Energy Savings in Distribution Network With Smart Grid-Enabled CVR and Distributed Generation

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***Abstract*— When conservation of voltage is applied aiming to the reduction in energy consumptions by lowering the voltage in such an effective and controlled manner so that it does not violate ANSI Standard C84 voltage limits known as Conservation of Voltage Reduction (CVR). However enabling of CVR with traditional methods is limited with voltage reduction range and without taking account of customer end voltage. This paper proposes a smart grid enabled CVR operation which considers the customer end voltage through advanced metering infrastructure (AMI) and controls the volt-var control (VVC) device settings of distribution feeder with the advance distribution management system (ADMS) and VVC server. An additional reactive power support has been injected through DGs during the deeper level of voltage reduction to maintain the feeder voltage profile within limits. The Effect of penetration of distributed generations during CVR operation is also being incorporated. IEEE 13 node test feeder of radial distribution network has been considered for analysis of CVR effect. The test system is modeled and simulated in Open distribution system simulator (OpenDSS) environment. From simulation results, it is observed that significant energy consumptions and peak load demand can be reduced with combined operation of smart grid enabled CVR and distributed generations with proper feeder voltage profile.**

Keywords*— *Smart Grids; Distribution System; Volt-Var control; CVR; Distributed Generation, OpenDSS

I. INTRODUCTION

CVR technology is being globally considered in the energy saving program. Outcomes of various pilot projects demonstrate that energy consumptions can be reduced annually to the extent of 1 to 3% with the deployment of advance CVR program [1]. According to IAE report that if United States deploys CVR technology national wide it could reduce two to three percentage wastage of energy which is approximately equivalent to fifteen million cars off of the road or reducing carbon emissions from about seven million houses annually [2].

Last thirty years lot of research work on CVR has been reported in the form of pilot projects, studies by various utilities and grid planners. During the decade of 1980-90s, the reduction of voltage for CVR operation is performed by traditional methods discussed in [3-6]. Conventional methods are load tap changer (LTC), Line drop compensation (LDC) and Home voltage reduction (HVR to reduce their peak power demand and yearly energy consumption [7]. Wide scale CVR implementation was not possible with traditional methods due to some hurdles such as lack of information about load end side, manually operated distribution assets and regulatory issues. In the 21st century, the interest rate has increased rapidly due to the implementation of energy policy structures and the emergence of smart grids [8]. Recently, United States have deployed CVR technology to all distribution feeders and obtained 3.04% reduction in the annual national energy consumption [1]. CVR was also widely tested in other countries. Australia, Ireland has achieved 2.5% and 1.7% energy saving by reduction of 1% of voltage respectively [9], [10].Research work reported in last decades can be classified in mainly three dimensions first is the validation of load modeling from field data have discussed in[11-12].Second is measurement and verification of CVR effect have well documented in [13-14]. The third one is the development of various heuristic optimization techniques to optimize the parameters of volt-var devices for CVR operation well documented in [15-16].

Integration of DGs in electrical power system especially in distribution network has increased rapidly in the current scenario. Benefits such as stand/backup power source, reactive power support, mitigation of power quality issues, maintain voltage profile, losses reduction and peak load reliefs are forced to power utilities to stepping up the functioning of DGs [17]. However, the integration of DGs in distribution network can reverse the direction of power resulting from huge impact variations in the power flow and feeder voltage profile [18]. This situation will take place because of control methods, and systems are planned to power flow from transmission to the loads. Various researches have been reported in last few years in the area of placement and sizing of DGs [19-20]. Methods reported in the literature for optimal placement of DGs for loss minimization and voltages flattening are sensitivity based analytical and intelligent algorithms. In this work combined effect of CVR with distributed generation on distribution network for the analysis, energy efficiency has been proposed. Few research works have been reported for the analysis of the impact of DG during CVR operation. Authors [17-18] have analyzed the placement of DG for active and reactive power support during CVR operation. Effect of DER penetrations with different levels during CVR implementation has been analyzed in [21-22].

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II. SMART GRID-ENABLED CVR

The fundamental concept of CVR is lowering the delivery voltage into the lower half of the tolerance band without affecting the performance of the end user's devices. However, while reducing the voltage, CVR should meet the international Standards ANSI C84.1–2006[23]. Smart grid-enabled CVR operation is equipped with smart grid assets such ADMS, AMI, smart Volt\Var optimization (VVO) controllers and advance information and communication technologies (ICTs). Proposed smart grid enabled CVR scheme is the combination of CVR server and Volt- Var control (VVC) processor with advance DMS server connected through IEC61850 communication link have shown in fig.1 [24]. CVR server is regularly monitoring and evaluating the voltage profile throughout the distribution network with advance DMS applications. Controlled parameters of different assets of distribution network are calculated with VVC server with the coordination of CVR server to achieve the best energy efficiency for customers on the circuit. Accurate load model is the one of the essential requirement for enabling the model to support CVR server. AMI data provide the foundation for the load model planning phase or real-time assessment of CVR effect.

CVR factor is used to measure the effect of CVR. In term of energy savings, CVR factor (kWh) is measured as the ratio of percentage of energy consumption reduction (ΔE %) to percent voltage reduction (ΔV %) [25]:

$$CVR_E = \frac{\%\Delta E}{\%\Delta V} \tag{1}$$

In term of active power demand, CVR factor (kW) is the ratio of percent of active power demand reduction (ΔP%) to percent voltage reduction

$$CVR_P = \frac{\%\Delta P}{\%\Delta V} \tag{2}$$

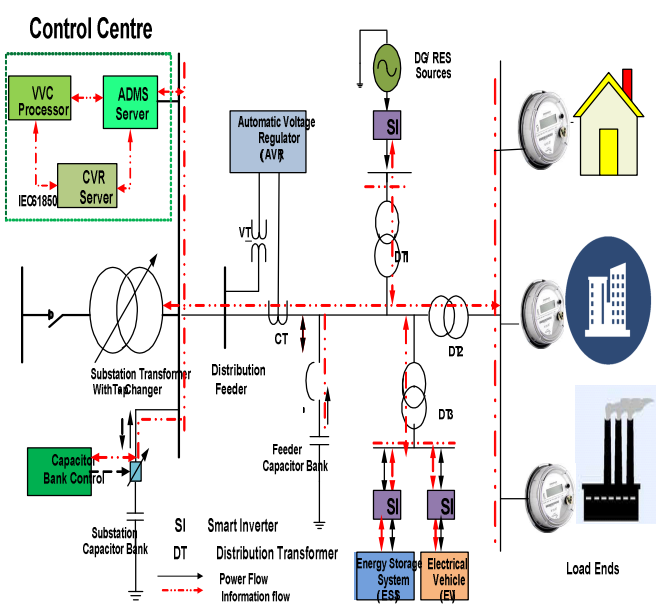

Fig.1. Substation based Smart Grid enabled CVR [24].

III. DISTRIBUTED GENERATION

Distributed generation is known as various names as distributed energy sources, onsite power generation source.etc. DGs broadly divided into two categories as renewable and non-renewable distributed generation. Further classification can be inverter type DG which operates at unity power factor generally, and other is synchronous or non-synchronous machine having 0.9 leading power factors [17]. Rapid development in this field of power electronics and control field it is quite possible that renewable DGs can provide not only active power, as well as reactive power support. Due to global popularity and the potential of fast controlling reactive power with fine-tuned var output, the grid-connected solar PVs with smart inverter considered as a DG source in this study. For performing power flow calculations, PV source considered as a PQ node with known value of real and reactive powers with their limits in below equations:

$$P_{DG,Min} \le P_{DG} \le P_{DG,Max} \tag{3}$$

$$Q_{DG,Min} \le Q_{DG} \le Q_{DG,Max} \tag{4}$$

$$P_{DG}^2 + Q_{DG}^2 \le S_{DG,rated}^2 \tag{5}$$

With the equations of (3), (4) and (5) power facility curve can be defined.

$$\left|Q_{DG}^{Inj}\right| \le Q_{DG,Max} = \sqrt{S_{DG,rated}^2 - P_{DG}^2} \tag{6}$$

It is quite possible to develop a variable solar DG VAr source (ΔQ^{Inj}_{DG}) model for voltage regulation. The injected reactive power (Q_{DG}^{Inj}) must satisfy the equation (6) and other constraints.

IV. DISTRIBUTION NETWORK MODELLING

Most of the distribution networks have the combination of untransposed line segments with unbalanced loading pattern. So, accurate modelling of all three phases of the feeder is necessary for close observation of distribution network. Modelling of distribution overhead and underground line segments is a crucial stage in the study of a distribution network. So, it is essential to consider the actual line phase and the accurate spacing between conductors. Voltages and currents equations belong to input node n, and output node m are developed by Applying Kirchhoff's current law (KCL) at node m and Kirchhoff's voltage law in the model. These fallowing equations are obtained and taken from [26].

$$[VLG_{abc}]_n = [a]\cdot[VLG_{abc}]_m + [b]\cdot[I_{abc}]_m \tag{7}$$

$$[a] = [u] + \frac{1}{2}[Z_{abc}].[Y_{abc}] \tag{8}$$

Where [u] is identity matrix,

$$[b] = [Z_{abc}] \tag{9}$$

$$[VLG_{abc}]_m = [a]^{-1}\cdot([VLG_{abc}]_n - [b]\cdot[I_{abc}]_m) \tag{10}$$

$$[I_{abc}]_n = [c]\cdot[VLG_{abc}]_m + [d]\cdot[I_{abc}]_m \tag{11}$$

$$[c] = [Yabc] + \frac{1}{4}\cdot[Yabc]\cdot[Z_{abc}]\cdot[Yabc] \tag{12}$$

$$[d]=[u]+\frac{1}{2}[Z_{abc}].[Y_{abc}] \quad (13)$$

Equation (7) & (11) can be rearranged in equation (14) as follows:

$$\begin{bmatrix} [VLG_{abc}]_n \\ [I_{abc}]_n \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} [VLG_{abc}]_m \\ [I_{abc}]_m \end{bmatrix} \quad (14)$$

A. Automatic Voltage Regulator(AVR):

In order to maintain acceptable voltage profile throughout the feeder end line, regulation of voltages plays an important role. Step type voltage regulators, load tap changing transformers (LTC) and shunt capacitors are commonly used for regulation of voltage. AVR is a step voltage regulator with the combination of an autotransformer and load tap changing mechanism. It can be modeled as a tap-changing autotransformer with very small series impedance and shunt admittance. The regulation in voltage is achieved by altering the taps of the series winding of the autotransformer. Generally, a standard AVR has 32 tap positions (*Tap*) excluding the nominal tap (tap zero) with reversible switch ±10% regulator range. The amount varies with per step is 0.625% or 0.75 Volt with 120V base. The effective regulation equation between Tap and regulator ratio (a_R) for type B AVR which is widely used for downstream feeders than type A is defined as follows:

$$a_R = 1 \mp 0.00625 \cdot Tap \quad (15)$$

Line Drop Compensator (LDC) Setting:

Control circuit usually governs by LDC for changing of taps on a regulator. The LDC setting that is most crucial is the value of R_2 and X_2 calibrated in volts. These values must represent the equivalent impedance from the regulation ratio the load center. *R* and *X* settings in ohms for LDC are shown in equation (16) as follows.

$$Rcomp_{\Omega} + jXcomp_{\Omega} = (Rline_{\Omega} + jXline_{\Omega}) \cdot \frac{CT_p}{N_{PT} \cdot CT_s} \Omega \quad (16)$$

The compensator *R* and *X* settings in volts are determined by multiplying the compensator *R* and *X* in ohms times the rated secondary current in amps (*CTs*) of the current transformer have shown in below equation (17):

$$R' + jX' = (Rcomp_{\Omega} + jXcomp_{\Omega}) \cdot CT_s \quad (17)$$

Equations (15), (16) & (17) are taken from ref [26]. Detail modelling of AVR and LDC are well documented in [26].

B. Capacitor Banks (CB):

The capacitor bank is the collection of switchable shunt capacitors. In order to control the operation of shunt capacitors, a capacitor controller is required. Generally, CB controller equipped with monitoring device such as CTs, PTs situated at the load side of the bus which is connected with CBs. Cap control device control takes samples of voltage and current through CTs & PTs at the monitored location. After that, it takes the decision whether the capacitor stakes should ON or OFF and what is the number of steps required based on selected type control criteria such as kVAR, power factor, voltage, current, or time of day at monitored devices[26]. Turn ON CB module switches when monitored line voltage is below 0.95p.u& turn OFF-CB module switch line voltage is above 1.05p.u. The following equation defines reactive power supply by CBs at each switching operation:

$$Q_{sc} = Nsw \cdot \Delta Q_{sc} \quad (18)$$

Where Q_{sc} is reactive power supplied by switched capacitors, Nsw is number of switching step, ΔQ_{SC} is step variation in reactive power.

C. Smart Inverter:

Smart inverter used for integration of PV panel generally known as PV inverter. The maximum reactive power ($Q_{,T,max}$) injection or absorption capacity for a period T can be defined as [27]:

$$Q_{T,Max} = \sqrt{S_{\max}^2 - P_T^2} \quad (19)$$

On the basis of active power produced (P_T) and apparent power rating of the inverter (S_{max}), it is recalculated at every Time period T. Functional operation of PV inverter is in two quadrants with five modes[21].

Mode1- Only active or real power (P), Q=0
Mode2- Active power, With Inductive Q power
Mode3- No active power (P=0), Only Inductive Q
Mode4- No active power (P=0), Only Capacitive Q
Mode5- Active power (P), Capacitive Q

Here, an inbuilt Inverter controller from Opendss [27] with intelligent VoltVar function is used while operating in mode 4&5.

D. End UserLoad Model.

Generally, customer loads are the combination of all loads. So here composite load model constant ZIP model have been considered for analysis of CVR effects. Constant ZIP load model is voltage dependent load model which is the mixer of constant impedance, constant current and constant power type load model. Voltage-dependent constant ZIP load model with total consumed real (P) and reactive (Q) power at point of interest have shown in below equations (20)-(21):

$$P = P_O \cdot [Z_P \cdot (\frac{V}{V_0})^2 + I_P \cdot (\frac{V}{V_0}) + P_P] \quad (20)$$

$$Q = Q_O \cdot [Z_q \cdot (\frac{V}{V_0})^2 + I_q \cdot (\frac{V}{V_0}) + P_q] \quad (21)$$

$$Z_P + I_P + P_P = 1 \quad (22)$$

$$Z_q + I_q + P_q = 1 \quad (23)$$

In equation (20-21) Zp, Ip, Pp & Zq, Iq, Pq are the constant parameters of impedance, current, power for real and reactive powers satisfying with equation (22-23) respectively. P_0 &Q_0 are the base power at nominal voltage (V_0).

TableI. ZIP Load Model Parameters

Loading Type	ZIP Coefficients[11]		Node No.
	[Zp, Ip, Pp]	[Zq, Iq, Pq]	
Residential	[0.85 -1.12 1.27]	[10.96 -18.73 8.77]	634,671, 611,652
Commercial	[0.4 -0.06 0.63]	[4.06 -6.65 3.59]	645,646, 692
Industrial	[0 0 1]	[0 0 1]	670, 675

E. Power Flow Algorithm

Conventional load flow methods such as Gauss-Seidal and Newton-Raphson are not suitable for distribution network because of most of the distribution feeders are radial with unbalanced loading pattern and untransposed lines. Due to fast convergence, the ladder iterative technique is widely used in the radial distribution network. Ladder iterative algorithm uses forward/backward sweeping technique. To determine the corresponding voltage and current backward sweep is applied to equations (7) & (11) while the forward sweep uses equation (10) to find the voltages in a distribution feeder. The sweeping process is repeated until the difference between the defined and calculated source voltage is below a defined tolerance limit.

V. SIMULATION AND RESULTS DISCUSSION

For assessment of CVR effect an IEEE, 13 node distribution test feeder with the voltage-dependent ZIP load model has been considered in this study. Fig.2 shows the test feeder model which consists 13 nodes, one online tap changer with AVR, two capacitor banks and additional power from PV distribution generations is feed from at nodes 684 and 692[28]. Modeling of the distribution network, controllers, PV system and load flow calculations has been carried out in OpenDSS platform which is developed by Electric Power Research Institute, USA [27].Test feeder is simulated in three modes with constant ZIP load throughout a typical day. Load profile curve has shown in fig.3. Simulation modes are explained below:

I. No- CVR Mode: In this mode test system is simulated with VVC devices in normal operation with the regulated voltage of 125V that is upper range of the service voltage. Simulated results are shown in table II.

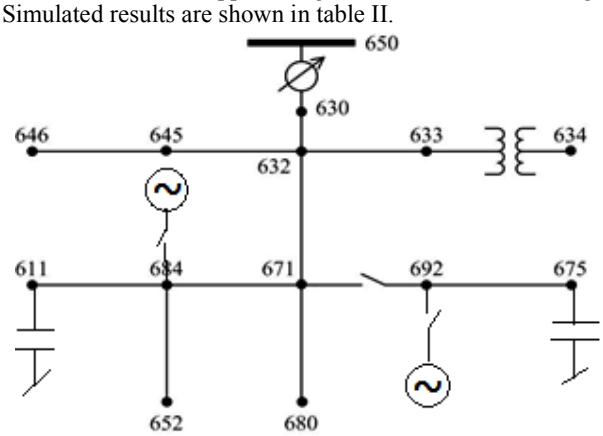

Fig.2. IEEE 13 node distribution test feeder [28]

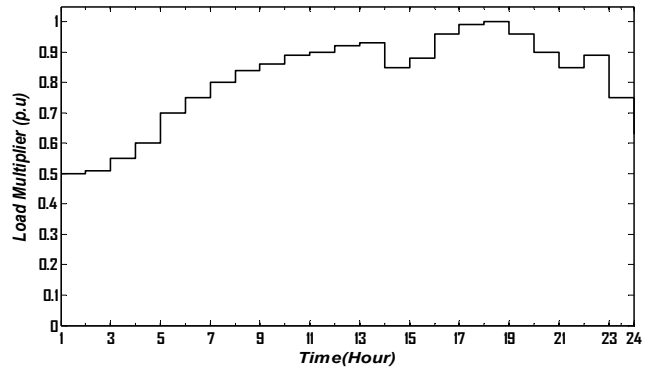

Fig.3. Forecasted Load Profile for a typical day.

II. Base CVR Mode: In this mode test system is simulated with VVC devices with CVR and operation is carrying out through LDC setting with different regulated voltages. Operation of CVR in this mode carried out in three cases as:

A. CVR at 120V Regulated Voltage ($V_{reg.}$)
B. CVR at 119V Regulated Voltage
C. CVR at 117V Regulated Voltage

Simulated Results have been shown in table II and demonstrate that significant energy consumption and peak load demand can be reduced with base CVR operations. Lowest node voltage profile throughout the feeder length during No-CVR and CVR operation has been shown in fig.4. From fig.4 it is observed that during higher CVR operations as below 120V regulated voltage, feeder voltage limits may violate. CVR operation during regulated voltage of 119,117V has crossed their minimum voltage limit at the load end. However, CVR operation at 120V regulated voltage is operating well with their limits.

Table.II Simulation Results for ZIP load model

Mode	Vreg	$E_{consuption}$ (kWh)	E_{losses} (KWh)	CVR Factor	
				CVR_P	CVR_E
No-CVR	125V	72606.19	1924.56	-	-
Base- CVR	120V	71388.12	1953.76	0.34	0.33
	119V	71222.44	1985.83	0.33	0.32
	117V	70536.92	2018.79	0.39	0.36
CVR With DG	119V	**69565.88**	**1807.83**	**0.74**	**0.70**
	117V	**68025.45**	**1744.65**	**0.72**	**0.79**

III. CVR with Distributed Generation Mode: During deeper voltage reduction level, feeder voltage profile limits are violating. Therefore, to maintain minimum allowable voltage throughout the feeder length, CVR is carried out with DG. An additional reactive power is provided through DG to keep the feeder voltage within limits. Table III shows the information related to DG system. Most of the cases it is observed that lowest voltage is experienced at nodes 611 and 675 during the deeper base CVR operation. Considering this observation, distributed PV generations PV1& PV2 are allocated at node 684,692.

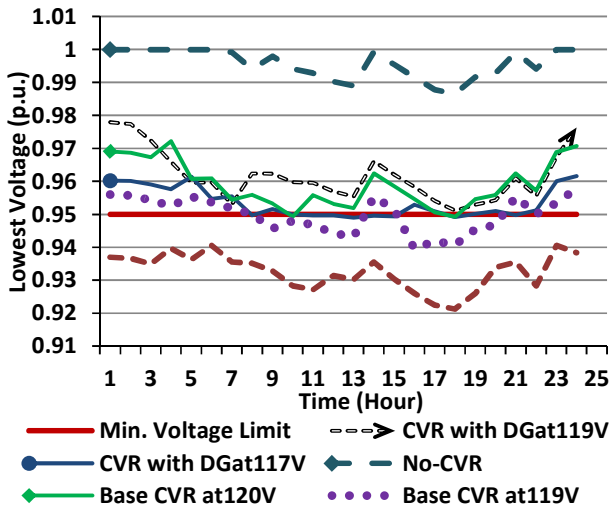

Fig.4. Minimum Node Voltage Profile at the load end.

The PV system output is controled by Smart inverter controller. It operates in two modes 4, 5 as explained in section IV part C followed by equation (19). During night mode four will operate, and only capacitive reactive power injected into the system. While during day time or having low solar irradiation, mode five activates and PV system injects both active and reactive power within its limit. As base CVR operation under 119V, 117V regulated voltage, load end voltage below 0.95 p.u. So, in this Mode the test system is simulated with CVR and DG in following cases:

a). *CVR with DG at 119V Regulated Voltage*:
CVR operation is done with a distributed generation power source at 119V regulated voltage. Only PV1 additional DG source is supplying active and reactive power into the system and this injected power is sufficient to maintain the feeder voltage profile within the acceptable range. From fig.4 it is seen that minimum node voltage profile during operation of CVR with DG (PV1) is above the minimum voltage limit throughout the day. Injected active and reactive power by PV1 has shown in fig.6.

b). CVR with DG at 117V Regulated Voltage:
For deeper voltage reduction as 117 regulated voltages, CVR operation is accomplished with high penetration of DG source to meet the minimum feeder voltage limit. In this case, the

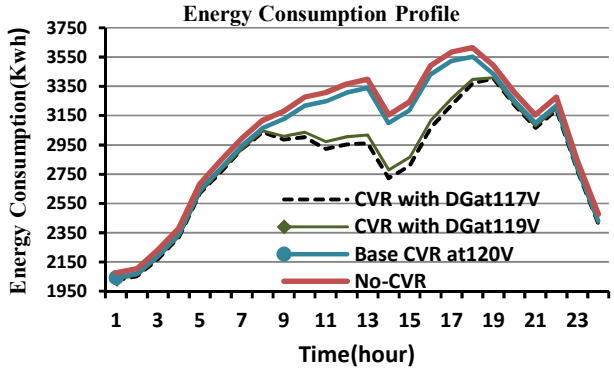

Fig.5. Energy consumption Profile throughout a day

only PV1 source is not sufficient to balance the lowest voltage profile. Therefore, an additional distributed power source PV2 is also providing reactive power support during CVR operation on 117 V. This combined (PV1+PV2) penetration has achieved desired voltage profile and lower the energy consumption more in comparison to other modes as shown in fig.4. Active and reactive power injected by PV1 & PV2 has demonstrated in fig.6, 7 respectively

.Table III. Distributed Generation Ratings

DG System	Location (node)	Smart Inverter KVA Rating
PV1	684	160
PV2	692	100

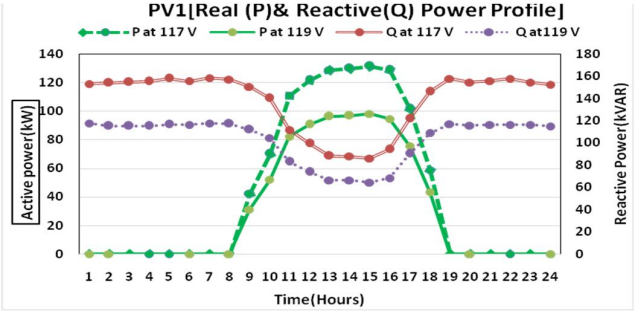

Fig.6. Active & Reactive power penetration by DG-PV1

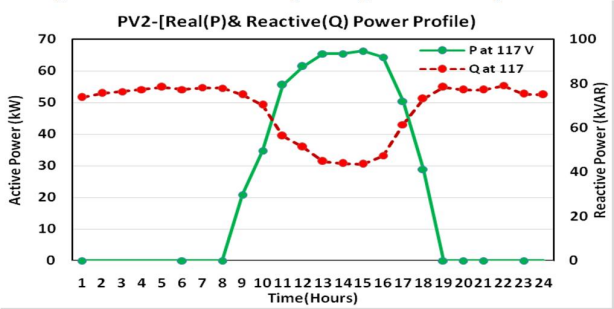

Fig.7. Active & Reactive power penetration by DG-PV2

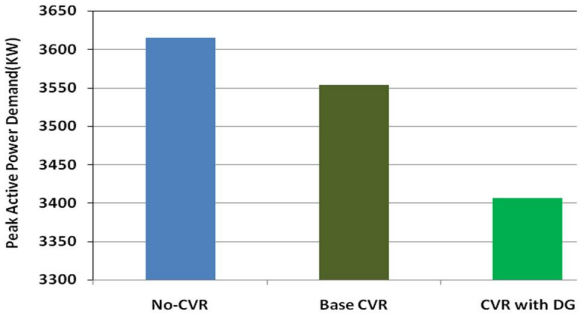

Fig.8. Active Power Demand Compression in all modes.

From figure 5, 8 and table II, it is concluded that significant energy consumption and peak MW load can be reduced with the operation of smart grid enabled CVR. For higher energy consumption and peak demand reduction CVR with DG achieving better energy savings in compression to base or only CVR operation with proper load end voltage profile. There is a significant reduction in energy losses also

obtained. However, during base CVR mode operation, reduction in energy losses not achieved. To verify the effectiveness of CVR operation, CVR factor is calculated in term of KW (CVR_P) and KWh (CVR_E). The CVR factor in both form KWh & KW is higher in CVR with DG mode as compared to base CVR mode. During higher level DG penetration overvoltage problem may occur but if penetration of DG did with CVR, this problem could be eliminated. However, during the simulation with DG, the feeder node voltage does not violate their maximum and minimum limits.

VI. Conclusion and Future Work

This paper analyzed the combined effect of smart grid enabled CVR and distributed generations technology in the electric distribution network with voltage-dependent load profile. In this paper IEEE, 13 nodes unbalance distribution feeder is simulated with constant ZIP load type during CVR mode with and without additional reactive power support. Distribution generation provides this extra reactive power compensation. From simulation results, it is observed that CVR operation with distributed generations shows the higher reduction in energy consumptions and peak load demand with healthy feeder voltage profile in comparison to only CVR operation. The loading pattern during CVR operation and accurate load model load also affect the CVR savings. However, an important finding concludes that power demand reduction is highly influenced by end user load type and additional reactive power compensation. The economics analysis of reactive power support and energy saved during CVR will be discussed in future work. To achieve more savings and peak demand reduction smart grid-enabled CVR operation is more beneficial in comparison to tradition CVR. For better controlling and coordination of CVR and DG technology different intelligent optimization techniques will be used in further research. Effect of penetration of electrical vehicles and storage systems with proposed CVR technology will be examined in future research work.

REFERENCES

[1] F. K. Schneider, F. Tuffner, and R. Singh, 2010, Evaluation of Conservation Voltage Reduction (CVR) on a National Level. [Online]. Available: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19596.pdf.

[2] Voltage optimization: right-sizing grid voltage saves money and cuts pollution blogs.edf.org/energyexchange/files/Voltage-Optimization-Fact-Sheet-Nov-2015.pdf

[3] J. De Steese, Assessment of Conservation Voltage Reduction Applicable in the BPA Service Region, 1987.

[4] V. Warnock and T. Kirkpatrick, "Impact of Voltage Reduction on Energy and Demand: Phase II," IEEE Transactions on Power Apparatus and Systems, Vol. 1(2), 1986, pp.92-95.

[5] D. Kirshner, "Implementation of conservation voltage reduction at Commonwealth Edison," IEEE Trans. Power Syst., vol. 5, pp. 1178–1182, 1990

[6] B. Kennedy and R. Fletcher, "Conservation Voltage Reduction (CVR) at Snohomish County PUD," IEEE Transactions on Power Systems, Vol. 6(3), August 1991, pp. 986-998.

[7] Zhaoyu Wang; Jianhui Wang, "Review on Implementation and Assessment of Conservation Voltage Reduction,"IEEE Trans on Power Systems,vol.29, no.3, pp.1306,1315, May 2014.

[8] S. Singh and S. P. Singh, "A smart volt-var optimization engine for energy distribution system," 2016 International Conference on Emerging Trends in Electrical Electronics & Sustainable Energy Systems (ICETEESES), Sultanpur, India, 2016, pp. 35-41.

[9] W. Ellens, A. Berry, and S. West, "A quantification of the energy savings by conservation voltage reduction," in Proc. 2012 IEEE Int. Conf. Power System Technology (POWERCON), pp. 1–6, 2012.

[10] . Diskin, T. Fallon, G. O'mahony, and C. Power, "Conservation voltage reduction and voltage optimisation on Irish distribution networks," in Proc. CIRED 2012 Workshop Integration of Renewables into the Distribution Grid, pp. 1–4,2012.

[11] M. Diaz Aguiló et al, "Field Validated Load Model for the Analysis of CVR in Distribution Secondary Networks: Energy Conservation", IEEE Transactions on Power Delivery, Vol. 28, No. 4, October 2013, pp. 2428-2436.

[12] Manbachi, Moein, Hassan Farhangi, Ali Palizban, and Siamak Arzanpour. "Quasi real-time ZIP load modeling for Conservation Voltage Reduction of smart distribution networks using disaggregated AMI data." Sustainable Cities and Society, Elsevier, vol. 19,pp. 1-10,2015.

[13] W. G. Sunderman, "Conservation Voltage Reduction System Modeling, Measurement, and Verification," T& D Conference and Exposition (T&D), 2012 IEEE PES, Orlando, FL, May 7-10, 2012, pp. 1-4.

[14] Z. Wang, M. Begovic, J. Wang, Analysis of Conservation Voltage Reduction Effect Based on Multistage SVR and Stochastic Process, IEEE Transactions on Smart Grid, Vol. 5, No. 1, pp. 431 – 439, January 2014

[15] Antonio P.-F , D. Q. Rodezno, and J. R. S. Mantovani, "Volt-VAR Multiobjective Optimization to Peak-Load Relief and Energy Efficiency in Distribution Networks" IEEE Trans. on Power Delivery, Vol. 30, No. 2, April 2015.

[16] Schneider, K.P.; Weaver, T.F., "A Method for Evaluating Volt-VAR Optimization Field Demonstrations," Smart Grid, IEEE Transactions on, vol.5, no.4, pp.1696, 1703, July 2014.

[17] A. Bokhari *et al*., "Combined Effect of CVR and DG Penetration in the Voltage Profile of Low-Voltage Secondary Distribution Networks," in *IEEE Transactions on Power Delivery*, vol. 31, no. 1, pp. 286-293, Feb. 2016

[18] R. Singh, F. Tuffner, J. Fuller and K Schneider, "Effects of Distributed Energy Resources on Conservation Voltage Reduction (CVR)," PES General Meeting, 2011 IEEE, San Diego, CA, July 24-29, 2011.

[19] T. Shukla, S. P. Singh, V. Srinivasarao, and K. Naik, "Optimal sizing of distributed generation placed on radial distribution systems," Electric power components and systems, vol. 38, no. 3, pp. 260–274, 2010

[20] Vijay and Dahiya, "Direct search approach for multiple distributed generator allocation in radial distribution systems," in Power India international conference, 2014. IEEE, pp. 1–6, IEEE, 2014

[21] Hao Jan Liu," Smart-Grid-Enabled Distributed Reactive Power Support with Conservation of Voltage Reduction" Master'thesis University of Illinois at Urbana-Champaign, 2013

[22] D. A. Quijano and A. P. Feltrin, "Assessment of Conservation Voltage Reduction effects in networks with distributed generators," *Innovative Smart Grid Technologies Latin America (ISGT LATAM), 2015 IEEE PES*, Montevideo, 2015, pp. 393-398.

[23] ANSI C84.1-1995, American National Standards for Electric Power Systems and Equipment—Voltage Ratings (60 Hz), 1995

[24] S.Singh, D.Shukla, S.P. Singh, "Peak Demand Reduction in Distribution Network with Smart Grid-Enabled CVR", IEEE PES Innovative Smart Grid Technologies (ISGT Asia), 28,Nov- 01, Dec. 2016, Melbourne, Australia (Accepted).

[25] S.Singh, S.P. Singh, "Opportunities and Challenges for Deployment of CVR/VVO Methodology in Indian Smart Energy Distribution System." Int.Conf.and Exibition on Smart Grid andSmart Cities (India Smart Grid Week) at ISGF, New Delhi on March 15-19,2016.

[26] W. H. Kersting, Distribution System Modeling, and Analysis. New York,NY: CRC Press, 2001.

[27] OpenDSS Manual, Electric Power Research Institute, July 2010.

[28] . IEEE PES distribution test feeders. <http://www.ewh.ieee.org/soc/pes/dsacom/ testfeeder