DOI: https://doi.org/10.24113/ijoscience.v3i5.54

Survey of Smart Grid Volt-VAR Optimization in Energy Distribution Networks

Syed Sanjar Ul Islam
Department of Power Electronics
Millennium Institute of Technology and Science
Bhopal, M.P., India
syedsanjar1709@gmail.com

Santosh Kumar Yadav
Department of Power Electronics
Millennium Institute of Technology and Science
Bhopal, M.P., India
santosh_en@rediffmail.com

***Abstract*-The electrical distribution networks across the world are witnessing a steady infusion of smart grid technologies into every aspect of their infrastructure and operations. Technologies such as Energy Management Systems (EMS), Distribution Management Systems (DMS) and Advanced Metering Infrastructure (AMI) have partially addressed the needs of the distribution networks for automation, control, monitoring and optimization. The present paper aims to study of a a novel smart grid adaptive solution for one of the well-known techniques typically employed for distribution network voltage and reactive power optimization called Volt-VAR Optimization (VVO).**

Keywords:-Energy Management System (EMS), Voltage VAR optimization (VVO), conservation of voltage reduction (CVR)

I. Introduction

Emerging smart grid technologies have made an incredible impact on power utilities/grid planner and end users. Smart grid technologies are promising to provide better solutions and better quality of service [1]. Rapid growths in the field of information and communication technology (ICT) are offering great opportunities to solve the problems quickly and secured manner [2]. Electrical power system has divided in to fallowing part mainly as generation, transmission, distribution and end users [3]. Distribution System has given less attention in compare to other areas. It needs more attention so that energy crises and quality of power can be improved. Energy saving in distribution network is one of the most essential concern for power engineers and researchers in recent. Technologies such as DMS, Energy Management System (EMS), and Reconfiguration of Distribution Network, Substation Automation (SA), CVR and Distribution Generations (DGs) have made significant impact on distribution networks to make the system more efficient, reliable and secure [4]. There are still numerous challenging problems such as high aggregate technical and commercial losses (AT&C), inefficient operation, unreliable and poor quality of services (QOS) are faced by distribution system operator (DSO) and customers. These problems are mainly due to rapid increase in load growth, mismatch load demand and generation ratio, unplanned distribution network and variety of load patterns [5]. Energy distribution systems are significantly affected by political, social and theft hindrance in developing countries. Distribution losses are mainly two types first is technical losses and other is non-technical losses. For complete analysis of the distribution system, it is essential to observe the distribution network at the end of line (EOL) within the concept of smart grid. Distribution network optimization is one of the prime tasks for electric power utilities to deal with new smart distribution grid systems. Hence, in order to optimize such distribution grids utilities are adopting more efficient technique such as Voltage VAR optimization (VVO) and conservation of voltage reduction (R) [6]. Synchronization of CVR and VAR optimization makes a complete VVO system. VVO is a commercially accessible technology that includes the benefits of Conservation Voltage reduction (CVR) techniques and VAR optimization [7].VVO/CVR technology has ability to improve the energy efficiency at the distribution level and lower the system losses by conservation of voltage and reducing the load demand of the end-uses.

II. Literature Review

Shailendra Singh et al. [1], Volt-Var Optimization (VVO) is a renovated smart grid technology that utilized the advance smart grid assets such as Advance Metering Infrastructure (AMI), Distribution Management System (DMS) and Advanced Communication System. VVO offers energy savings with associated reduction in greenhouse gas emission and other directly or indirectly benefits to customers and/or utilities. The main function of the VVO is to determine the operational setting of volt/var control devices, to minimize the system loss of the distribution network and switching operation of the On-load Tap Changer (OLTC), Automatic Voltage Regulator (AVR), and

Capacitor Banks (CBs). VVO is an advanced method that optimizes voltage and/or reactive power (VAR) of a distribution network based on predetermined aggregated feeder load profile. This paper presents a critical review of VVO/CVR technology with traditional and existing techniques in the era of smart grid. A Smart Volt-Var optimization engine also proposed for medium and low voltage distribution feeders.

Gungor, V et al. [2], it is known that structure and characteristics of each distribution feeder is unique. Hence, benefits resulted by CVR plans could be different from one feeder to another. CVR approach could also be determined according to the availability of VVCCs and load characteristics of a feeder. In general, CVR approaches are getting more sophisticated as new technologies and components emerge. One of the simplest CVR approaches in blind feeders can be done in the presence of substation LTC and feeder VR that are set by Line Drop Compensator (LDC) for end-of-line voltages. Another basic CVR technique that is on-site involves voltage regulation in one specific location of a feeder. In more sophisticated techniques, distribution automation control is used to determine the operating strategies of OLTC, VR, or in some cases CBs. This technique can operate without consumer feedback, or it can utilize feedback from termination points depending on the availability of measurement units at the end of line. Another applicable CVR technique is rule-based CVR that includes independent operation of VVCCs based on preconfigured settings that could be updated frequently by control center through SCADA.

Farhangi, H et al. [3], Particle swarm-based optimization technique has been applied for optimal coordination of DGs, and other Volt-VAR control devices such as LTC and feeder capacitors in. In [3], two optimization-based models have been proposed. Single-level optimization is employed for computing the maximum penetration level of DG and a bi-level optimization model is designed to evaluate the power value that a distribution system can transmit to network end-users. A study has stipulated that the recent smart grid initiatives have created growing interest in the deployment of more advanced VVC systems for efficiency improvement, demand reduction, and better overall asset utilization. Possible effects of smart grid actual functions on load tap changers of distribution transformer discussed. The abovementioned papers have focused on concepts such as: advantages, challenges and functional requirements of VVO in smart grids which could be considered as the early stages of smart grid-based VVO design. Thus, such reviews could assist in forming the basis for the smart grid-based Volt-VAR Optimization algorithms. Rahimi et al. [4], Research into control strategies, such as have identified decentralized control strategies as suitable for future VVO engines, but have not discussed these in detail. A real-time simulation of multi-agent systems for decentralized secondary voltage control in distribution network is presented in [6]. It uses a real-time digital simulator (RT-Lab) with a Java Agent Development framework (JADE) applied to model distributed systems. Moreover, a decentralized architecture for optimal voltage regulation in smart grids has been assessed in [7]. The study strives to define a decentralized architecture to compute the actual value of cost functions and to propose distributed cooperative optimization strategies result in optimal asset of the voltage controllers. Given the fact that these studies have only considered voltage, a comprehensive decentralized integrated solution for VVO is needed.

Hamed Ahmadi et al. [5], the prospect of large penetration of dispatch-able customer side resources (cogeneration loads), such as EV's, has also brought new challenges and opportunities to distribution networks. Although, system planners tend to demand new command and control strategies to accommodate and minimize the load impact of co-generations, others may regard the dispatch-able energy they provide as means to optimize the distribution service as a whole. Diverse research studies have reviewed the impact of EVs on distribution networks. Some have mainly focused on G2V (Grid to Vehicle) loading effect on distribution network, while others have proposed coordinated EV charging strategies to optimize the grid by minimizing the active power loss of the network individually. The foremost gap in research studies can be the shortcomings of studies encompassing the effects of EVs on a reliable VVO. Furthermore, new studies have proven the fact that new EV inverter technologies could provide reactive power injection (positive or negative injection (aka absorption)) opportunity for future grids.

III. BACKGROUND OF CVR/VVO TECHNOLOGY

CVR/VVO is not a new technology in the area of conservation of energy, the tests have been already performed in early of 1973. However, interest in CVR technique is increasing drastically because of rapid development in the field of smart grid technologies.

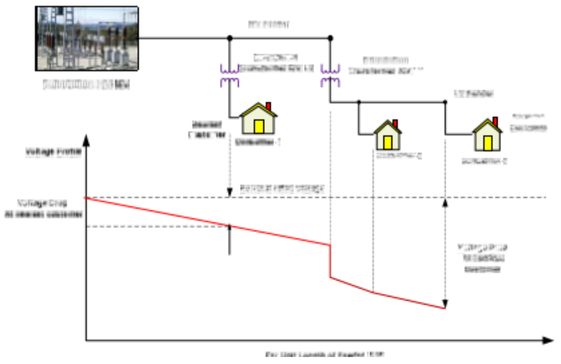

Figure 1: Voltage Profile along a Feeder Supplying Residential Loads

It is known that structure and characteristics of each distribution feeder is unique. Hence, benefits resulted by CVR plans could be different from one feeder to another. CVR approach could also be determined according to the availability of VVCCs and load characteristics of a feeder. In general, CVR approaches are getting more sophisticated as new technologies and components emerge. One of the simplest CVR approaches in blind feeders can be done in the presence of substation LTC and feeder VR that are set by Line Drop Compensator (LDC) for end-of-line voltages. Another basic CVR technique that is on-site involves voltage regulation in one specific location of a feeder. In more sophisticated techniques, distribution automation control is used to determine the operating strategies of OLTC, VR, or in some cases CBs. This technique can operate without consumer feedback, or it can utilize feedback from termination points depending on the availability of measurement units at the end of line. Another applicable CVR technique is rule-based CVR that includes independent operation of VVCCs based on preconfigured settings that could be updated frequently by control center through SCADA.

IV. SMART GRID FUNCTIONALITIES IN VVO

Few studies have just pursued the smart grid issues on VVO. Particle swarm-based optimization technique has been applied for optimal coordination of DGs, and other Volt-VAR control devices such as LTC and feeder capacitors in. In [3], two optimization-based models have been proposed. Single-level optimization is employed for computing the maximum penetration level of DG and a bi-level optimization model is designed to evaluate the power value that a distribution system can transmit to network end-users. A study [3] has stipulated that the recent smart grid initiatives have created growing interest in the deployment of more advanced VVC systems for efficiency improvement, demand reduction, and better overall asset utilization [4]. Possible effects of smart grid actual functions on load tap changers of distribution transformer discussed in. The abovementioned papers have focused on concepts such as: advantages, challenges and functional requirements of VVO in smart grids which could be considered as the early stages of smart grid-based VVO design. Thus, such reviews could assist in forming the basis for the smart grid-based Volt-VAR Optimization algorithms.

Research into control strategies, such as have identified decentralized control strategies as suitable for future VVO engines, but have not discussed these in detail. A real-time simulation of multi-agent systems for decentralized secondary voltage control in distribution network is presented in. It uses a real-time digital simulator (RT-Lab) with a Java Agent Development framework (JADE) applied to model distributed systems. Moreover, a decentralized architecture for optimal voltage regulation in smart grids has been assessed in [4]. The study strives to define a decentralized architecture to compute the actual value of cost functions and to propose distributed cooperative optimization strategies result in optimal asset of the voltage controllers. Given the fact that these studies have only considered voltage, a comprehensive decentralized integrated solution for VVO is needed.

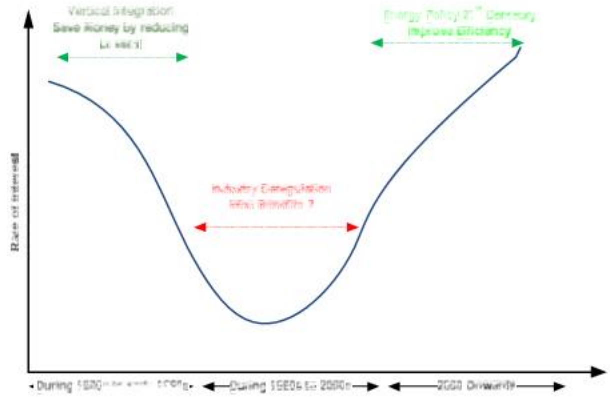

Figure 2: Interest Cycle of CVR\VVC [9]

From Figure 2, it can be observed that automated voltage var control (VVC) is a thought that has grasped the varying levels of interest over the years [9]. During the decade of 1980-90s, vertically integrated utilities have firstly examined that advanced VVC as an effective technique to reduce electrical demand losses and electrical losses in distribution system. After 1990's when deregulation of power system occurred, a serious issue raised that who will benefited from VVC saving. In many cases utilities were not benefited from the improvement of VVC because of savings in electrical losses were delivered to customers or absorbed by suppliers and load demand balanced by several forms of generation suppliers. So during this period of time the interest in deployment of VVC improvements fell down dramatically [9]. In recent scenario, smart grid era has focused on the need for improved efficiency, energy conservation and renewed attention in automated VVC as an effective technique to fulfil the smart grid objectives. Public Service Commission of New York and American Electric Power System (AEP) have established their first implementation of CVR in 1973. After that, numerous utilities such as BC Hydro [7], Dominion Virginia Power, Southern California Edison (SCE) [9], Hydro Quebec (HQ)[30].Bonneville Power Administration (BPA) [1] and Northwest Energy Efficiency Alliance (NEEA) implemented their CVR tests and gained significant results of energy savings related to voltage reduction[18]. By reducing 1% of feeder voltage, usually 0.3% to 1% load reduction is achieved. Recently, United States have deployed CVR technology to all distribution feeders and obtained 3.04% reduction in the annual national energy consumption [2]. CVR was also widely tested in other countries. Australia, Ireland has obtained 2.5% and 1.7% energy saving by reduction of 1% of voltage respectively

V. Smart Grid Adaptive VVO

Quasi real-time local measurements do not need to travel from the field to the back-office and the new settings for VVO assets are determined locally, rather than by a centralized controller. This approach, might lead to less AMI cost, better system reliability and faster optimization process.

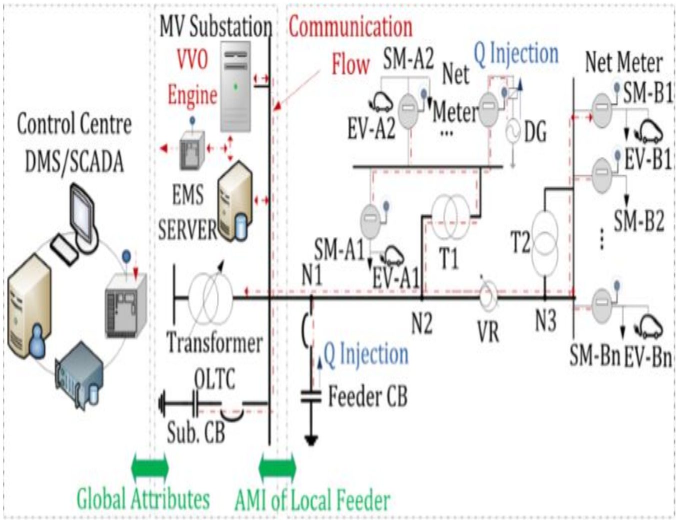

Figure 3: Basic Topology of Smartgrid adaptive VVO

Furthermore, this VVO strategy takes advantage of local dispatch-able energy sources such as V2G sources. Typically, local data that proposed VVO receives are active power, reactive power and voltages of system nodes. The global attributes that VVO engine receives from control center include, but not limited to weather forecast, calendar data, breaker's status, and feeder configuration.

This technique consists of a quasi-real-time smart grid-based VVO engine that can readily control VVO in an integrated way through a DCC structure. Here, VVO engine tries to find the optimal setting of the abovementioned assets through system main variables.

VI. Conclusion

In order to improve Energy saving, efficiency, peak load demand reduction, voltage profile and power factor deployment of Smart Volt-Var Optimization Engine in distribution system provides better solution. Concept of CVR/VVO technology, centralized/decentralized VVO/CVR control methods with the application of most desirable assets such as AMI, DMS and distributed SCADA and optimization algorithms for VVO operation have been discussion.

REFERENCES

[1] Shailendra Singh and and S.P. Singh, “A Smart Volt-Var Optimization Engine for Energy Distribution System”, International Conference on Emerging Trends in Electrical, Electronics and Sustainable Energy Systems (ICETEESES–16) 978, 2016 IEE.

[2] Gungor, V. Cagri, D. Sahin, T. Kocak, S. Ergut, C.Buccella, C.Cecati, and G. P. Hancke. "A survey on smart grid potential applications and communication requirements.", IEEE Trans. on Industrial Informatics, vol. 9, no. 1, pp. 28-42, 2013.

[3] Farhangi, H., "A Road Map to Integration: Perspectives on Smart Grid Development," IEEE Power and Energy Magazine, vol.12, no.3, pp.52-66, May-June 2014.

[4] Rahimi, Saaed, M.Marinelli, and F.Silvestro."Evaluation of requirements for volt/var control and optimization function in distribution management systems." IEEE International conf. of Energy and Exhibition (ENERGYCON), pp. 331-336., 2012.

[5] Hamed Ahmadi, José R. Martí, Hermann W. Dommel, “A Framework for Volt-VAR Optimization in Distribution Systems,” IEEE Trans. on Smart Grid, vol.6, no.3, pp.1473-1483 may 2015.

[6] Rahimi, Saeed, Stefano Massucco, and Federico Silvestro. "Coordinated closed-loop voltage control by using a real-time Volt/VAR Optimization function for MV distribution Networks." 15th IEEE International Conference on Environment and Electrical Engineering (EEEIC), 2015, pp. 1222-1228. 2015.

[7] Dabic, V.; Cheong Siew; Peralta, J.; Acebedo, D., "BC Hydro's experience on Voltage VAR Optimization in distribution system," IEEE PES Transmission and Distribution Conference and Exposition, vol., no., pp.1,7, 19-22 April 2010.

[8] Dabic, Valentina, and D. Atanackovic. "Voltage VAR optimization real time closed loop deployment-BC Hydro

challenges and opportunities." IEEE Power & Energy Society General Meeting, vol., no, pp. 1-5. 2015.

[9] Manbachi, M.; Farhangi, H.; Palizban, A.; Arzanpour, S., "Predictive algorithm for Volt/VAR optimization of distribution networks using Neural Networks," Electrical and Computer Engineering (CCECE),2014 IEEE 27th Canadian Conference on, vol., no., pp.1,7, 4-7 May 2014.

[10] Uluski, R.W., "VVC in the Smart Grid era," IEEE Power and Energy Society General Meeting, vol., no., pp.1,7, 25-29 July 2010. [10] Schneider, K.P.; Weaver, T.F., "A Method for Evaluating VoltVAR Optimization Field Demonstrations," Smart Grid, IEEE Transactions on, vol.5, no.4, pp.1696, 1703, July 2014.

[11] Electric Distribution Systems, Sallam, A. Malik, O., Wiley-IEEE Press, 2011, ISBN: 9780470943854.

[12] Antonio P.-F, D. Q. Rodezno, and J. R. S. Mantovani, "Volt-VAR Multi objective Optimization to Peak-Load Relief and Energy Efficiency in Distribution Networks" IEEE Trans. on Power Delivery, vol. 30, no. 2, pp.618-626, April 2015.