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Analysis Stduy of Different Control Schemes used for the Improvement of Transient Stability: A Review

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***Abstract*—** In this paper various control schemes used for the enhancement of tranisent have been studied. There are two main control schemes used for transient stability enhancement: Prevntive controle scheme and Emergency control scheme. In this paper the main focus is on emergency control scheme. Further various emergency schemes have been presented in this paper like fast valving, braking resistors, fast valving in coordination with braking resistor, HVDC link for the improvement of transient stability. At the end of this paper a new control scheme has also been proposed in which PMU's are used in coordination with HVDC link for the improvement of transient stability. PMU's are used for the continuous monitoring of the system parameters.

***Keywords*—** HVDC link, Emergency control scheme, PMU, MPC, SIME**.**

I. Introduction

Transient stability shows the system ability to maintain synchronism when the sytem is in normal operating condition and regain the state of synchronism when a severe disturbance occurs in the system. The severe disturbance may occurs as a result of three phase fault on the transimission line, failure of generating unts, or disconnection of major portion of load. Due to these disturbances the sytem may loss synchronism because of the increase in rotor angle [1,2]. Due to the loss of synchronism a blackout occurs if there is a cascading tripping of the generating units [3]. Therefore to avoid the cascaded tripping of generatings various control schemes have been proposed. These control schemes are classified into two major categories: Preventive control and Emergency control scheme.

In preventive control scheme the system is prepared for any future severe contingency to be withstanded by changing the operating conditions that result the system to become unstable. Many researchers have worked on emergency control scheme for the system transient stability improvement. In reference [4] an another control scheme has been presented which wotk on the dynamic characteristics of the system limits of stability.. Reference [5] proposes an emergency control scheme for shedding of generator using PMU. Reference [6] proposes an open loop control scheme for the tripping and rescheduling of generator. In [7] and [8] closed loop emergency control scheme has been designed for transient stability. There are other control schemes which are used as an emergency control schemes such as braking resistors are used in coordination wit fast valving for the improvement of transient stability [9]. Excitation system may also be utilized for the enhancement of transient stability [10]. Tie-line reactance is also used for transient stability enhancement[11].

Many other control schemes have been proposed for the improvement of transient stability like Model Pridictive Control scheme (MPC). MPC is widely used for the applications of power system. In reference [12] MPC is used for electomechenical oscillation damoing where variable reactance is used, in reference [13] MPC technique is proposed for voltage control, in [14] MPC has been proposed to reduce thermal overload. In reference [15] MPC technique has been proposed for the control of Flexible Alternating Current Transmission System (FACTS) making the system more stable during transient. MPC collects real time information through Wide Area Monitoring System (WAMS). It calculate the control actions for maximizing transient stability at various discrete time intervals and uses these control actions to modulate power flow through the HVDC line [16].

II. Emergency Control Scheme

It is one of the effective control scheme used for the improvement of transient stability [17]. As many of the old controls are off-line. They have the disadvantages of large computation time, therefore the system response to any change is slow and poor. This was the reason that researchers worked to design an on-line emergency control scheme for the transient stability and therefore an on-line scheme was introduced [18]. There are two types of emergency control scheme: Open loop control scheme and Closed loop control scheme [19], [20].

Open loop emergency control (OLEC) [21]:

OLEC uses the following method for the improvement of the stability:

1. the negative margine of the system going to instability is calculated and on the basis of this negavtive margine the critical machines are determined.
2. Once the critical machines are determined, The number of machines are found to be tripped which are connected with emergency control scheme.
3. The Single Machine Equivilant (SIME) is run, and it is run from the start and it has been running upto the tripping delay of the generator and the machines selected in step 2 are tripped out. The simulation is continued till the system becomes stable [22].
4. The simulation is run again and again until the negative margin become that changes the machines from noncritical to critical machines. An extra task may be done, If Optimum Power Flow (OPF) is also used [23].

Closed loop emergency control scheme:

As in open loop emergency control scheme, the power system actions are controlled in off-line mode based on simulation and it can not be readjusted when the system is in on-line mode. Therefore, the best alterntive for the control of power system operation is the Close Loop. In Closed loop emergency control scheme it is first checked that the fault that is occurred will make the system unstable and if the system becomes unstable due the fault, the control actions are triggered appropriately so as to make the system stable [8].

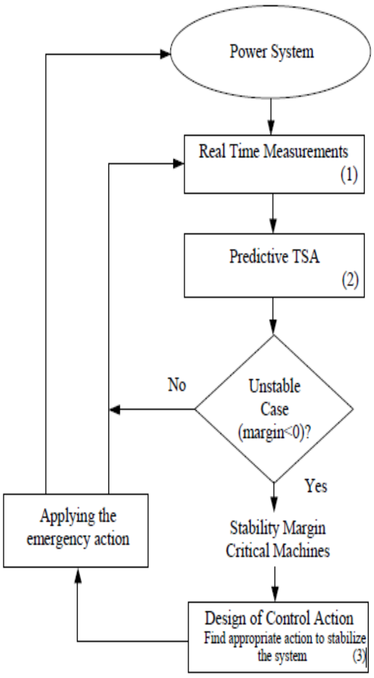

Figure-1 general algorithm for closed loop control [28].

Closed Loop Emergency Control is also called Emergency-SIME is proposed in [24], [25], [26]. The whole process includes the determination of the system stability, the size of the instability, control actions designing, and triggering of the system [27]. Figure-1 is the general algorithm for design Close Loop Emergency Control Scheme.

Although the Close Loop is more effective than Open Loop however the wole process in Closed Loop takes a lot of time and the controller is slower as compared to Open Loop. In such situations Open Loop is sbetter than Close Loop [6].

concept of SIME

SIME is a simulation method used for the enhancement of transient stability which replace the whole system by a Single Machine Equivalent (SIME). SIME combines the Equal Area Criteria and Time Domain analysis. The Equal Area Criteria is used for emergency control and the Time Domain Analysis for preventive method. However both have the same basic principles. The characteristics of the whole system are replaced by One Machine Infinite Bus (OMIB) and more accurate informations are obtained [29].

Emergency-SIME (E-SIME):

Once the fault is cleared after the occurance of fault, the transient stability margin is checked by E-SIME. If the system has the possibility of loss of synchronism, the control actions are selected and triggered to avoid the system from any loss of synchronism . The selected control actions are continuously monitored whether they are enough to avoid the loss of synchronism or should be readjusted. The informations obtained from E-SIME are measured in real time [30]. After occurance of the faut, the machines are divided into critical machines and non-critical machines.

Critical machines are close to the stability limits and may cause the system to loss synchronism. Non-critical machines are strong enough to remain stable even if the synchronism has been lost [32, 33]. Figure-2 represnets three machine system which are subjected to a disturbance. Machine 2 and 3 are divided into Critical machines and machine 1 is divided into Non-critical machine [34].

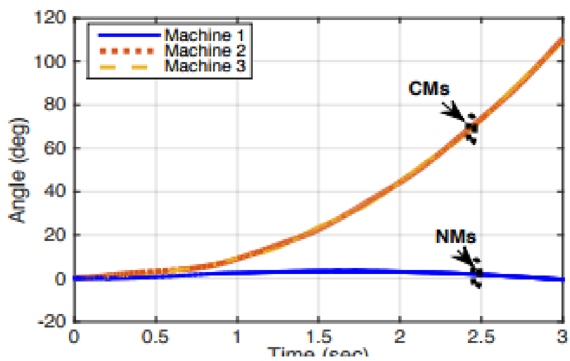

Figure-2: critical and non-critical machines [34].

FACTS devices are also used for the enhancement of the system stability. These devices are used as emergency control devices for the stability of the system. For instance tie line reactacne controller, fast valving and braking resistors, excitation system etc. [29].

Fast valving and braking resistors:

Fast valving and Braking Resistors belong to the family of Discrite Suplementary Controllers (DISCOS). These two members of DISCOS are the supplementary controllers which only active during the faulty conditions and they do not work when the system is in normal operating condition [35]. Speed governor and excitation system are the primary controllers used only for small variation and these controllers may not work during transient faults [36]. The use of DISCOS as an alternative of primary controller is necessary. The cost of theses controllers are less even for the construction of new transmission line. [37].

Braking resistors:

Braking resistor may be installed at any location in the system however the preferred location for installation of braking resistor is that bus where weakest generators are connected. Weakest generators are those that are operating close to the stability limits. Many researchers have worked to sort out the suitable switching strategy for the Braking resistors [38]. Reference [39] shows three strategies in which resistors resistor reactor, and reisistor capacitor are used for the enhancement of transient stability. Reference [40] proposes two new strategies in which in one thyristor rectifier has been used and the in the second diode rectifier and chopper have been used. In [41], [42] control strategies for single insertion and multiple insertion brakes of braking resistors heve been presented of braking resistors

Fast valving:

Fast valving are the most effective means for transient stability improvement which were used before 1929 but this technique was largely used in the period 1970s and 1980s. There are two ways of applying fast valving; Sustained Fast Valving (SFV) and Momentary Fast Valving (MFV). In MFV the valve is closed for a very short movement after the occurrence of fault and reopens and restores the driving power of the turbine while in SFV the steam is passed through the bypass system[43]. For small variation the governor control is enough however in case of large variation the governor control is not sufficient to adjust the variation. In such situation the system may loss synchronism. If the system loss synchronism, the power will reduce almost to zero. In scuh case fast valving is one the effective solution to avoid the loss of synchronism [44].

In case of fault the valve of the turbine is closed and kept close for a while to check the increase in mechanical torque in the form of acceleration of the rotor. The circuit breaker takes a time to remove the faulted area from the rest of the system [9]. For the improvement of the system transient stability using fast valving, many control schemes have been designed. For instance [26] proposes a control scheme which basis on the tracking of active power and rotor angle. In [27] the turbine power is controlled depending upon the fault severity.

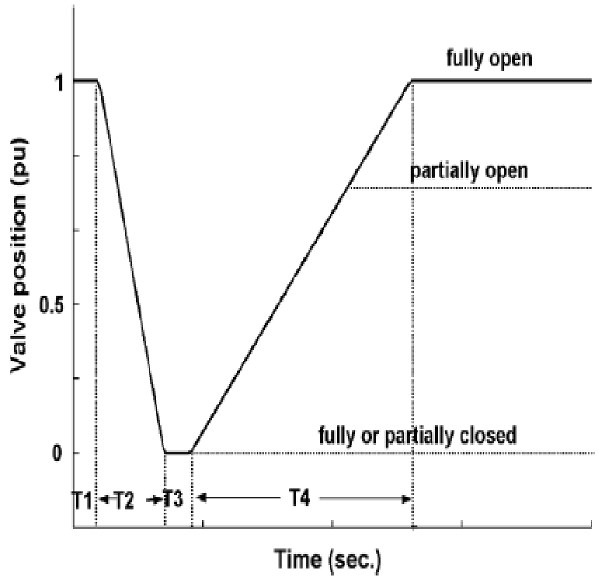

Figure-3 shows fast valving scheme [9]

High Voltage Direct Current (HVDC):

In beginning of 1880, for the transmission of electric power DC was used. The transmission of low voltage DC power over long distance was difficult [45, 46]. Also wth the arrival of induction motor, transoformer, synchronous motor, electronics converters AC replaced the DC. It became easy to transmit AC at High, Extra high voltage over long distances. DC power has the advantage of controllability over AC power. It is easy to control the DC power as compared to AC power [45]. DC power has other advantages such as interconnection of power system which may be operating in different mode of operation [47, 48]. In 1903 when the mercury arc was first introduced, the growth of HVDC was started. The first contract of 60 Mw power transmission over a distance of 115 km but unfortunately this project never become operational due to world war 2. The first DC system of 20 MW in 1954 was commissioned. The transmission voltage used by this system was of 115 kv. However with the arrival of thyrister valves, the HVDC system got more attention [49].

HVDC main components:

Figure-4 represents the genral arrangement of HVDC . conversion from AC into DC and back to AC from DC is the main pupose of HVDC system. Conversion from AC into DC takes place at the sending end and from DC into AC at receiving end.

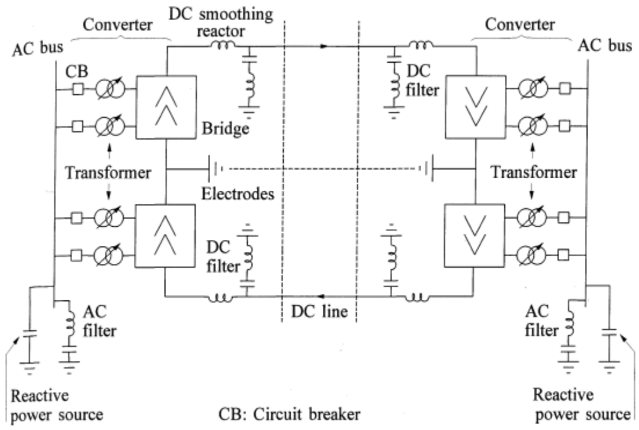

Figure-4 General components of HVDC [47]

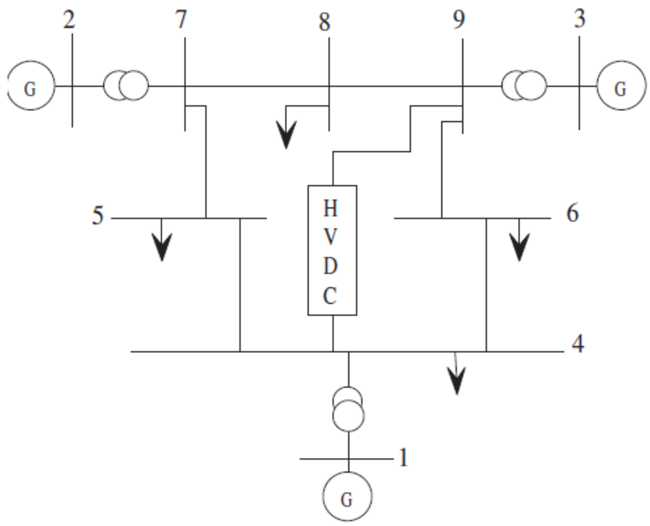

Figure-5 IEEE 9 bus system with HVDC link

III. Transient stability through HVDC

Researchers have worked to propose various control scheme for the enhancement of tranisent stability by modulating power flow through the HVDC line. In reference [52] a control scheme has been proposed in which VSC-HVDC is utilized for the improvement of the system stability. VSC-HVDC has the ability to control both the active and reactive powers independently. That is the size of equipments used in VSC-HVDC is small as compared conventional HVDC system [53]. Model Predictive Control (MPC) has been also for transient stability improvement [54]. In reference [55] for the improvement of the system stability Voltage Source Converter-HVDC is used, which uses the active power control through the HVDC line. In [56] a control strategy has been proposed modulating HVDC power flow using the same transmission line of AC.

Model Predictive Control HVDC Scheme:

MPC collects real time information through Wide Area Monitoring System (WAMS). It calculate the control actions for maximizing transient stability at various discrete time intervals and uses these control actions to modulate power flow through the HVDC line. Figure-5 shows a 9-bus system incorporated with a single HVDC line, in which the concept of MPC is utilized [57].

Figure-6 shows a 24-bus system incorporated with two HVDC links. This system was alos simulated for the improvement of transient [].

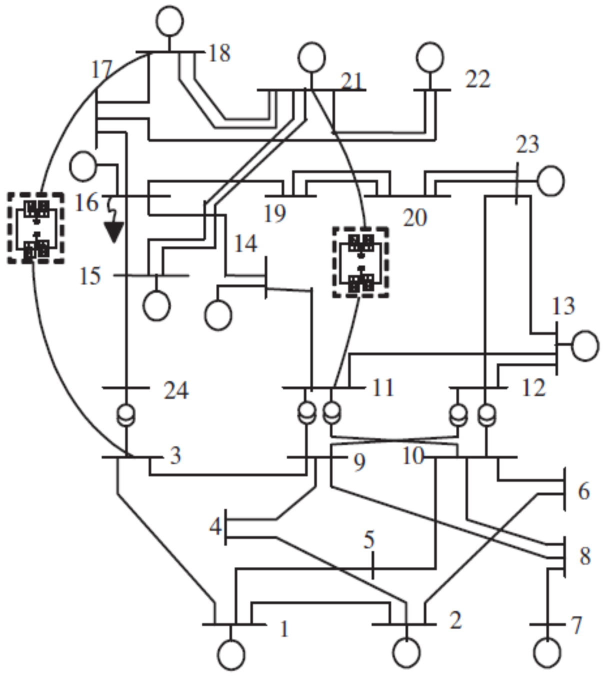

Figure-6 IEEE 24 bus system with two HVDC links

Control Mode of VSC-HVDC:

Pulse width modulation technique is used in VSC-HVDC , in which the magnitude and phase angle of VSC may be controlled separately. Each VSC in normal operation is independent of the other VSC, therefore the reactive power through each VSC can be controlled independently. However the injection of active power into the DC system must be equal the power coming out from the system. The active power can be kept balance when one of the VSCs utilize DC voltage for the control of power and the othe VSC control its power [58].

NEW PROPOSED CONTROL SCHEME

A new scheme is proposed in which Phasor Measurement Units (PMUs) are used in coordination with HVDC link for the enhancement of the stability. This new proposed scheme uses PMUs for the continuous monitoring of the system parameters where HVDC link is used for the modulation of powere flow through it. The advantage of using PMU for measuring the system parameters is that PMU measure the parameters in real time. Therefore it is easy to monitor the system parameters in real time using PMUs [59].

CONCLUSION

In this paper the detailed study of the control schemes used for the improvement of the transient stability have been carried out. The two main schemes preventive and emergency control schemes have been discussed; however the main focus in this paper was given on emergency control scheme. Furthermore, each emergency control shceme such as braking resistor, tie-line reactacne, fast valving, HVDC link has been discussed. At the end of this paper a new control scheme is proposed in which the combination of PMU and HVDC link is used for the enhancement of the system stability. All the schemes discussed in this paper are only for the three phase sysmmetrical faults. A more advance control scheme may be designed which can be used for all types (symmetrical and non-symmetrical) of faults.

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