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

Naveed Ullah¹, Muhammad Naeem Arbab², Uzair Muhammad³, Tanvir Ahmed⁴, Nisar Ahmed⁵
¹²³⁴ Multinational Research, United States of America
²³⁴⁵ PNAC for Advance studies in Energy, University of Engineering and Technology, Peshawar, Pakistan
naveedullah491@gmail.com¹, mnnarbab@nwfpuet.edu.pk², uzairmuhammad416@gmail.com³, tanvir.ahmad@uetpeshawar.edu.pk⁴, nisarmarwat10@gmail.com⁵
Received: 10 September, Revised: 18 September, Accepted: 22 September

Abstract— In this paper various control schemes used for the enhancement of transient have been studied. There are two main control schemes used for transient stability enhancement: Preventive control 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 system 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 transmission line, failure of generating units, or disconnection of major portion of load. Due to these disturbances the system 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 generating units 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 withstood 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 work 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 with 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 Prirdictive Control scheme (MPC). MPC is widely used for the applications of power system. In reference [12] MPC is used for electromechanical oscillation damping 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].

© Authors retain all copyrights 2019 IJEW. This is an open access article distributed under the CC-BY License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
Open loop emergency control (OLEC) [21]:

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

1. the negative margin of the system going to instability is calculated and on the basis of this negative margin 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 Equivlant (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 alternative 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].

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 fault, 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

Figure-1 general algorithm for closed loop control [28].
reactance 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 Discrete Supplementary 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 these 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 resistor 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 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 have 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 lose synchronism. If the system loss synchronism, the power will reduce almost to zero. In such 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.

**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 with the arrival of induction motor, transformer, 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 thyristor valves, the HVDC system got more attention [49].

**HVDC main components:**

Figure-4 represents the general arrangement of HVDC. Conversion from AC into DC and back to AC from DC is the main purpose of HVDC system. Conversion from AC into DC takes place at the sending end and from DC into AC at receiving end.
III. TRANSIENT STABILITY THROUGH HVDC

Researchers have worked to propose various control schemes for the enhancement of transient 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 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 to conventional HVDC system [53]. Model Predictive Control (MPC) has been also for transient stability improvement [54]. In reference [55], for the improvement of 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 calculates 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 also simulated for the improvement of transient stability [58].

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 to the power coming out from the system. The active power can be kept balance when one of the VSCs utilizes DC voltage for the control of power and the other VSC controls 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 power 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 scheme such as braking resistor, tie-line reactance, 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 symmetrical faults. A more advance control scheme may be designed which can be used for all types (symmetrical and non-symmetrical) of faults.

REFERENCES

[1] P. Kundur, “Power System Stability and Control”. McGraw-Hill, 1994.
[2] M. Pavella, D. Ernst, and D. Ruiz-Vega, “Transient Stability of power systems”. Kluwer Academic, 2000.
[3] P. Gomes, “New strategy to improve bulk power system security: lesson learned from large blackout”, 2001.
[4] Y. Mei, K. Hou, R. Zhang, and Q. Tu, Ö “a new method for generation shedding and load shedding in power system emergency control”. Ö in Proc. IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies, vol. 1, April 2004, pp. 210-214.
[5] Chunyan Li, Changhong Deng, Y. Sun, and X. Chen, Ö “an on-line transient stability emergency control strategy based on PMU forecasted trajectory”, in Proc. International Power Engineering Conference, Dec 2007, pp. 807-812.
[6] D. Ruiz-Vega and M. Pavella, ÖA comprehensive approach to transient stability control. II. Open loop emergency control, Ö IEEE Trans Power System, vol. 18, no. 4, pp. 1454-1460, Nov 2003.
[7] D. Ernst and M. Pavella, Ö“closed-loop transient stability emergency control”, in Proc. IEEE Power Engineering Society Winter Meeting, vol. 1, 2000, pp. 58-62.
[8] M. Glavic, D. Ernst, D. Ruiz-Vega, L. Wehenkel, and M. Pavella, Ö “E-SIME - a method for transient stability closed-loop emergency control: achievements and prospects”, in Proc. iREP Symposium- Bulk Power System Dynamics and Control - VII, Revitalizing Operational Reliability, Aug 2007, pp. 1-10.
[9] R. Patel, T. S. Bhatti, and D. P. Kothari, Ö“a modified approach to transient stability enhancement with fast valving and braking resistor applications”, in J Electrical Power & Energy Systems, vol. 28, no. 10, 729-738, Dec 2006.
[10] N. Fermedopulou and R. Ramshaw Ö “Domain of stability of synchronous machine with excitation control-a cell mapping approach, Electric Power Systems Research, vol. 27, no. 3, pp. 173-181, Aug 1993.
[11] D. K. Reitan and N. Ramanarao, Ö“a method of improving transient stability by bang-bang control of tie-line reactance”, IEEE Trans Power Apparatus and Systems, vol. PAS-93, no. 1, pp. 303-311, Jan 1974.
[12] D. Ernst, M. Glavic, F. Capitanescu, and L. Wehenkel, Ö“reinforcement learning versus model predictive control: a comparison on a power system problem”, IEEE Transactions on Systems, Man, and Cybernetics - Part B: Cybernetics, vol. 39, pp. 517-529, April 2009.
[13] M. Larsson, D. Hill, and G. Olsson, Ö“Emergency voltage control using search and predictive control”, International Journal of Power and Energy Systems, vol. 24, no. 2, pp. 121-130, 2002.
[14] B. Otemega, A. Marinakis, M. Glavic, and T. Van Cutsem, Ö“Model predictive control to alleviate thermal overloads”, IEEE Transactions on Power Systems, vol. 22, pp. 1384-1385, August 2007.
[15] J. Ford, G. Ledwich, and Z. Dong, Ö“Efficient and robust model predictive control for first swing transient stability of power systems using flexible ac transmission systems devices,” IET Proceedings on Generation, Transmission, and Distribution, vol. 2, no. 5, pp. 731–742, 2008.
[16] Y. Phulpin, J. Hazra, D. Ernst, Ö“Model predictive control of HVDC power flow to improve transient stability in power system”, Smart grid communications, 2011.
[17] C. Li, C. Deng, Y. Sun, and X. Chen, ÖÖ-an on-line transient stability emergency control strategy based on PMU forecasted trajectory”, in Proc. International Power Engineering Conference, Dec 2007, pp. 807-812.
[18] Y. Xue, Ö“practically negative effects of emergency controls”, in proc.1997 IFAC/CIIGRE symposium on control of power system and power plants, pp.134-138.
[19] M. Pavella, D. Ernst, and D. Ruiz-Vega, ÖTransient Stability of Power Systems: A Unified Approach to Assessment and Control. Norwell, MA: Kluwer, 2000.
[20] L. Wehenkel, Ö“Emergency control and its strategies,” in Proc. Power Syst. Comput. Conf., vol. 1, Trondheim, Norway, June 28-3 July 2002, pp. 35-48.
[21] Daniel Ruiz-Vega, Mania Pavella, Ö“A Comprehensive Approach to Transient Stability Control: Part II-Open Loop Emergency Control”, IEEE TRANSACTIONS ON POWER SYSTEMS, vol. 18, no. 4, NOVEMBER 2003.
[22] D. Ruiz-Vega and M. Pavella, Ö“A comprehensive approach to transient stability control—Part 1: near-optimal preventive control,” IEEE Trans. Power Syst., vol. 18, pp. 1446–1453, Nov. 2003.
[23] D. Ruiz-Vega, Ö“Dynamic Security Assessment and Control: Transient and Small Signal Stability,” Ph.D. dissertation, Univ. Liege, Liege, Belgium, 2002.
[24] Y. Zhang, L. Wehenkel and M. Pavella. ÖA Method for Real-Time Transient Stability Emergency Control, Proc. of CPS/PST! I FAC/CIIGRE Symp. On Control of Power Systems and Power Plants, August 1997, Beijing, China, pp. 673-678.
[25] D. Ernst, A. Bettiol, Y. Zhang, L. Wehenkel and M. Pavella. ÖReal Time Transient Stability Emergency Control of the South- Southeast Brazilian System., SEPOPE, Salvador, Brazil, May 1998, (Invited paper, IP044).
[26] D. Ernst, M. Pavella, ÖClosed-Loop Transient Stability Emergency Control, Proc. of IEEE/IPS Winter Meeting, Singapore, 2000.
[27] Daniel Ruiz-Vega, Mevludin Glavic, Damien Ernst Ö transient stability emergency control combining open loop and closed loop techniques”, 1999.
[28] J. Hazra, Y. Phulpin, D. Ernst, Ö“HVDC control strategies to improve transient stability in interconnected power system”, Power Tech, IEEE Bussharet pp.1-6 oct. 2009.
[29] Daniel Ruiz-Vega, Louis Wehenkel, Damien Ernst, Alejandro Pizano-Martinez and Claudio R. Fuerte-Esquivel, Ö“Power system transient stability preventive and emergency control, chapter 5”.
[30] Daniel Ruiz-Vega, Mevludin Glavic, Damien Ernst Ö transient stability emergency control combining open loop and closed loop techniques”, 2009.
[31] Pavella M, Ruiz-Vega D. and al. SIME: A Comprehensive Approach to Transient Stability. Real-Time Stability Assessment in Modern Power System Control Centers, John Wiley & Sons, Inc 2008; 353-400.
[32] Pavella. M., D. Ernst, and al. ÖTransient Stability of Power Systems: A Unified Approach to Assessment and Control, Kluwer Academic Publishers 2000.
Yousef Oubahi, Salem Arif, “Securing transient stability Assessment Using Single Machine Equivalent Method”, Electrical Engineering (IECE), pp. 1-4, Dec 2015

Durrant CW. Boiler response to partial load rejection resulting from System upsets. IEEE Trans 1982; PAS-101(8):2630–9.

IEEE Working Group on Special Stability Controls Power System Engineering Committee. Bibliography on the application of discrete Supplementary controls to improve power system stability. IEEE Trans 1987; PWRS-2(2):474–85.

Ramnarayan Patel, T.S.Bhati, D.P.Kothari, “A modified approach to transient stability enhancement with fast valving and braking resistor applications”, electric power and Energy system. p.729-738, 2006

Patel Ramnarayan, Bhatti TS, Kothari DP. Dynamic braking control strategies: a comparative analysis. In: Proceedings international conference on energy automation and information technology 2001

A.H.M.A. Rahim, A.I.J. Al-Sammak, “Optimal switching of dynamic Braking resistor, reactor or capacitor for transient stability of power system”, IEE Proceedings C-Generation, Transmission and distribution, pp. 89-93 vol 138 Jan 1991.

Riya Saluja, Mohd. Hasan Ali, “Novel Braking resistor models for transient stability enhancement in power grid system”, Innovative Smart Grid Technologies (ISGT), April 2013

Al-Azzawi FJ, Omar F. Dynamic brake switching time in multimachine Power system during emergency: Proceeding of the 24th University power engineering conference, Belfast, Britain, September 1989. p. 101–6.

Al-Azzawi FJ, Al-Wafi NM, Jassim AK, Omar F. Braking resisrorsize, switching instants and assessment of power system transient stability by direct methods. J Inst Engrs (India) 1995;76:175–80.

Patel, Ram Narayan. Bhatti, T.S. Kothari, D.P. “Improvement of Power System Transient Stability using Fast Valvings: A Review”, Electric Power Components and Systems, P-927-938, Nov 30, 2010

A.H.M.A. Rahim, A.I.J. Al-Sammak, “Optimal switching of dynamics braking resistor, reactor, or capacitor for transient stability of power system”, IEE proceeding C-Generation, Transmission and Distribution, vol 138, no.1, pp-89-93, 1991

G.GKarady, M.A.Mohammad, “improving transient stability using fast valving base on tracking rotor angle and active power”, power engineering society meeting summer, 2002.

K.Koyanagi, T.Komukai, “a study of fast valving as an aid to power system transient stability part1. Some considerations of control methods for fast valving”, p.1-5, 1977

Shri Bhagwan, “A Review: High Voltage Transmission System”, International Journal on Recent Technologies in Mechanical and Electrical Engineering (IJRMEE) pp. 1-4, vol 02.

Vijay. K. sood, “High Voltage Direct Current And FACTS controller”, USA Kluwer Academic Publisher 2004.

N. Florentzou, V. G. Agelidis, and G. D. Demetriades, “VSC based HVDC power transmission system: an overview”, IEEE transaction on power electronics, vol. 24, pp. 593-602, March 2009.

Chan-ki Kkim, Vijay K. Sood. Gil-Sood Jang, Seong-Joo Lim, and Seok-Jin Lee, “High Voltage Direct Current transmission” chapter 01 Development of HVDC Technology.

P. Kundur, “Power system Stability and Control”, McGraw-Hill, 1994.

Compendium of HVDC schemes throughout the world”, International conference on Large High Voltage Electric systems, CIGRE WG 04 of SC 14. 1987.

Ibrahim. Bekki, Mohamed Moujahid, Mouhamed. Boudiaf, “Transmission System Transient stability enhancement based on VSC-HVDC”, Journal of Electrical Engineering, pp. 1-6

Schetter F, Huang H, Christl N, “HVDC transmission systems using voltage source converter-design and applications” IEEE Power Engineering Society Summer Meeting, July 2000.