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Simulation and Fault Analysis using Reactive Energy Control for HVDC Line

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Abstract – As we see modern civilization heavily depends on consumption of electrical energy for commercial, industrial, domestic, agricultural and social purposes. HVDC is most economical way to transmit bulk power over longer distances, complexity in controlling of the power flow, asynchronous power grid interconnections and due to its flexible power control. Among the numerous techniques concerning HVDC system, DC transmission line protection is one of the important unit thus it provides fast fault clearance and guarantees the operation security of the entire HVDC transmission system. In HVDC transmission lines uses the voltage differential protection in which voltage differential rate to identify the faults takes place on transmission line but this technique not efficient due to not detect high impedance faults and its sensitivity to faults resistance. This paper proposes a novel directional protection scheme based on reactive energy for HVDC transmission systems. In this paper reactive energy is defined as the integral of reactive power during a period of time. The Hilbert transform is employed to continuously calculate the reactive energy, and then, the reactive energy flow directions are applied to identify internal and external faults. Compared to the traditional current differential scheme, this protection has a smaller time delay, thus significantly increasing the protection speed.

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INTRODUCTION

General:

As we see modern civilization heavily depends on consumption of electrical energy for commercial, industrial, domestic, agricultural and social purposes. HVDC is most economical way to transmit bulk power over longer distances, complexity in controlling of the power flow, asynchronous power grid interconnections and renewable energy integration due to its flexible power control. Among the numerous techniques concerning HVDC system, DC transmission line protection is one of the important unit thus it provides fast fault clearance and guarantees the operation security of the entire HVDC transmission system. In HVDC transmission lines uses the voltage differential protection in which voltage differential rate to identify the faults takes place on transmission line but this technique not efficient due to not detect high impedance faults and its sensitivity to faults resistance.

In high-speed travelling wave-based protection to transmission line, but its performance is easily affected by disturbance takes place in system. Distance protection is another method to identify the faults take place on transmission line by fault distance calculation. In the time difference between the initial wave and reflected wave from the fault point is utilized to calculate the fault distance, but it is difficult to distinguish the reflected wave from the disturbing waves in some cases. This paper proposes a novel directional backup protection scheme based on reactive energy for HVDC transmission systems. In this paper reactive energy is defined as the integral of reactive power during a period of time. The Hilbert transform is employed to continuously calculate the reactive energy, and then, the reactive energy flow directions are applied to identify internal and external faults. Compared to the traditional current differential scheme, this protection has a smaller time delay, thus significantly increasing the protection speed. Various simulation results indicate that the proposed protection per-forms well under various situations, and the sensitivity and reliability of the protection are satisfactory

HVDC SYSTEM

The electric power is produced, transmitted and distributed as an AC power. From the generating stations, power is transmitted to the end user via transmission and distribution lines. Transmission lines are long and operates at high or extra high voltages.

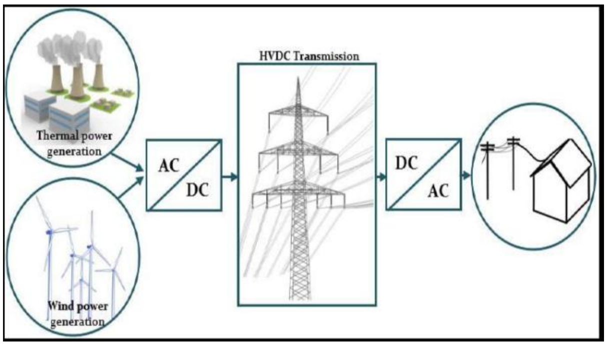


Figure 1 HVDC system

The components of an HVDC transmission system to assist the designers of transmission systems, the components that comprise the HVDC system, and the options available in these components, are presented and discussed. The three main elements of an HVDC system are: the converter station at the transmission and receiving ends, the transmission medium, and the electrodes.

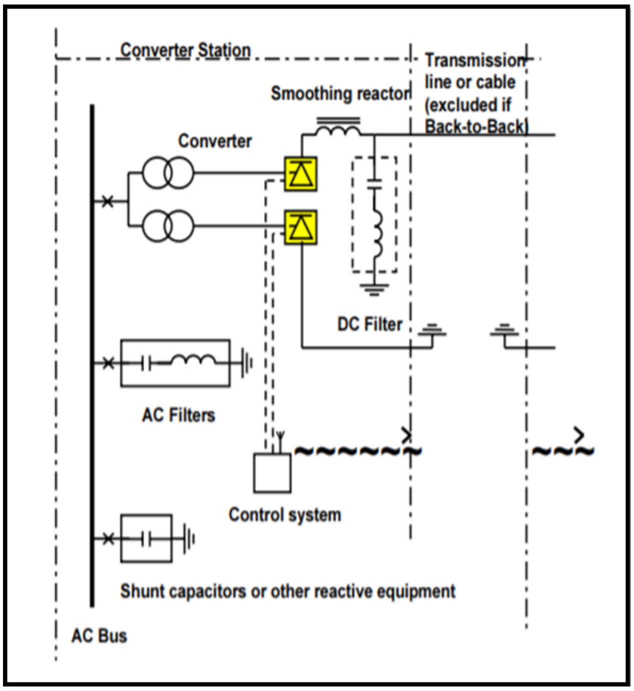


Fig 2 - Block Diagram of HVDC System

Design, Construction, Operation and Maintenance considerations: -

In general, the basic parameters such as power to be transmitted, distance of transmission, voltage levels, temporary and continuous overload, status of the network on the receiving end, environmental requirements etc. are required to initiate a design of an HVDC system. For tendering purposes a conceptual design is done following a technical specification or in close collaboration between the manufacturer and the customer. The final design and specifications are in fact the result of the tendering and negotiations with the manufactures/suppliers. It is recommended that a turnkey approach be chosen to contract execution, which is the practice even in developed countries.

DIRECTIONAL PROTECTION SYSTEM

Principle of Protection Scheme

In HVDC systems mostly transmit active power under normal operating condition, but in fault condition the less amount of reactive power flow due to small harmonic components in systems. The harmonic reactive power generated on the DC line depends on components of system like DC filters and the smoothing reactors.

The total quantities of the harmonic current and voltage are typically less than10% to 15% of the rated values. When DC line fault occurs, the current and voltage at the terminals of the DC line will contain a transient due to the inductive and capacitive components in the system, thus resulting in significant reactive power flows on the DC line. In traditional HVDC systems, shunt capacitor banks are commonly used for compensating the reactive power which the converters consume due to sudden change in firing angle. Reactive power control is designed to maintain the reactive power balance by switching the capacitor banks.

► ***Reactive Energy Measurement***

In digital signal processing Hilbert transform is useful method for determine instantaneous attributes of time series, especially the amplitude and frequency. It is used to calculate the reactive power, which is defined as follows:-

$$\hat{x}(t) = x(t) * h(t) \quad = x(t) * \frac{1}{\pi t} \quad = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{x(\tau)}{t-\tau}\, d\tau \qquad (1)$$

Where

$\hat{x}(t)$ Is the Hilbert transform result of $x(t)$ and '*' is the operator for time domain convolution.

The frequency characteristic of $h(t)$ is expressed in(eq.2). $h(t)$ induces a -90 degree shift for positive frequency components and a + +90 degree shift for negative frequency components.

$$H(\omega) = -j\ \mathrm{sgn}(\omega) = \begin{cases} -j & for \quad \omega < 0 \\ 0 & for \quad \omega = 0 \\ j & for \quad \omega > 0 \end{cases} \quad \textbf{... (2)}$$

The Hilbert transform can be discretized as,

$$\hat{X}[n] = x[n] * h[n] \qquad \textbf{..... (3)}$$

Where

$$h[n] = \begin{cases} 0 & for\ n\ is\ even \\ \frac{2}{n\pi} & for\ n\ is\ odd \end{cases} \quad \text{.... (4)}$$

A Hamming window function is used to truncate *h*[*n*]for finite calculations in practice.

The instantaneous reactive power is the multiplication of the current signal *i*(*t*) and the Hilbert transform of the voltage signal *v*(*t*)

$$q(t)=\hat{v}(t) * i(t) \quad \text{..... (5)}$$

The reactive energy during a period of time *t* is calculated in

$$W(t)=\int_0^t q(\tau)d\tau = \int_0^t \hat{v}(\tau) * i(\tau)d\tau \quad \text{..... (6)}$$

► ***Fault Direction Identification***

Directional protection scheme is used for internal and external fault identification. The reference direction of reactive energy is from the rectifier side to the inverter side. If the reactive energies of each side have different directions, an internal fault is identified. Otherwise, an external fault is detected. Thus, the fault direction identification criteria can be expressed as-

$$\text{internal fault} : W_R(t)W_I(t) < 0 \quad \text{..... (7)}$$

$$\text{external fault} : W_R(t)W_I(t) > 0 \quad \text{...... (8)}$$

Where $W_R(t)$and$W_1(t)$are the reactive energies measured at the rectifier side and inverter side, respectively. In a monopolar HVDC system, single pole reactive energy is used for direction identification, whereas in a bipolar system, the sum of the reactive energies at the two poles is used.

► ***Start-up Component***

A protection start up component is introduced to ensure the reliability of the protection scheme in case of disturbances. In this study, the DC voltage differential *du*/*dt* or current differential *di*/*dt* is used as the start-up component. Once the start-up requirement is satisfied, the protection scheme is triggered to start the calculation process.

► ***Time Delay***

Frequent energy exchange due the inductive and capacitive components at the beginning of the fault so the reactive energy varies between positive and negative values, which results in fluctuate directions during this period. So time delay is required to prevent this fluctuating nature of reactive energy direction.

► ***Threshold Setting***

A threshold for the reactive energy is necessary to preventable-operation during disturbances. When the calculated reactive energy is larger than the threshold value, the fault direction identification module is activated.

► ***Flow Diagram***

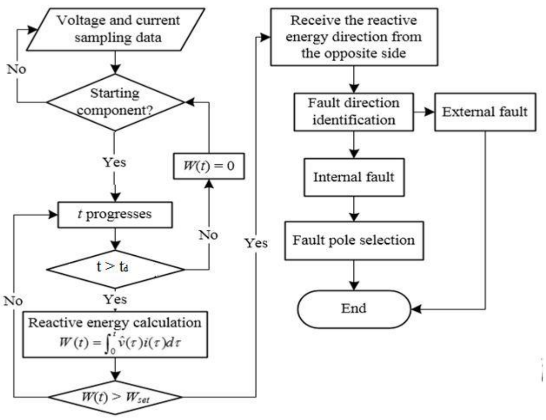


Fig.3 Flowchart of protection scheme

The protection scheme integrated flow diagram is shown in Fig.3. When faults occur the start-up condition is satisfied. As time progresses *t* is incremented. When the time delay is satisfied, the protection scheme begins to calculate reactive energy from fault voltage and fault current. If the calculated reactive energy is larger than the setting threshold value of reactive energy, an internal or external fault can be identified according to the reactive energy directional information from the other side. Finally, the faulty pole is selected in the internal fault situation by measuring the reactive energy on both poles.

MODELLING AND SIMULATION

Under normal operating situations, HVDC systems mostly transmit active power, whereas the reactive power flow on the DC line is nearly zero except for some small harmonic components. The quantity of the harmonic reactive power on the DC line depends on the filtering effects of the DC filters and the smoothing reactors. The total quantities of the harmonic volt-age and current are typically less than 5% of the rated values [1]. However, when a line fault occurs, the voltage and current at the terminals of the DC line will contain a transient component due to the inductive and capacitive components in the system, thus resulting in significant reactive power flows on the DC line.

In traditional HVDC systems, shunt capacitor banks are commonly used for compensating the reactive power which the converters consume. Reactive power control is designed to maintain the reactive power balance by switching the capacitor banks [1]. The consumption of reactive power can only be changed in steps by switching in or out of the capacitor banks. This discrete kind of control needs to be blocked during the transient process to avoid frequent switch operations, and the control speed is typically 10-20 s per step [1]. Thus, the reactive power is uncontrolled during the fault period, and it is primarily affected by the characteristics of the system components. As analyzed in this section, the uncontrolled reactive power flows from the source to the fault point during the fault transient process, indicating that the reactive power has different directions in internal and external fault situations. According to the above analysis, the reactive power on the DC line can be utilized to identify the fault occurrence and distinguish the internal and external faults.

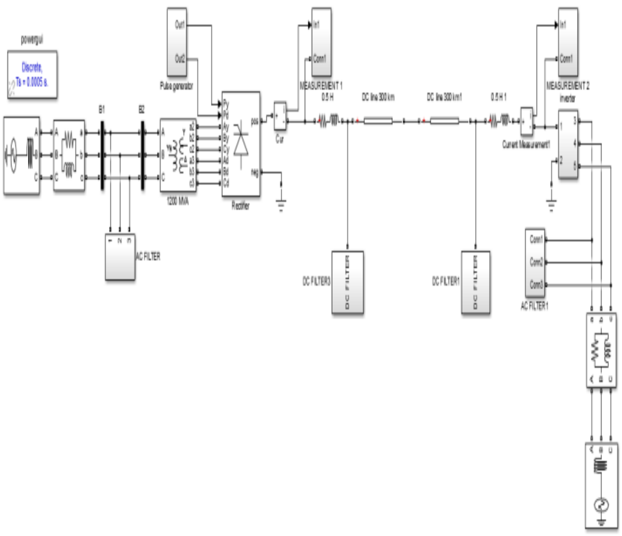
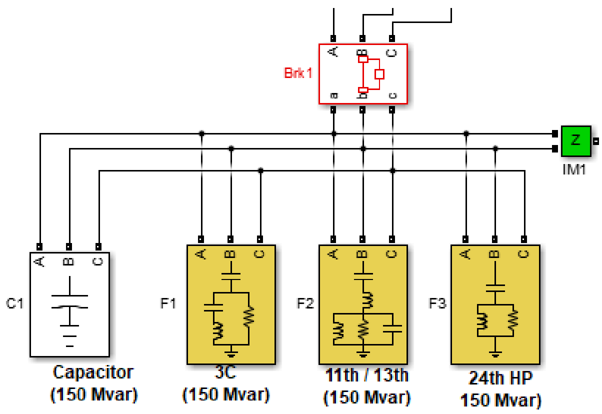
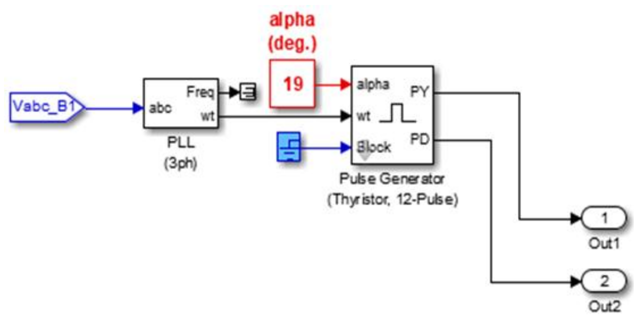


Fig Main Proposed System

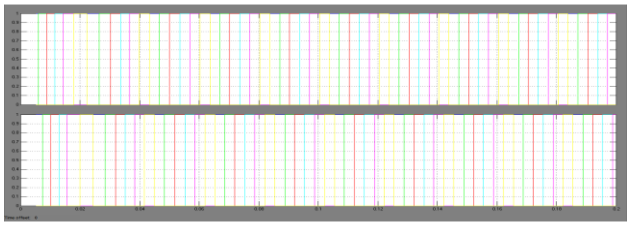
Ac Filter



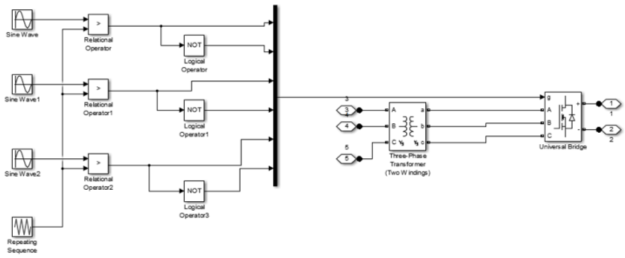
Pulse Generator



Pulse Generation



SPWM Inverter



Rectifier Side Fault (Dc fault)

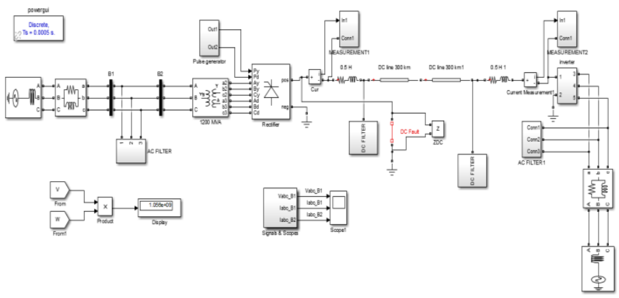
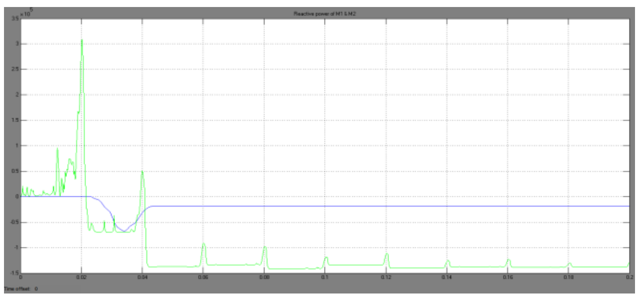
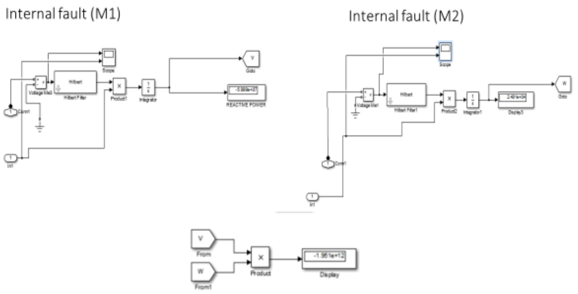


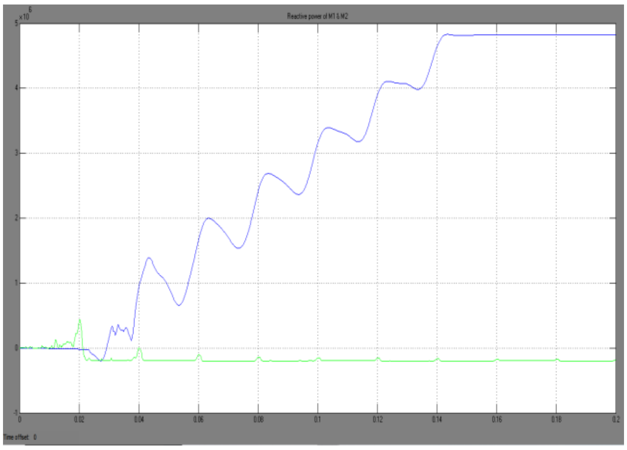
Fig Fault Condition of Proposed System

Rectifier side fault (Waveform)

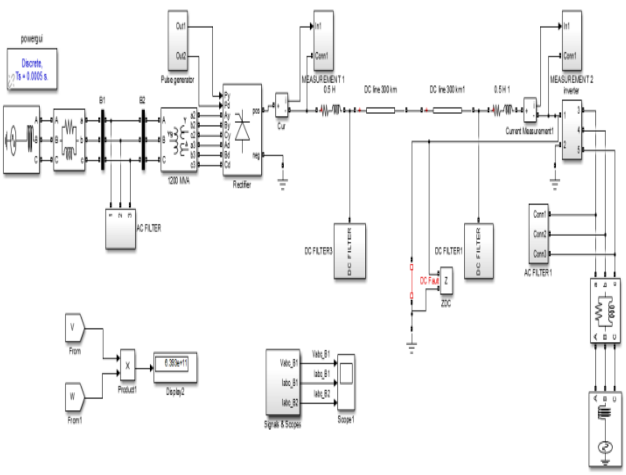




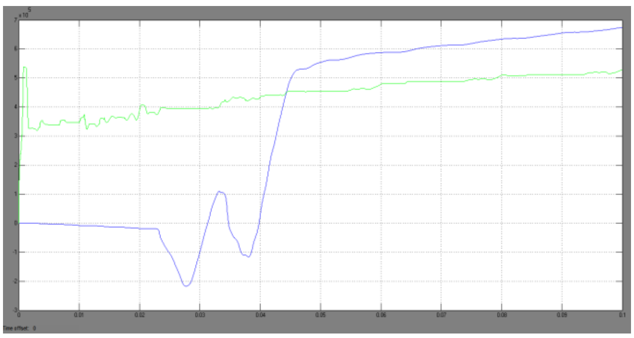
Reactive power for internal fault



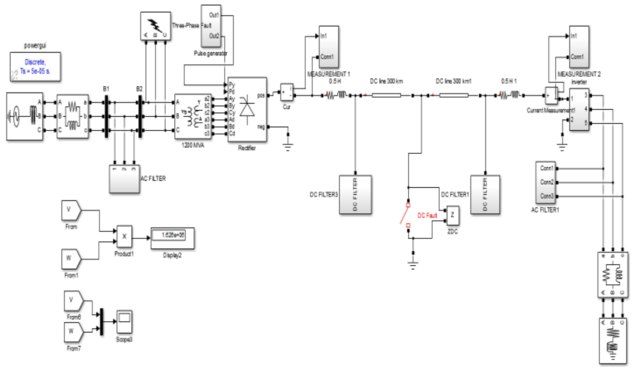
External Fault at Inverter Side (Dc Fault)



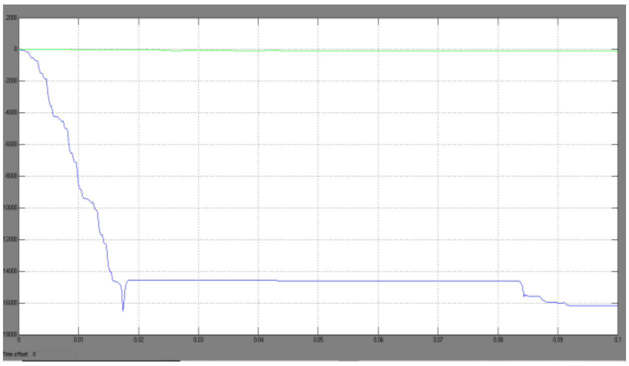
Reactive power External Fault at Inverter Side



Ac system Fault (Rectifier Side)



Reactive Power for Ac fault



CONCLUSION

This paper proposes a novel protection scheme based on reactive energies for HVDC transmission lines. Based on the type of fault occurring in the system i.e. internal or external fault reactive energy are calculated at both ends of the line to determine the type of fault in the system. Ac system Faults are also been characterized by the system based on reactive energy concept.

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