International Journal of Innovative Technologies

WWW.IJITECH.ORG

ISSN 2321-8665
Volume.06, Issue.01,
January-June, 2018,
Pages:0266-0275

Reducing Fault Current by Adaptive Stabilizer in Distribution System

T. LAKSHMI NEELASREE[1], K. R. SIVAPRASAD[2], P. NAGARJUNA[3]
[1]PG Scholar, Dept of EEE(EPS), CBIT, Proddatur, Andhrapradesh, India.
[2]Assistant Professor, Dept of EEE, CBIT, Proddatur, Andhrapradesh, India.
[3]Assistant Professor, Dept of EEE, CBIT, Proddatur, Andhrapradesh, India.

Abstract: A fast power restoration operational scheme and relevant stabilizing control is proposed for active distribution power systems with multi-terminal DC network in replacement of the conventional normal open switches. This project takes a systematic view on the control and protection of medium power DC networks in an active distribution power system considering fault current limiting, system control, and converter design. Reduced terminal capacitance and extra DC impedance are used to limit DC fault current and reduce the required converter current rating for medium power DC networks. The proposed power restoration scheme is based on the coordination among distributed control among relays, load switches, voltage source converters and autonomous operation of multi-terminal DC system. A DC stabilizer is proposed with virtual impedance method to damp out potential oscillation caused by constant power load terminals. A stabilizing method is also proposed to improve system dynamics from the power terminal side by modifying the large constant power terminal impedances. An adaptive DC power stabilizer is proposed to alleviate possible system instability brought by the fault current limiting settings in the presence of constant power load. The effect of the current limiting method and the proposed stabilizer on DC fault current and stability enhancement are validated by MATLAB/SIMULINK simulation studies using a simple two-converter DC network and a multi-terminal DC network in an active distribution power system.

Keywords: Active Distribution Power System, DC Microgrid, DC Power System, DC Protection, DC Stabilizer.

I. INTRODUCTION

In particular the effective protection of the converters after a DC fault due to the discharging of the DC link capacitors and fault current feeding from AC side via the freewheeling diodes in DC/AC converters is one of the major concerns of modern DC power system. Fast acting DC circuit breakers (DCCBs), e.g. semiconductor based can effectively isolate the fault within a short period (typically less than 1ms) though with increased cost and conduction power loss. On the other hand, mechanical AC and DC Circuit Breakers have negligible losses and lower cost but are with slow breaking response, typically over a few tens of mini-seconds. Fault current limiting (FCL) techniques are proposed to reduce the peak fault current and its rising rate to facilitate circuit breaking. Series impedance injection is the basic idea considered in DC fault current limiting. It can be divided into two main types: resistive and inductive. Superconductor based techniques are employed in resistive type FCL, but they consume considerable power during steady state operation in order to maintain superconductivity. The other type is inductive based FCL which can effectively limit fault current rising rate and reduce peak fault current though it does not reduce (or might even increase in some cases) the total discharging energy during a DC fault. If the DC current and fault energy can be limited to allow the converter to survive the fault transient before current interruption, AC side breakers or slow mechanical DCCBs can provide a much simpler and cost effective solution compared to the fast DCCB option. Constant power loads (CPL) can potentially introduce system instability in a DC power system. The stabilization of CPLs in a small scale DC network within a confined area has been well studied. Adding physical resistors were initially suggested though with considerable power losses. Active damping was proposed thereafter.

Impedance matching based techniques were developed to modify the small signal characteristics at the point of load from the source side control, though with a fixed power flow direction. Global system stabilization was proposed based on state-space modeling to provide damping for bidirectional power flow. However, both of the above two stabilization methods require real-time knowledge of the overall system configuration. This requires high bandwidth communication, which is neither economical nor reliable in a DC system with a considerable distribution length. In addition, the system configuration is not likely to be fixed in a broader network, where intermittent renewable sources, plug-and-play loads and system reconfigurations are expected. Local stabilization techniques are also proposed to be implemented on the load side or constant power generation side. The main drawback of these techniques is that they require the access to the control of the target converter terminals including their instant power, which makes these methods not applicable to systems with inaccessible constant power terminals. In addition, the rigid configurations of stabilizing algorithms make them sensitive to the variations of constant power terminals and system configurations.

Smart grid technology includes the application of automation and intelligent controls to power systems, and it includes several significant characteristics, including: 1) increased use of digital control and information technology with real-time availability; 2) dynamic optimization relating to grid operability; 3) inclusion of demand side response; 4) demand side management strategies; 5) integration of distributed resources including renewable and energy storage; 6) deployment of smart metering; 7) distribution system automation; 8) smart appliances and customer devices at the point of end use. It is envisioned that the trend of using more DC systems will grow over time and some point in the future may even dominate over the conventional AC systems. DC distribution systems a number of advantages such as reduced losses, higher power quality, compactness, fast and accurate control of power flow, as well as controllable transient response to disturbances and faults in the system. The measure taken for fault current limiting using increased DC inductance and reduced DC capacitance can further tense up the instability problem along with considerable distribution length, which has rarely been investigated before. And the stabilization of a more expanded DC system, typically up to a few kilometers, with autonomous variable load has rarely been explored with DC protection simultaneously considered. In this project, a systematic view on protection, stability control and converter design is taken to enable the application of medium power DC system with considerable distribution length.

An adaptive stabilizer is proposed to compensate local negative impedance based on its own local detections hence no need for high bandwidth global information acquisition. The proposed adaptive control is also independent from both the constant power terminal and the grid side conditions, and the flexibility of being able to incorporate into CPL terminal control if required. Modern DC distribution systems increasingly use switching-mode power converters for energy transformation and power distribution. Specifically, power distribution in aircraft, vehicular systems large ships, and even buildings require modular and efficient high bandwidth power devices to satisfy critical system requirements on flexibility of control, high power density, as well as robustness with respect to outages and component failures. The measure taken for fault current limiting using increased DC inductance and reduced DC capacitance can further tense up the instability problem along with considerable distribution length, which has rarely been investigated before. And the stabilization of a more expanded DC system, typically up to a few kilometers, with autonomous variable load has rarely been explored with DC protection simultaneously considered. In this paper, a systematic view on protection, stability control and converter design is taken to enable the application of medium power DC system with considerable distribution length. An adaptive stabilizer is proposed to compensate local negative impedance based on its own local detections hence no need for high bandwidth global information acquisition. The proposed adaptive control is also independent from both the constant power terminal and the grid side conditions, and the flexibility of being able to incorporate into CPL terminal control if required.

II. ACTIVE DISTRIBUTION POWER SYSTEM

The increasing quantities of Distributed Energy Resources (DERs), often based on Renewable Energy Source (RES), but also the ageing infrastructure, the increasing consciousness of environmental issues, the rising energy costs, the regulatory pressure, the growing demand of energy and the rapid innovations in technology are both drivers and challenges for the distribution business. Therefore, a Smart Grid is fundamental for a sustainable energy future, because it is capable of addressing all the challenges previously mentioned. An important step towards this new electric system model is the concept of the Active Distribution Networks (ADNs). The above-mentioned revolution in the power system, that is the increasing quantities of DER (RES, batteries and loads), but also the ageing assets and lack of circuit capacity (that requires high capital costs for replacement/reinforcement), but also the limitation previously stated before require more active approach of planning and managing distribution networks. The possibility to better integrate the RES in the Distribution Network is given by the ADN. ADN would be considered by most to be under the Smart Grids umbrella term, but instead of the term Smart Grid, widely used in the industry associated with the development of different applications around a newly integrated information technologies layer to the power system, applied to both transmission and distribution networks, ADN is totally related to distribution networks.

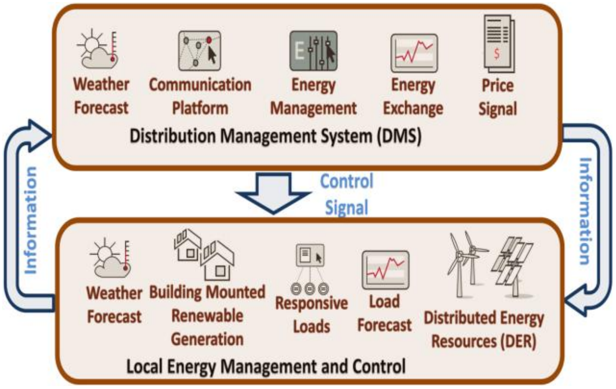


Fig.1.Different entities of active distribution system (ADS).

There are several ways to implement ADNs. They range from the innovative standalone operation of a single network element (e.g., On-Load Tap Changer, OLTC, on the transformer or voltage regulator relay) without the need of remote communications to the extensive use of the latter (i.e., ICT infrastructure), in order to manage network elements and participants/actors altogether, according to the corresponding application of the scheme. In order to exploit the full potential of ADS and obtain mentioned goals, different applications are needed for DMS.. Examples of required application or data exchange are weather and load forecast, possibility of energy exchange, price signal to end-user and communication platform. Fig.1 shows different components of ADS and their relationship. As it is shown, information flow is bidirectional and local energy management and control is an essential part of ADS. With the increasing penetration of renewable generation on the distribution power system, the growing intermittent power could potentially give rise to over-voltage or under-voltage at the "last-mile" feeders of a distribution power system. Medium power DC links can therefore be placed in between these weak feeders to improve their voltage profile and provide more flexible power flow regulations as is shown in Fig 2. As the possible increasing load demand of EV charging may arouse further load mismatching, one option is to integrate the charging station (and other renewable generations) on the DC link side as shown in Fig. 2. In this way the charging load flow and intermittent renewable power can be managed in a more flexible way. Such a system could further benefit from emergency power supply from the charging station along with renewable sources when there is an outage on the AC utility grid side. For a multi-terminal DC network within an active distribution power system, the AC/DC converters may be located some distance away from the loads including CPL (e.g. charging station) and for economical reasons existing overhead line paths may be used for DC distribution.

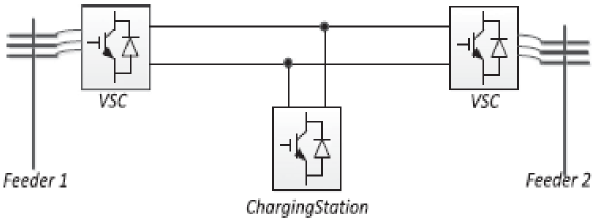


Fig.2. DC network in an active distribution power system.

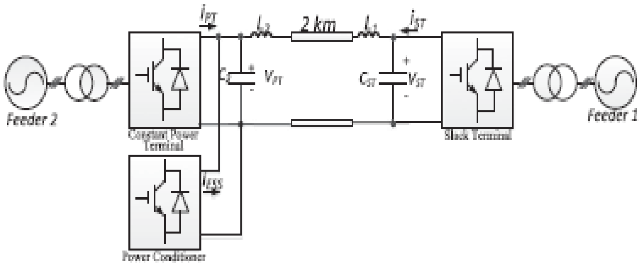


Fig.3. Sample system with single power terminal and conditioner.

As a result, possible DC fault has to be considered. Protecting the converters from DC faults and, meanwhile, ensuring DC system stability when there is considerable distance between the loads and AC/DC converters have to be dealt with. Reduced DC capacitances with extra impedance on the DC terminal can effectively reduce the DC fault current. However, such arrangements can potentially cause system instability especially when connecting to a remote constant power terminal. To tackle this problem, an adaptive DC power stabilizer is proposed for stabilizing the DC power system with small DC capacitance and additional DC terminal impedance. In this section, the dynamic effect brought by the extra impedance for DC fault current limiting is analyzed first to show how the FCL configuration can deteriorate system stability when there is CPL in operation. Based on the analysis, an adaptive DC power stabilizer is then proposed and installed at the CPL terminal to avoid potential system instability. A single constant power terminal based DC power network is established as shown in Fig. 3. Two-level VSCs and additional DC impedances for extra fault limiting capability are employed to integrate the DC system to the AC utility grid.

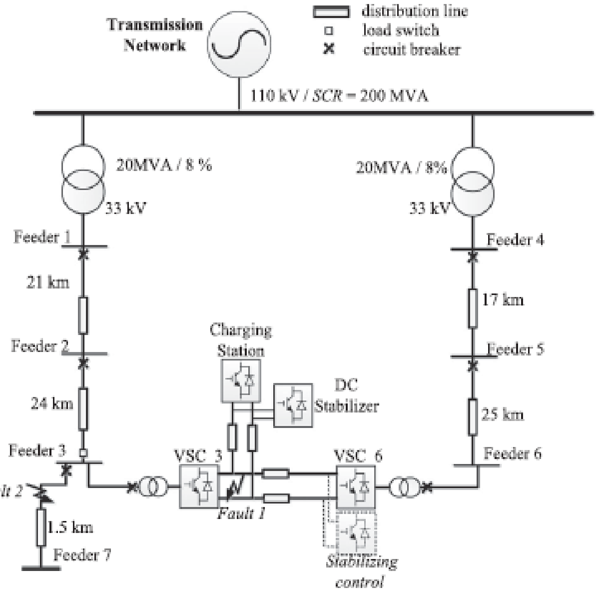


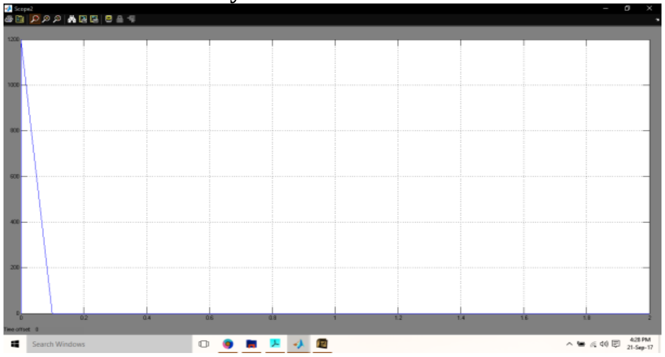
Fig.4. Active distribution power system configuration.

To further examine the effectiveness of the DC current limiting capability and stability enhancement of the proposed system configuration and power stabilizer concept, a 7-feeder active distribution power system is established as Fig.4 shows with its parameters. One VSC operates as the constant power terminal and the other is the slack terminal controlling the DC voltage. The distance between the two converters is 2 km. A small DC–DC converter with super capacitor based energy storage system (ESS) is placed at the constant power terminal side as the power stabilizer. A three-terminal medium power DC network is inserted between Feeder 3 and Feeder 6 with an EV charging station incorporated. VSC 6 (at Feeder 6) is designed to be the main constant power terminal within the DC power system whose internal control is typically accessible by the system operator for illustration. On the other hand, a charging station is incorporated in the DC system operating as an inaccessible/independent constant power terminal. VSC 3 operates as the slack terminal throughout the tests in this section. A virtual DC stabilizer is incorporated within the accessible constant power terminal side (i.e. VSC 6) as shown by the dotted diagram in Fig.4 and an actual DC stabilizer is installed at the inaccessible power terminal of the charging station in Fig.4. All the DC terminals are designed with extra fault limit capability and the charging station is assumed to be able to isolate the DC fault current with galvanic isolated topology.

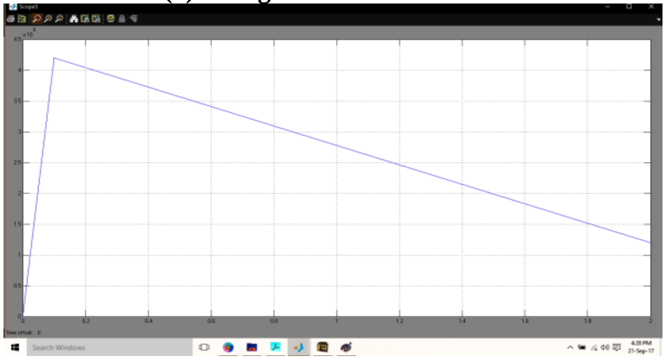
III. SIMULATION RESULTS

The effect of the current limiting method and the proposed stabilizer on DC fault current and stability enhancement are validated by simulation studies using a simple two-converter DC network and a multi terminal DC network in an active distribution power system.

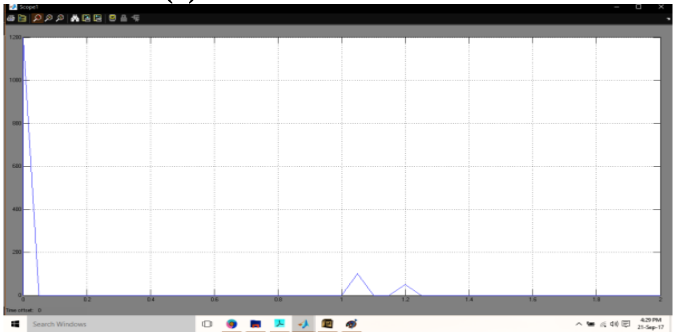
Case A: Simulation Diagram Of Dc Network In An Active Distribution Power System



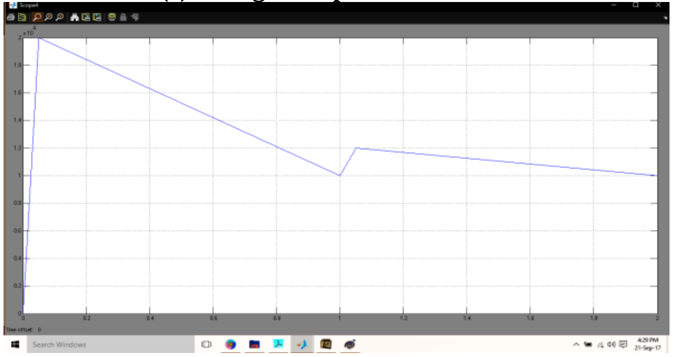
(a) voltage of a slack terminal



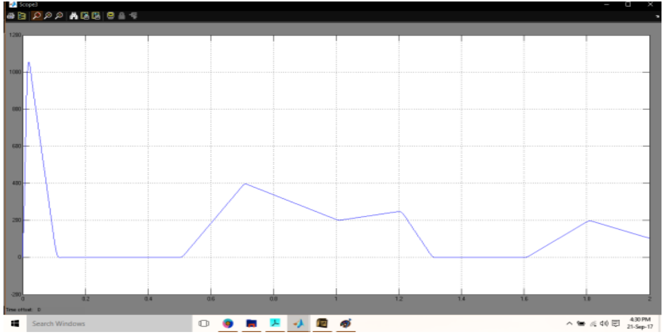
(b) current of a slack terminal



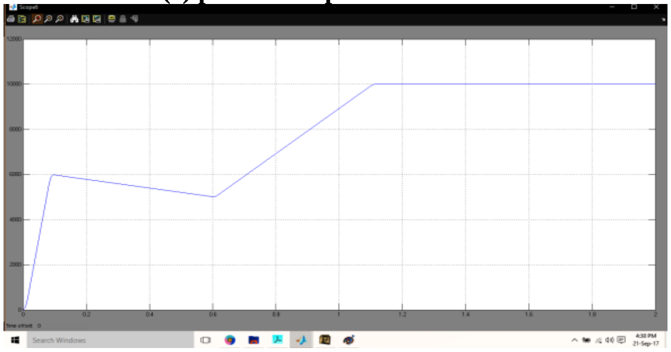
(c) voltage of a power terminal



(d) current of a power terminal



(e) power of a power terminal

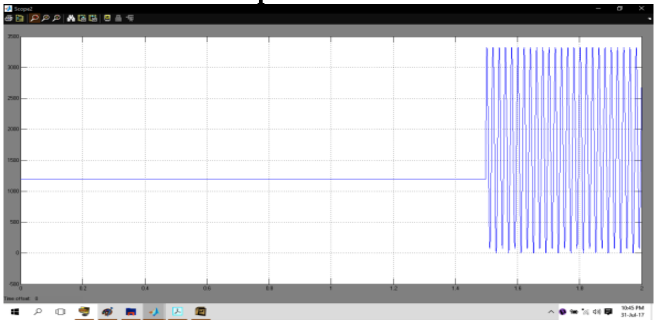


(f) current of a power terminal

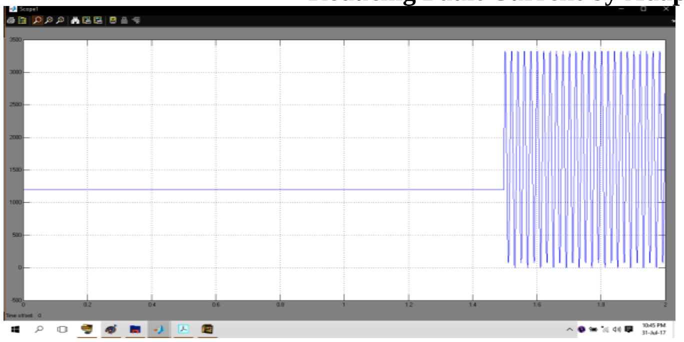
Fig.5. System performance with dc network in an active distribution power system,(a)V_{ST} (b) I_{ST} (c) V_{PT} (d)I_{PT} (e) P_{PT} (f) I_{PT}.

The DC fault behavior is depicted in Fig. 5 where the DC fault occurs at *t* = 0 ms. No current limiting measure is taken and the IGBTs are assumed to be blocked immediately after the fault. As a result the DC voltage *V*dc drops to 0 and the fault current *i*LDC reaches as much in less than 1 millisecond. This peak current is mainly produced by the discharging of the terminal capacitor. The discharging current in Stage 1 and the subsequent circulating current in Stage 2 are the main fault current components after the fault. This is due to the fact that a smaller terminal capacitance has reduced the total capacitor discharging energy at Stage 1 shown in Fig. 5. The fault current decays and circulates through the diodes after the DC voltage reaches 0. The extra inductance further reduces the fault current rising rate during stage 1 and the peak discharging current has been suppressed to less than 4 p.u. when the DC voltage drops to 0.

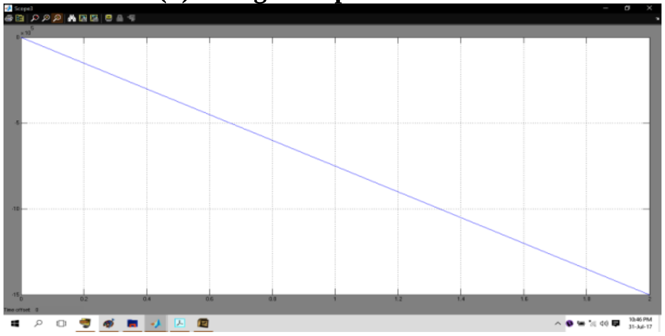
Case B: Simulation Diagram of Single Constant Power Terminal Without Adaptive Power Stabilizer



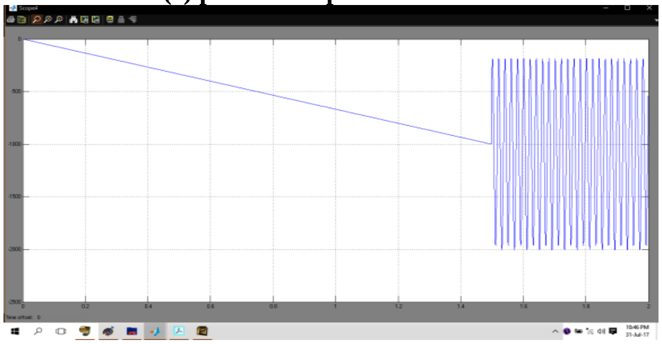
(a) voltage of a slack terminal



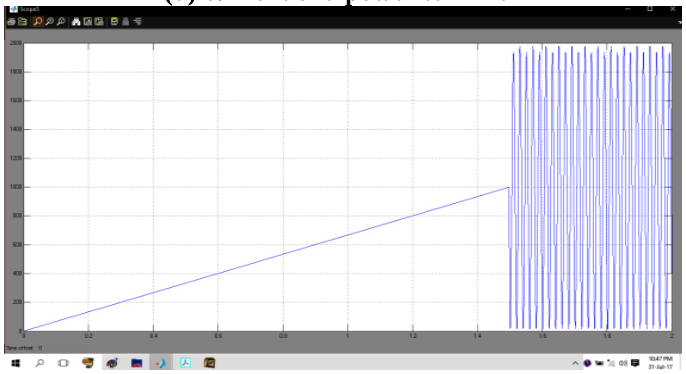
(b) voltage of a power terminal



(c) power of a power terminal



(d) current of a power terminal

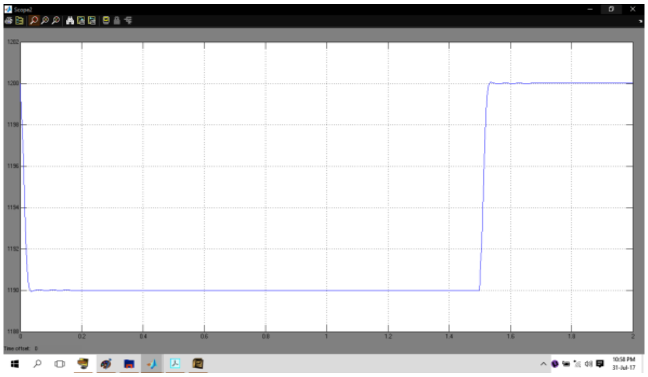


(e) current of a slack terminal

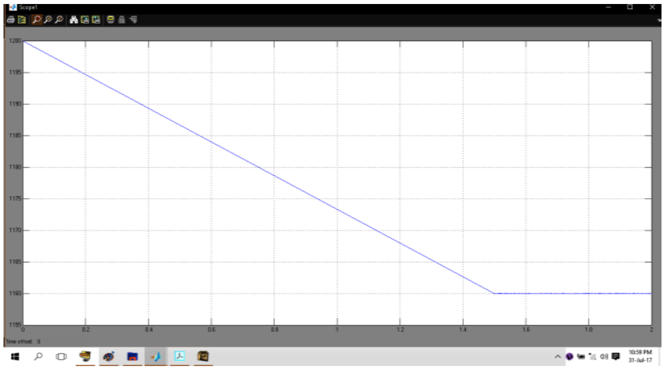
Fig.6. System performance with single constant power terminal without adaptive power stabilizer,(a)V_{ST} (b)V_{PT} (c)P_{PT} (d)I_{PT} (e)I_{ST}.

By deactivating the power stabilizer, the system is tested with a defined power ramp from the constant power terminal. The simulation results are shown in Fig.6. It can be seen that when the power terminal starts to drain power from the DC network, the current are balanced by the slack terminal accordingly.

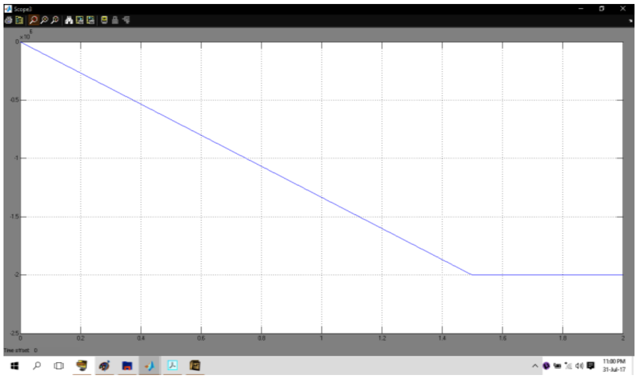
Case C: Simulation Diagram Of Single Constant Power Terminal With Adaptive Power Stabilizer



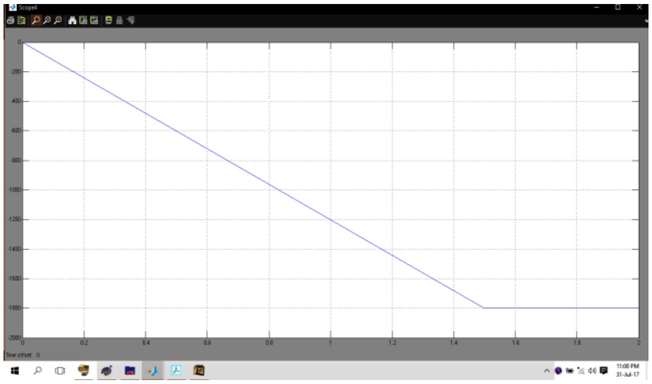
(a) voltage of a slack terminal



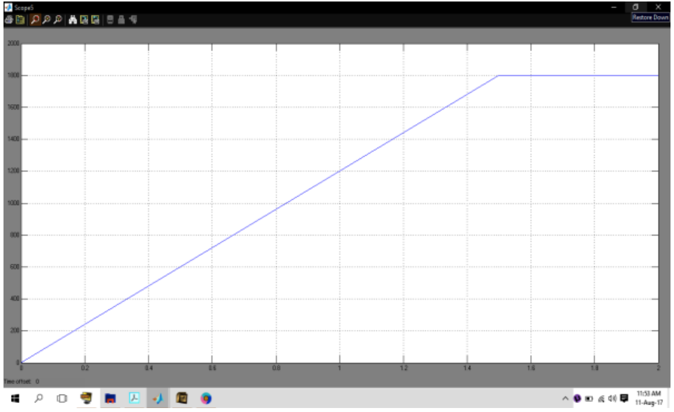
(b) voltage of a power terminal



(c) power of a power terminal



(d) current of a power terminal



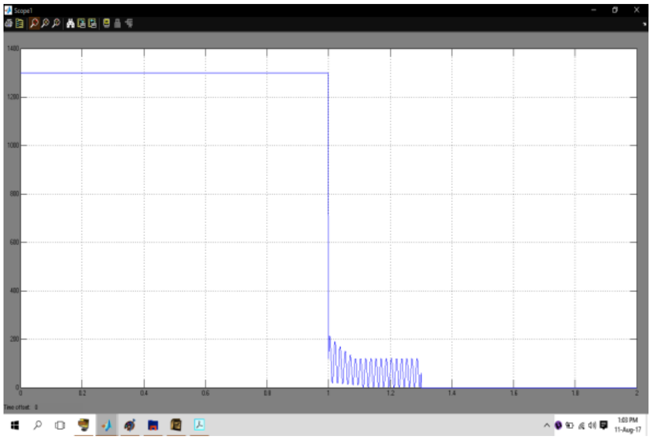
(e) current of a slack terminal

(f) battery storage system

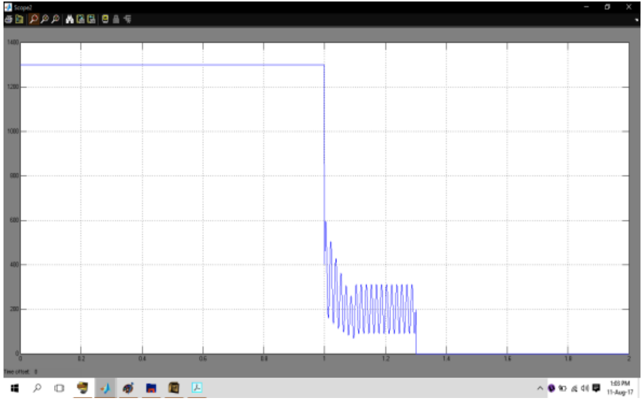
Fig.7. System performance with single constant power terminal without adaptive power stabilizer,(a)V_{ST} (b)V_{PT} (c)P_{PT} (d)I_{PT} (e)I_{ST} (f)I_{ESS}.

On the contrary shown in Fig.7, the DC stabilizer is activated and the power ramp of the constant power terminal The DC voltages are well regulated throughout. The power stabilizer only consumes 50 A at its peak, which is less than 3% of the rated current of the constant power terminal and gradually drops to zero after the ramp indicating only a small energy and power rating is required for the storage.

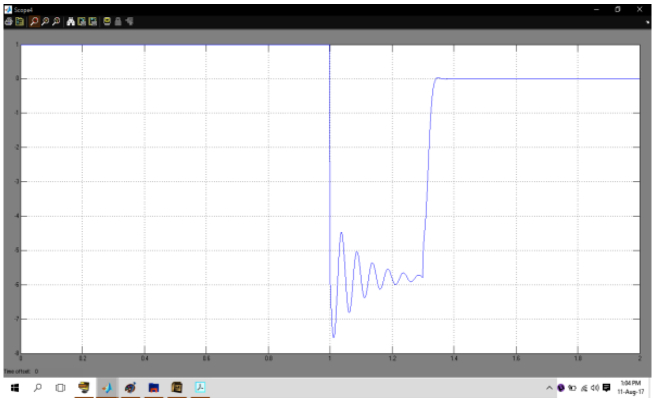
Case D: Simulation Diagram Of Dc Fault Behavior At VSC3



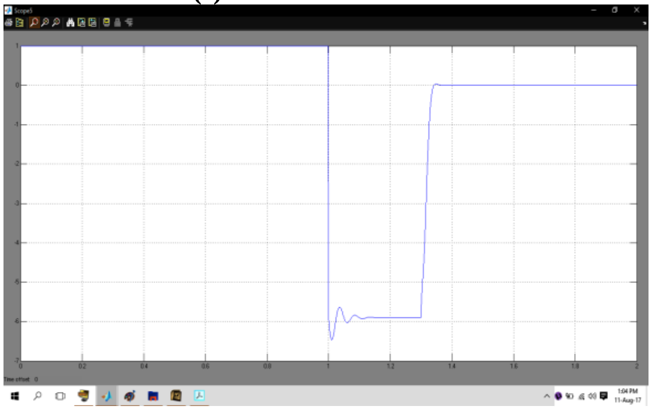
(a) DC voltage at VSC3



(b) DC voltage at VSC6

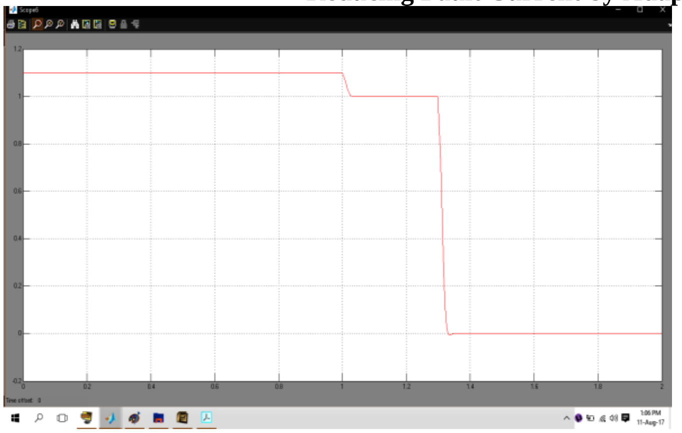


(c) DC current at VSC3

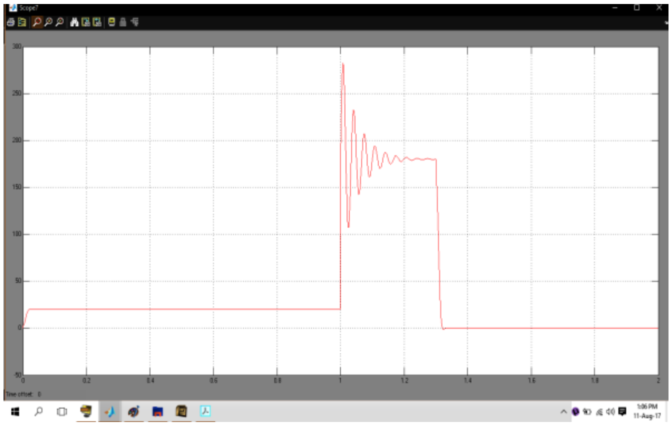


(d) DC current at VSC6

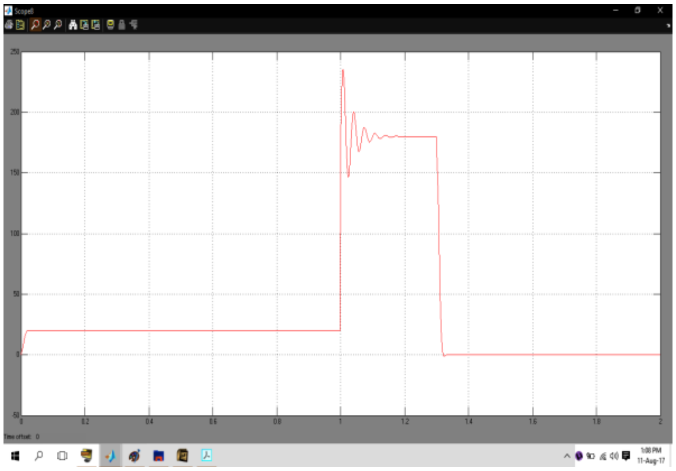
(e) AC voltage at VSC3



(f) AC voltage at VSC6



(g) AC current at VSC3

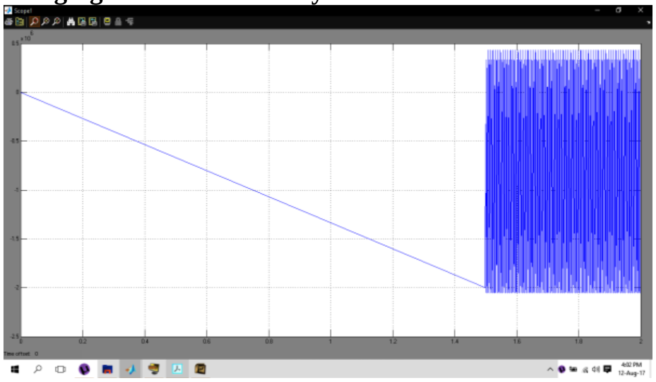


(h) AC current at VSC3

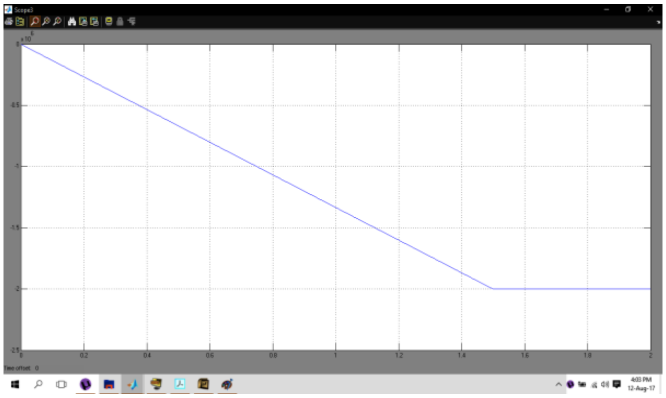
Fig.8. DC fault behavior at VSC3. (a)V_{DC3} (b)V_{DC6} (c)I_{fDC3} (d)I_{fDC6} (e)V_{AC3} (f)V_{AC6} (g)I_{AC3} (h)I_{AC6}.

Fig8 shows the DC fault behavior at VSC 3 which connects to Feeder 3. The system starts with VSC 6 importing a ramp power of the DC network and the charging station is idle. The circuit breakers at the AC sides of the VSC 3 and 6 are tripped to break the DC fault. As a result, the fault currents at both AC and DC sides are gradually extinguished and DC network is de-energized.

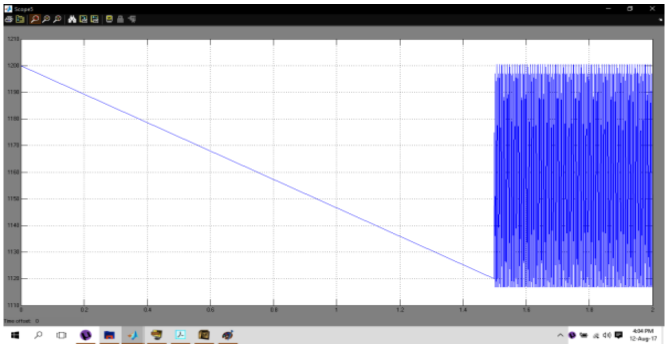
Case E: Simulation Diagram of Single Stabilizer Performance At The Charging Station With Ramp Charging Load Without Any Stabilizer



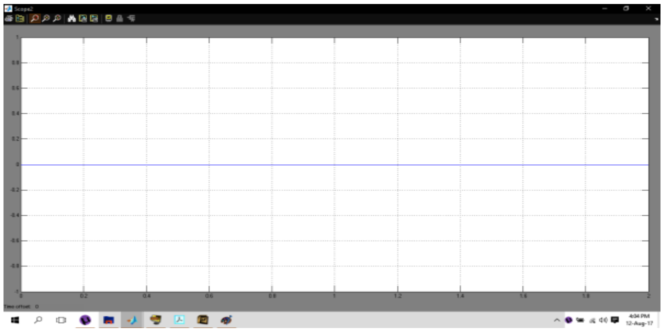
(a) P_{DC3}(power consumed by VSC 3)



(b) P_{Charg}(power discharged from the charging station)



(c) V_{DC}(DC voltage at the charging station bus)

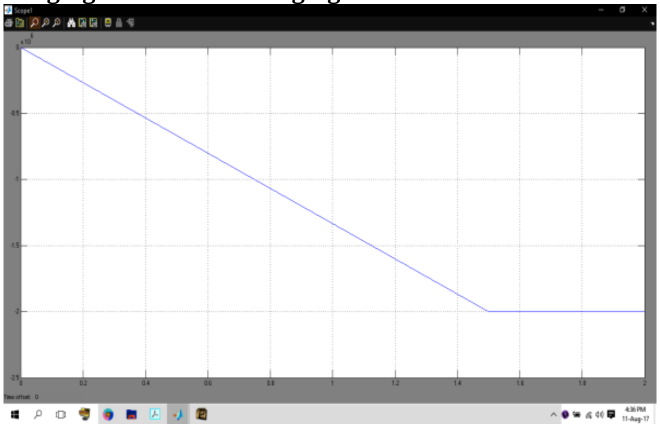


(d) P_{Cond} (power discharged by the DC stabilizer)

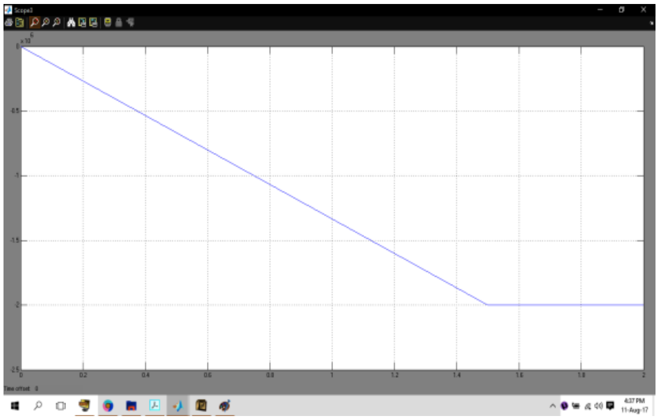
Fig.9. Single stabilizer performance at the charging station with ramp charging load without any stabilizer.

In Fig9, both the stabilizing control in VSC 6 and the charging station are deactivated. A ramp load of 0.5 MW/s is consumed at the charging station from T = 0 s till it reaches its full rating of 2 MW and the power is fully accommodated by VSC 3 as VSC 6 is given zero power order. It can be seen that when the charging power rise up to 1.9 MW, the DC system starts to oscillate. This demonstrates the superiority of the DC link over the AC link, as it does not reduce the equivalent short circuit impedance whereas the additional AC connection does.

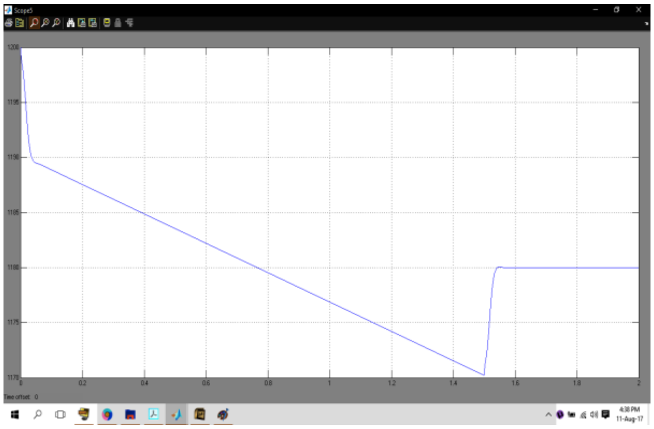
Case F: Simulation Diagram of Single Stabilizer Performance At The Charging Station With Ramp Charging Load With Charging Stabilizer



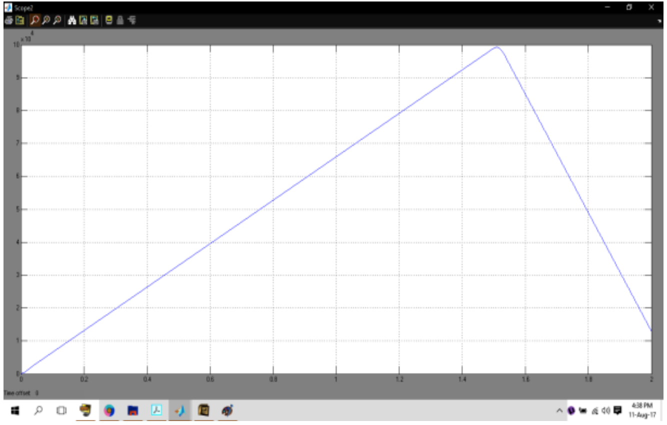
(a) P_{DC3}(power consumed by VSC 3)



(b) P_{Charg}(power discharged from the charging station)



(c) V_{DC}(DC voltage at the charging station bus)

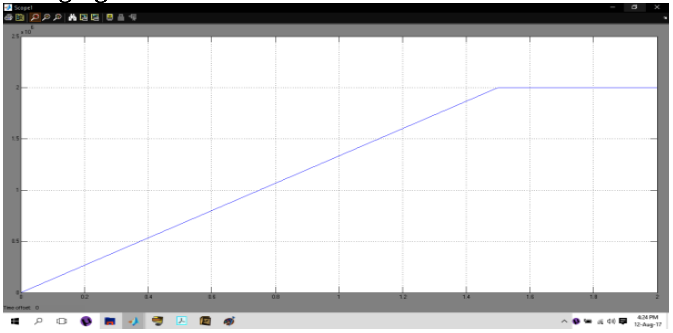


(d) P_{Cond} (power discharged by the DC stabilizer)

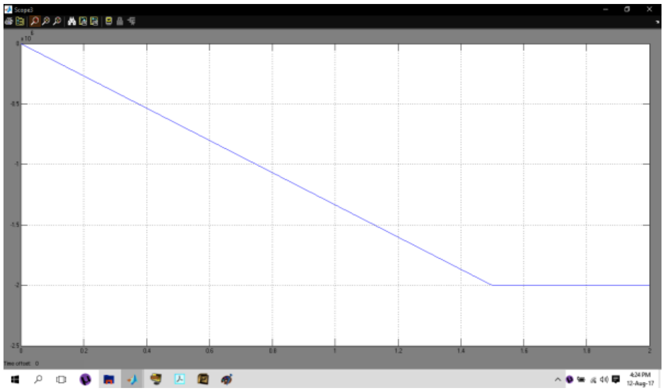
Fig.10. Single stabilizer performance at the charging station with ramp charging load with charging stabilizer.

On the contrary, the ramp charging load test is performed in Fig. 10 with charging side stabilizer activated. It can be seen that no oscillation is induced throughout this test. The maximum power shared by the stabilizer is less than which is 5% of the load rating. The stabilizing power gradually moves towards, since the stabilizer function only provides dynamic response due to the addition of the high-pass filter design. The proposed stabilizers can effectively eliminate undesirable oscillations caused by additional DC side impedance and constant power load in medium power DC network of an active distribution power system.

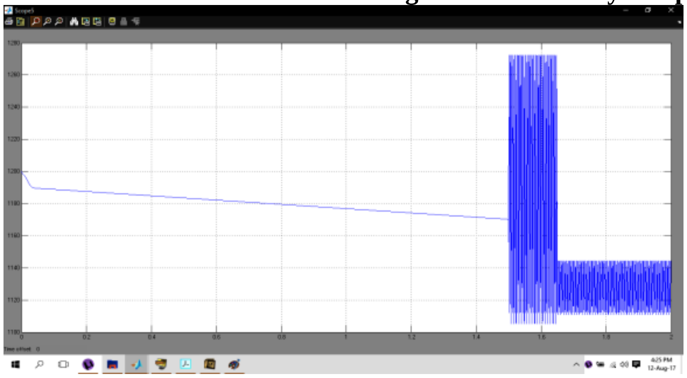
Case G: Simulation Diagram Of Dual Stabilizer Performance With Power Ramp At Vsc 6 With Only Charging Stabilizer



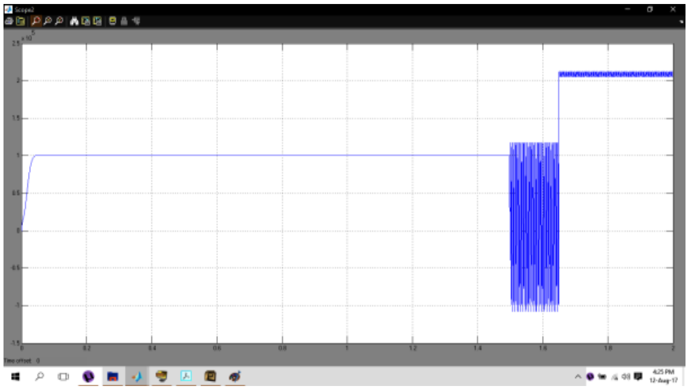
(a) P_{DC6} (power consumed by VSC 6)



(b) P_{Charg} (power discharged from the charging station)



(c) V_{DC} (DC voltage at the charging station bus)

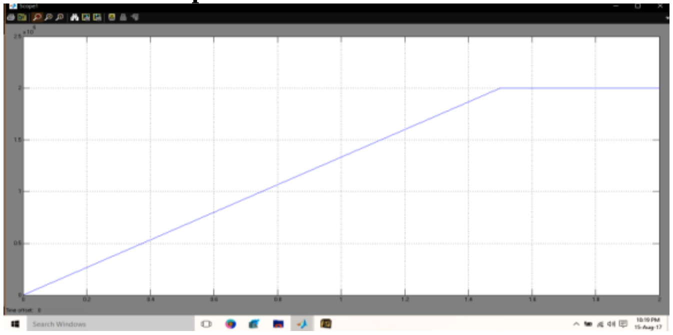


(d) P_{Cond} (power discharged by the stabilizer)

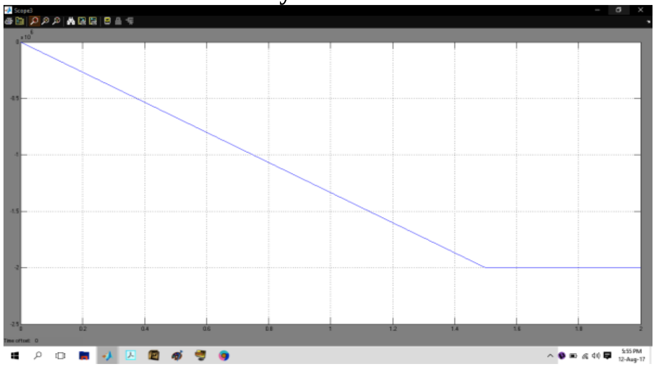
Fig.11. Dual stabilizer performance with power ramp at VSC 6 with only charging stabilizer.

As shown in Fig11 significant voltage oscillation is induced when the VSC 6 load increases to approximately 1.9MW. The maximum power of the actual stabilizer is only 0.01 MW (when system stable) indicating that the remote power terminal and its additional stabilizing control has negligible effect on the stabilizer at the charging station side. This result shows that the proposed stabilizer is not sensitive to remote variations. The required power rating of the stabilizer is very small compared to the power rating of the system and thus the additional cost of the stabilizer is trivial compared to the overall system cost. In addition, this allows the adoption of simple fault current limiting method using additional DC inductance and reduced DC capacitance.

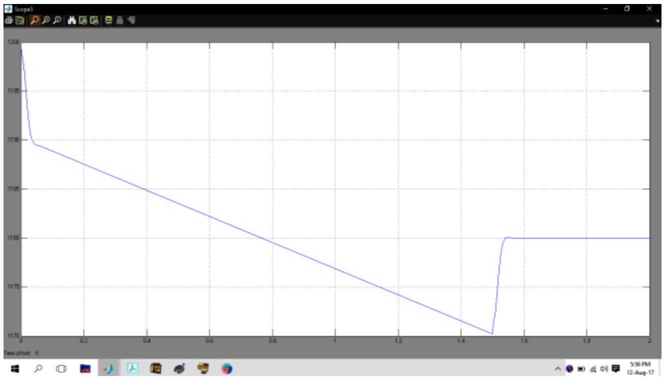
CaseH:Simulation Diagram of Dual Stabilizer Performance With Power Ramp At Vsc 6 With Both Stabilizers



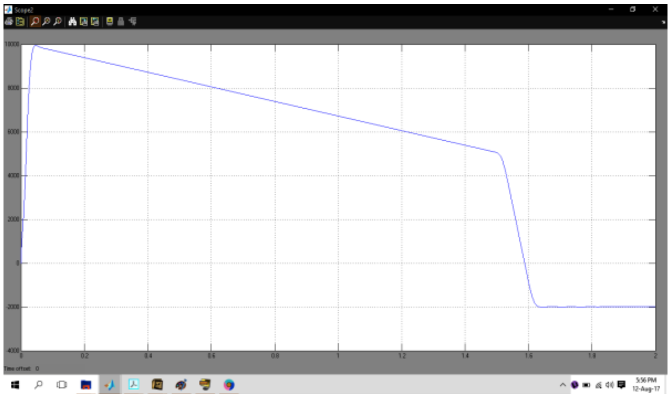
(a) P_{DC6} (power consumed by VSC 6)



(b) P_{Charg} (power discharged from the charging station)



(c) V_{DC} (DC voltage at the charging station bus)



(d) P_{Cond} (power discharged by the stabilizer)

Fig.12. Dual stabilizer performance with power ramp at VSC 6 with both stabilizers.

However, when the stabilizing control is activated the oscillation is eliminated and system is completely stable across the whole power range, as can be seen in Fig. 12. In order to effectively stabilize the DC power system, real and/or virtual stabilizers need to be located close to the CPL. It can also be seen that the stabilizer (either physical or virtual) can effectively neutralize instability effect though; it has very little effect on the remote constant power terminal and vice versa.

IV. CONCLUSION

A medium power DC system solution considering DC fault current limiting and stability for active distribution power system has been investigated. By replacing the normal open switch with a DC link, the distribution network achieves improved power distribution control and load ability without increasing AC fault current. Increasing DC inductance and reducing DC capacitance of the DC terminals can effectively reduce VSCs' peak fault current, current rising rate and accumulated diode I^2t before fault current interruption. However, this technique can give rise to instability when there are large CPL terminals within the medium power DC system due to the amplification of CPL's negative impact on small-signal stability by the additional DC inductance and reduced DC capacitance. To overcome the adverse effect on stability and alleviate sensitivity to system operational conditions, an adaptive DC stabilizer with limited power rating requirement is proposed which can either be placed close to the inaccessible CPL terminal or with its control function embedded into an accessible CPL control as a virtual stabilizer. The proposed DC stabilization scheme requires only local measurements and enables the use of simple fault current limiting methods by effectively stabilizing a DC system of considerable distribution length. The stabilizing control has been validated by simulations of a two-terminal DC system and a multi-terminal DC system in an active distribution network.

V. REFERENCES

[1] K. Kurohane, T. Senjyu, A. Uehara, A. Yona, T. Funabashi, and C.-H. Kim, “A hybrid smart AC/DC power system,” in Proc. IEEE 5th Conf. Ind. Electron. Appl., Jun. 15–17, 2010, pp. 764–769.

[2] P. Goli and W. Shireen, “PV integrated smart charging of PHEVs based on DC link voltage sensing,” IEEE Trans. Smart Grid, vol. 5, no. 3, pp. 1421–1428, May 2014.

[3] J. Yu, M. Xiao, and G. G. Karady, “Dynamic performance of embedded HVDC with frequency control strategy,” in Proc. IEEE Power & Energy Soc. General Meeting, Denver, CO, USA, 2015.

[4] J.Alcala,V. Cardenas, J. Perez-Ramirez, R. J. Betancourt, andH.Miranda, “Improving power flow in transformers using a BTB converter to balance low voltage feeders,” in Proc. IEEE Energy Convers. Congr. Expo., Sep. 15–20, 2012, pp. 2038–2044.

[5] H.Kakigano,Y. Miura, and T. Ise, “Low-voltage bipolar-type dc microgrid for super high quality distribution,” IEEE Trans. Power Electron., vol. 25, no. 12, pp. 3066–3075, Dec. 2010.

[6] D. Salomonsson, L. Soder, and A. Sannino, “An adaptive control system for a dc microgrid for data centers,” IEEE Trans. Ind. Appl., vol. 44, no. 6, pp. 1910–1917, Nov./Dec. 2008.

[7] D. Chen and L. Xu, “Autonomous dc voltage control of a dc microgrid with multiple slack terminals,” IEEE Trans. Power Syst., vol. 27, no. 4, pp. 1897–1905, Nov. 2012.

[8] X. Lu, J. Guerrero, K. Sun, and J. Vasquez, “An improved droop control method for dc microgrids based on low bandwidth communication with dc bus voltage restoration and enhanced current sharing accuracy,” IEEE Trans. Power Electron., vol. 29, no. 4, pp. 1800–1812, Nov. 2014.

[9] M. Barragan et al., “Operational benefits of multiterminal DC-links in active distribution networks,” in Proc. IEEE Power&Energy Soc.General Meeting, San Diego, CA, USA, Jul. 22–26, 2012.

[10] M. E. Baran and F. F.Wu, “Network reconfiguration in distribution system for loss reduction and load balancing,” IEEE Trans. Power Del., vol. 4, no. 2, pp. 1401–1407, Apr. 1989.

Author's Profile:-

T.Lakshmi Neelasree has received the B.Tech (Electrical and Electronics Engineering) degree from SVCE, Tirupati and persuing M.Tech (Electrical Power Systems) in CBIT, Proddatur, AP, India.

K.R.SivaPrasad has 10 years experience in teaching in Graduate and Post Graduate level and Presently working as Assistant Professor in department of EEE in CBIT, Proddatur, AP, India.

P.Nagarjuna has 8 years experience in teaching in Graduate and Post Graduate level and Presently working as Assistant Professor in department of EEE in CBIT, Proddatur, AP, India.