission lines is approximately 1045 km, out of which approximately 433 km will be in Ethiopia and 612 km in Kenya. At this proposed substation, HVDC will be inverted to HVAC.

III. SUBSTATION CONFIGURATION

The thyristor converters are the central equipment of d.c substation which is accommodated inside a valve hall. Outdoor valves have been applied both in Ethiopia and kenya. The d.c substation uses the two poles and is called as “bipole” configuration. The vital equipment in a DC substation is valve groups and converter transformers. Their perseverance is to transform the AC voltage to which the DC system is associated. The cost effective way is to use converter transformers for 12 pulse operation which encompassed of three phase units for higher rated d.c. substations with increased reliability. The converter bridges in the valve hall are connected with the secondary side of the converter transformers which is located in the switchyard. The connection of converter bridges and transformers has to make over the wall. It can be done in either of two ways. Firstly, by means of phase isolated bus bars where the bus conductors are accommodated inside insulated bus channels with insulating medium as oil or SF6 or secondly, by means of wall bushings. When the applied DC voltages is 400kV or greater, wall bushings need significant design and care should take to avoid external or internal insulation breakdown.

A. VSC based HVDC Fundamental Concept

The HVDC system consists of two converter stations with simplest Voltage Source Converter (VSC) topologies which is the conventional two-level three-phase bridge in Fig. 2. In order to supply higher blocking voltage ability for the converter, many series coupled GTOs are used for each semiconductor. It raises the DC voltage of the HVDC system. To confirm the four-quadrant action of the converter antiparallel diode is required. The DC capacitor delivers the essential energy storage so that the power flow can be well-ordered and deals DC harmonics filtering. The converter is normally controlled by sinusoidal PWM and the DC harmonics are directly linked with the switching frequency of each converter leg. Through a reactor, an each converter leg is connected to the AC system. To decrease the further harmonic content flowing into the AC system filters will be included on the AC side of the system [7-11].

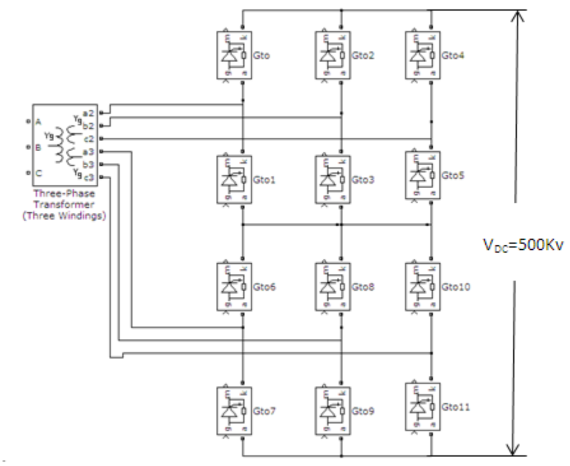

Fig.2. Twelve pulse valve group configuration

B. Mechanical Design of Thyristor Valves

A twelve pulse group for a ±500kV HVDC converter can be formed at both stations by twelve thyristor valves arranged in two serially connected 3-phase bridges. The thyristor valves in double-valve Multi-valve Unit (MVU) structure makes 12-pulse converters at both substations in Ethiopia and Kenya are accumulated in six double valves. Each double valve is put off from the valve hall through suspension insulators. To reduce the local electrical field strains due to high voltage transmission, individual MVU structures active components are covered by the stress shields as well as the corona shields. For switching impulse over-voltages, the valve arrester will be the central protection for the valve in reverse and forward direction. Each thyristor level encompasses one thyristor, linked damping, a gate electronics entity, and DC grading circuits. For the period of transient over-voltages, the internal delivery of valve voltages from DC to impulse wave-fronts will be carried out by the DC grading circuits, RC damping apparatuses and valve section capacitors.

Under standard and irregular operating situations the gate electronics element delivers electrical gating of the thyristor. It delivers normal triggering for control action and protective for overvoltage across thyristor level. The transportations between each thyristor level and valve Base Electronics (VBE) are supported by two various optical fibers, one fiber is ‘firing’ fiber used to transfers the ‘start/stop’ pulses and one ‘data-back’ fiber which gives an information on the condition of each thyristor level. For the period of the OFF-state intervals, the supplementary power for the gate electronics component at each level is given locally from the voltage across the thyristor in the course of the OFF-state intervals [8-11].

C. Direct Light-Triggering vs. Electrical-Triggering

It is essential to electrically detach the trigger element at ground potential from thyristors at high-voltage environment, for the reason that of the high-voltage potential of thyristors in HVDC valued up to 500 kV. Even the Electrically Triggered Thyristors (ETTs) are used; the thyristors trigger commands are communicated as a light pulse by means of a fiber-optic cable. The opportunity of thyristors triggering directly by light pulse create the situation to avoid the conversion of low-power light signal into a high-power electrical gate signal at thyristors potential environment while using an ETT. The usage of LTTs considerably diminishes the quantity of trigger electronic parts and to protect a thyristors, and consequently upturns the converter's reliability. The quantity of light desirable to trigger an LTT is approximately 1,000 times greater than the quantity of light required to transmit the trigger command to an ETT. The LTT in HVDC will be reasonable only since dependable optical light sources; components with low damping features come to be commercially obtainable. The incorporation of protection functions into mass-produced thyristors is a superior challenge. Once this was successfully incorporated, the quantity of electronic elements has been reduced and no more firing pulses could be produced at the thyristors. This considerably upturns the electromagnetic immunity of the system [12].

IV. SIMULATION RESULTS

The HVDC overhead transmission system simulation can be carried out by MATLAB/SIMULINK with the voltage source 400 kV, DC voltage of ±500 kV, transmission DC current of 4 kA, and DC of 12 pulse HVDC rectifier and inverter. To construct rectifier, two GTOs bridges of six pulses were used in series connection. Three phase transformer used as a connector between the system and the converter. Feeders comprise of RLC elements, resistive load with 1000MW, inductive load with 500VAR and capacitive load with 0.5Kvar connected to AC side in Kenya. To confirm the desired performance under normal operational condition and different AC fault conditions, the control system is designed. At the time of AC fault, there is no commutation failure with the VSC. But, active reduction of transient overvoltage and over-current is a challenge to the control design.

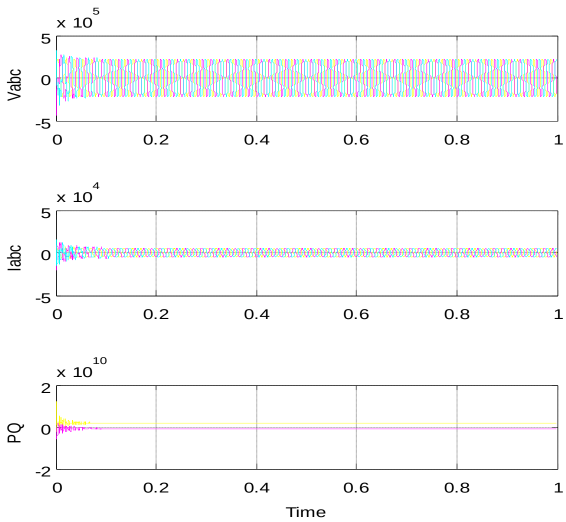

Fig.3. Voltages, Current, and Power under normal condition

For analysis of the HVDC system taken under consideration of normal and fault conditions in the system.

Fig.3 and Fig.4 shows the Voltage, current and power signal after applying DC-AC converter in a proposed system under normal and fault conditions respectively. The fault duration of 0.0833 Sec to 0.1666 Sec is assumed. The fault occurrence in the Ac side of the system will affect the magnitude of voltage, current and Power in AC side. However the magnitude of voltage, current and Power will not be disturbed in DC side due to the presence of protective circuits.

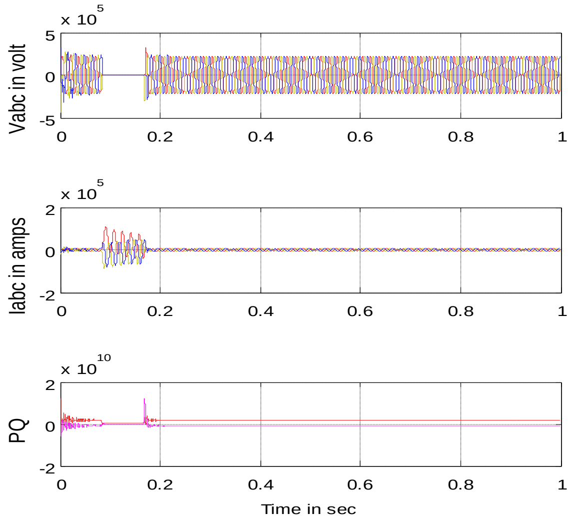

Fig.4. Voltages, Current, and Power under fault condition

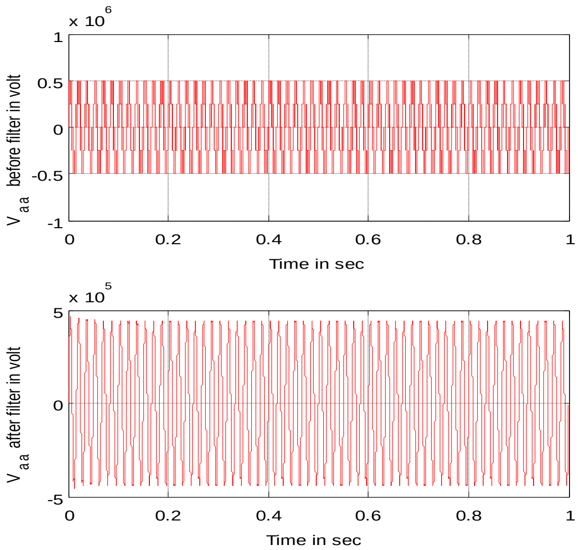

Fig.5. Voltages across inverter terminal under normal condition

Fig.5 and Fig.6 shows the waveforms of supply voltages, with and without LC type passive filters under normal and fault conditions respectively. It comprises of essential voltage only. Use of the LC type passive power filter eliminates the harmonic voltage, which was present in the essential supply voltage. Fig.7and Fig.8 shows the spectrum analysis of supply voltage before and after applying LC passive filter. The Total Harmonic Distortion of the supply voltage is reduced from 36.30% to 1.90%.

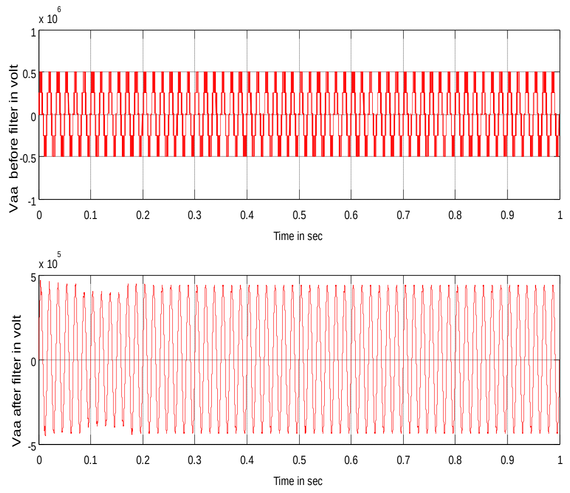

Fig.6. Voltages across the inverter terminal under fault condition

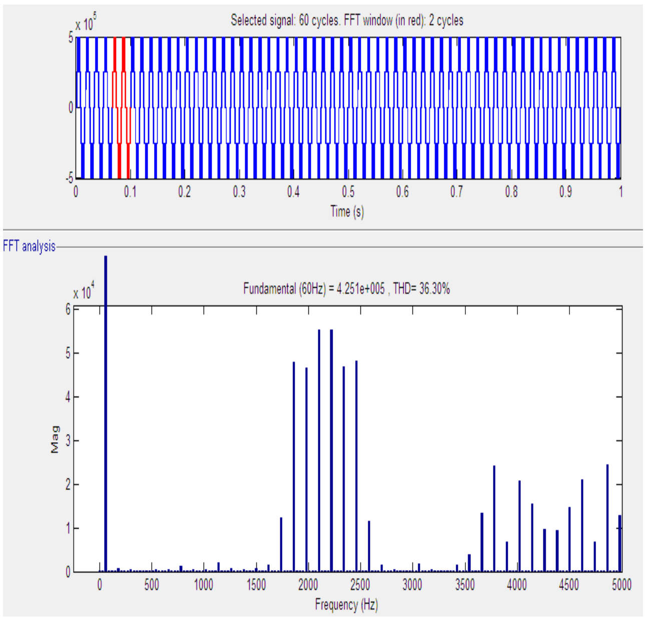

Fig.7. Harmonics spectrum of inverter voltage without filter

V. Conclusion

The proposed system in this research article is to develop bipolar high voltage direct current (HVDC) overhead system from Wolayta Sodo in Ethiopian side to Suswa in Kenyan side with the distance of about 1,045 km. Based on transient analysis, a method is proposed for dynamic simulation of the HVDC transmission system during normal and abnormal operation using MATLAB/Simulink. The waveforms of AC current and voltage under normal operation have been checked to confirm the accuracy of the proposed method. The faults in AC side disturb the system in Ac side only. The LC passive power filter reduces the harmonic voltage from 36.30% to 1.90%, which was present in the supply voltage. The analysis shows that VSC HVDC system provides a solution for adding new transmission lines for long distance.

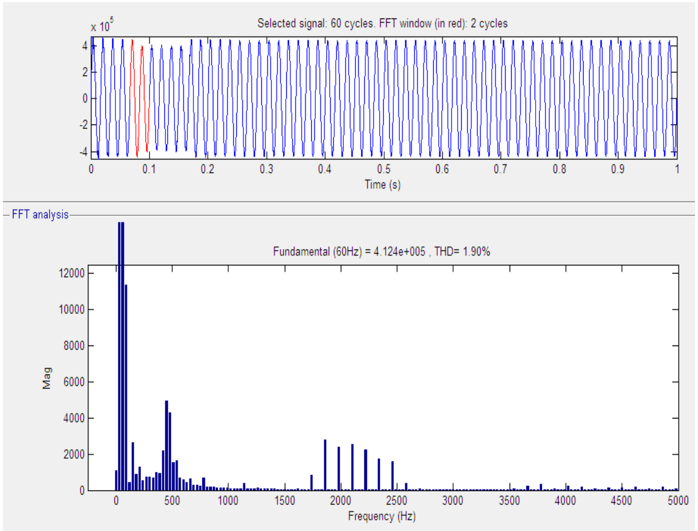

Fig.8. Harmonics spectrum of inverter voltage with filter

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