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Advanced Voltage Support Scheme for Grid Balancing Under Active Power Oscillations

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Abstract: On the occurrence of faults, balancing the grid is major requirement for large distribution power system. In many grid faults the working of Traditional Voltage Support scheme (VSS) is affected because of zero-sequence voltage. In this paper an advanced voltage support scheme is proposed to support voltage under various unbalancing conditions like under-voltage and over-voltage. This scheme, called Zero Sequence compensated voltage support scheme (ZCVS) is utilized in converter interface unit to precisely control the three phase voltages at the association point (PCC) inside security limits. This scheme compensates the zero sequence voltage and can be in resistive distribution system. Zero Sequence compensated voltage support scheme (ZCVS) combined with LAPO is also proposed which borders the active power oscillations in adjustable dc-link connected to converter to support the ac grid even under severe unbalances. The consequences of the proposed voltage support scheme and complimentary strategy are compared with traditional voltage support scheme.

Index Terms*: *DC-voltage ripples, oscillations limitation, power oscillation,voltage regulation, voltage sags, voltage swells, etc.

I. INTRODUCTION

Power converters are the real segments for interfacing distributedenergy framework to control power grid. The task of grid-connected converter (GCC) is more challenging because it is operation becomes complicated under various fault conditions. The increase in applications and modern loads may cause voltage unbalances, like voltage sags, swells which may harm the operation of grid connected converter[6]. If its operation is not stable it may result in cascading failure of GCC.

To maintain the grid under balance the quality of injected current [3] must be improved DC-voltage ripples [16] must be reduced, which should be satisfied by grid-connected converter (GCC). The operation of the grid connected converter should consider the limited issue flows, limited power oscillations, and boosted the Power stream. The above parameters are addressed with analytical expression (2)withregulatorylimits of GCC under unbalanced faults. The entire distribution system is operated with the GCC to regulate (PCC) voltage under unbalanced conditions. However the voltage at point of Common Coupling as per present survey [6] and [7] have three problems.

To begin with, they [7] don't consider the Zero-sequence voltage segment whose existence may result severe unbalances and accuracy of the system is affected.Secondly[6], traditional schemes are appliedonlyfor inductive grids as their X/R ratio is high. Third, severe active power oscillations are present in the grid[6].

This paper proposed anadvanced voltage support scheme (VSS) where the above issues can be understood. Initially, it totally considers the Zero sequence segment and precisely controls the three phase voltage with in preset security constrains under unbalancing conditions. Second, this proposed methodology can be connected to the resistive gridsand considers the active power oscillations toregulate the dc-bus voltage called limited active power oscillations (LAPO). The mathematical expressions of this analytical strategy are shown in section II.

II. GRID CONNECTED CONVERTER OPERATION UNDER UNSTABLE CONDITIONS.

Fig.(1) shows the GCC created distributed generation unit with several control parameters. Voltage unbalancing conditions at PCC may occur due to grid faults or unbalance loading. Under any unbalancing conditions, the positive and negative voltage sequence in $\alpha\,\beta$ can be shown in expression (1)

$$v^{+}=\begin{bmatrix} {v_\alpha}^{+} \\ {v_\beta}^{+} \end{bmatrix}=\begin{bmatrix} v^{+}\cos(wt+\delta^{+}) \\ v^{+}\sin(wt+\delta^{+}) \end{bmatrix}$$
$$v^{-}=\begin{bmatrix} {v_\alpha}^{-} \\ {v_\beta}^{-} \end{bmatrix}=\begin{bmatrix} v^{-}\cos(wt+\delta^{-}) \\ -v^{-}\sin(wt+\delta^{-}) \end{bmatrix} \tag{1}$$

To regulate the supportive performance from the grid connected converter, the current i can be alienatedintofourvectors are positive and negative, active and reactive sequence components through current controller.

$$i={i_p}^{+}+{i_p}^{-}+{i_q}^{+}+{i_q}^{-}i=\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}=$$
$$\begin{bmatrix} {i_p}^{+}cos(wt+\delta^{+})+{i_p}^{-}cos(wt+\delta^{-}) \\ {i_p}^{+}sin(wt+\delta^{+})-{i_p}^{-}cos(wt+\delta^{-}) \end{bmatrix} +$$
$$\begin{bmatrix} {i_q}^{+}cos(wt+\delta^{+})-{i_q}^{-}cos(wt+\delta^{-}) \\ -{i_q}^{+}cos(wt+\delta^{+})-{i_q}^{-}cos(wt+\delta^{-}) \end{bmatrix}$$

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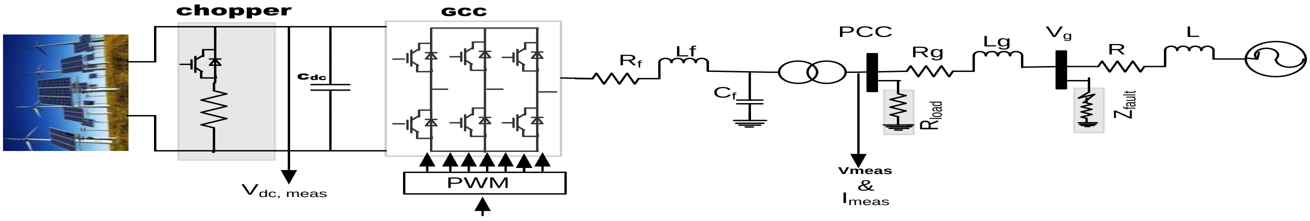

Fig.(1)circuit topology of network associated converter.

Where the notations "+" / "-" are the positive and negative sequence components and "p" / "q" are the active and reactive components respectively. These parts can give the required voltage at any framework conditions.

$$V = v^{+} + v^{-} = \begin{bmatrix} v_{\alpha}{}^{+} + v_{\alpha}{}^{-} \\ v_{\beta}{}^{+} + v_{\beta}{}^{-} \end{bmatrix}$$
$$= \begin{bmatrix} v_{g\alpha}{}^{+} + v_{g\alpha}{}^{-} + L_g \dfrac{di_{\propto}}{dt} + R_g i_{\propto} \\ v_{g\beta}{}^{+} + v_{g\beta}{}^{-} + L_g \dfrac{di_{\beta}}{dt} + R_g i_{\beta} \end{bmatrix} \tag{3}$$

The above expression shows ac side voltage in terms of active and reactive currents. Here "g" represents the grid component according to the circuit diagram.

$$\frac{I_p^-}{I_q^-} = \frac{R_g}{L_q\omega}, \qquad \frac{I_p^+}{I_q^+} = \frac{R_g}{L_q\omega} \tag{4}$$

If the above conditions are satisfied, then the positive and negative components are,

$$v^{+} - v_g{}^{+} = L_q\omega I_q^{+} + R_g I_p^{+}$$
$$v^{-} - v_g{}^{-} = R_q\omega I_p^{-} - L_g I_q^{-} \tag{5}$$

III. OPERATION OF ZERO SEQUENCE COMPENSATED VOLTAGE SUPPORT SCHEME (ZCVS)

The primary goal of this plan is to stay away from the over voltage and under voltage at the PCC if the grid is unbalanced. The three phase voltage can be regulatedin its preset safety limitswhich are $v_{max}^{set}$and v_{min}^{set},also does not ignore the active power regulation in the distribution network since it considers the resistance of the network and proposed plan will create and infuse the dynamic capacity to the appropriation arrange. Under unbalanced conditions the maximum and minimum voltage limits are shown in below expressions.

$$v_{max} = \max\{v_a, v_b, v_c\} \le v_{max}^{set}$$
$$v_{min} = \min\{v_a, v_b, v_c\} \ge v_{min}^{set}$$

From the above terminologiesv_a, v_b, v_c are the magnitudes of the 3∅voltages at the PCC of the GCC. The parameter values of the v_{min}^{set}- v_{max}^{set} are set to 0.9-1.1 PU and 0.8-1.2 PU respectively in the simulation test case which are helpful in balancing the grid. If the unbalanced conditions overcome the above values, using expression (6) the voltages at PCC must be brought between the limits, where the active, reactive and positive, negative sequence currents are injected to resistiveorinductive grid to balance the PCC voltages. The magnitudes of Phase-voltages can obtain in terms of magnitudes of positive sequence and negative sequence voltages are shown in expression (6),

$$v_a = \sqrt{(v^{+})^2 + (v^{-})^2 + 2\,(v^{+})(v^{-})\cos(\gamma)} + (v^{\circ})cos\,(\gamma^{\circ})$$

$$v_b = \sqrt{(v^{+})^2 + (v^{-})^2 + 2\,(v^{+})(v^{-})\,cos\left(\gamma - \frac{2\,\pi}{3}\right)} + (v^{\circ})\,cos\,(\gamma^{\circ} - \frac{2\pi}{3})$$

$$v_c = \sqrt{(v^{+})^2 + (v^{-})^2 + 2(v^{+})(v^{-})\,cos\left(\gamma + \frac{2\pi}{3}\right)} + (v^{\circ})cos(\gamma^{\circ} + \frac{2\pi}{3}) \tag{6}$$

Where$\gamma = \delta^{+} - \delta^{-}$and $\gamma^{\circ} = \delta^{\circ} - \delta^{+}$and most extreme and least voltages can be controlled by.

$$v_{max} = max\,\{v_a, v_b, v_c\}$$
$$= \sqrt{(v^{+})^2 + (v^{-})^2 + 2(v^{+})(v^{-})\lambda_{min}} + (v^{\circ})\lambda_{min}^{\circ}$$
$$v_{min} = min\,\{v_a, v_b, v_c\}$$
$$= \sqrt{(v^{+})^2 + (v^{-})^2 + 2(v^{+})(v^{-})\lambda_{max}} + (v^{\circ})\lambda_{max}^{\circ} \tag{7}$$

Where λ_{min}° , λ_{max}° , λ_{min} , λ_{max} can be determined below

$$\begin{cases} \lambda_a = \cos(\gamma) \\ \lambda_b = \cos(\gamma - 2\frac{\pi}{3}) \\ \lambda_c = \cos(\gamma + 2\frac{\pi}{3}) \end{cases} \rightarrow \begin{cases} \lambda_{min} = \min(\lambda_{a,}\lambda_b, \lambda_c) \\ \lambda_{max} = \max(\lambda_{a,}\lambda_b, \lambda_c) \end{cases}$$

$$\begin{cases} if\ \lambda_{min} = \lambda_{a \rightarrow \lambda_{min}^{\circ} = \cos(\gamma^{\circ})} \\ if\ \lambda_{min} = \lambda_{b \rightarrow \lambda_{min}^{\circ} = \cos(\gamma^{\circ} - 2\frac{\pi}{3})} \\ if\ \lambda_{min} = \lambda_c \rightarrow \lambda_{min}^{\circ} = \cos(\gamma^{\circ} + 2\frac{\pi}{3}) \end{cases}$$

And

$$\begin{cases} if\ \lambda_{max} = \lambda_a \rightarrow \lambda_{max}^{\circ} = \cos(\gamma^{\circ}) \\ if\ \lambda_{max} = \lambda_b \rightarrow \lambda^{\circ}_{max = \cos(\gamma^{\circ} - 2\frac{\pi}{3})} \\ if\ \lambda_{max} = \lambda_c \rightarrow \lambda_{max}^{\circ} = \cos(\gamma^{\circ} + 2\frac{\pi}{3}) \end{cases} \tag{8}$$

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The reference values of minimum and maximum phase energiesare v_{min}^{ref} , v_{max}^{ref}.

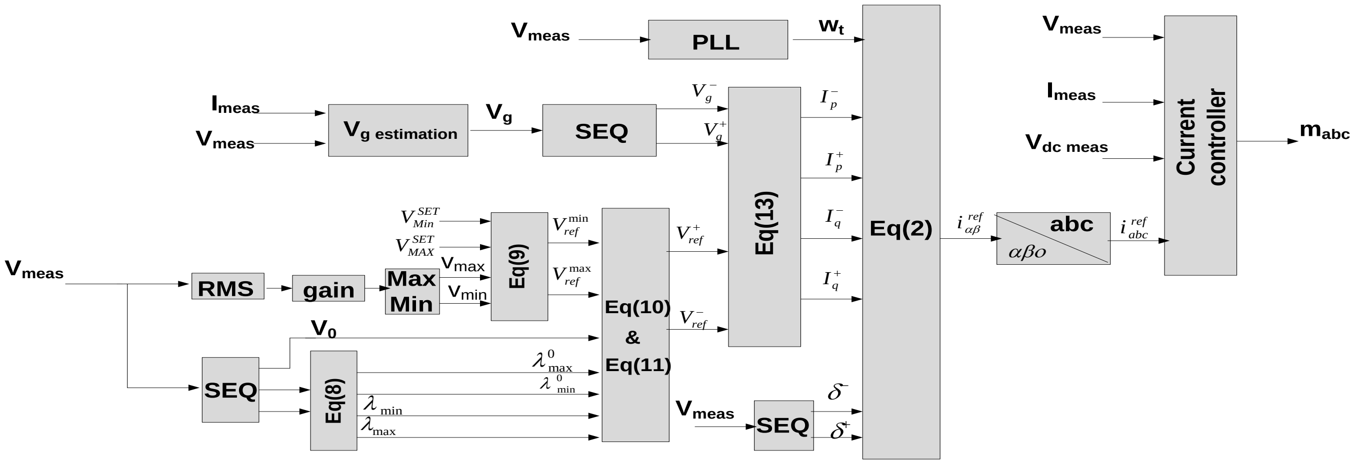

Fig.2 proposed ZCVS technique.

$$v_{min}^{ref} = v_{max}^{ref}$$

$$v_{max}^{ref} = \min(v_{max}^{set}, (v_{max} - v_{min})) \qquad (9)$$

After finding the v_{min}^{ref} , v_{max}^{ref} by expression (9) and applying them to (7) the reference values v_{ref}^+, v_{ref}^- can be follows below.

$$v_{ref}^+ = \frac{-A + \sqrt{B^2 - 4A^2}}{2}$$

$$v_{ref}^- = \frac{A}{v_{ref}^+}$$

$$A = \frac{v_H^2 - v_L^2}{2(\lambda_{max} - \lambda_{min})}$$

$$B = 2A \times \lambda_{max} - v_H^2$$

(11)

By using expressions (10) and (11)the reference values of the positive and negative sequences voltages are obtained. Then $v^+$and v^- are swapped with reference values obtained by expressions (10) and (11). However and can be projected by PCC measurement. Therefore(5) can be written as.

$$\begin{bmatrix} \Delta v_{ref}^+ \\ \Delta v_{ref}^- \end{bmatrix} = \begin{bmatrix} \omega L_q I_q^+ \\ -\omega L_q I_q^- \end{bmatrix} + \begin{bmatrix} R_g I_q^+ \\ R_g I_p^- \end{bmatrix}$$

(12)

The solution of (12) can determine the four current components are $(I_q^+, I_q^-, I_p^-, I_p^+)$ can obtained as.

$$I_p^+ = \frac{R_g}{X_g^2 + R_g^2} \times \Delta v_{ref}^+$$

$$I_p^- = \frac{R_g}{X_g^2 + R_g^2} \times \Delta v_{ref}^-$$

$$I_q^+ = \frac{X_g}{X_g^2 + R_g^2} \times \Delta v_{ref}^+$$

$$I_q^- = \frac{-X_g}{X_g^2 + R_g^2} \times \Delta v_{ref}^-$$

(13)

The above expression (13) submit on expression (2) can get i_α and i_β frames. These components are transmitted to GCC through current controller[5].

IV. ZERO-SEQUENCE COMPENSATED VOLTAGE SUPPORT SCHEME (ZCVS) IS COMBINED WITH LAPO STRATEGY

In dangerous unbalancesnegative sequence current component should be considered whichare obtained by ZCVS. These negative reactive current and voltage component give raise the oscillations in the dynamic or active power. Therefore the LAPO scheme is used to compensate the active power oscillations with in the safety allowable preset limits of p_{max}^{set}.

The dynamic or active power at GCC can calculated as below.

$$P = V.I = (v^+ + v^-).(i^+ + i^-)$$

(14)

From the expressions (1) and (2) the magnitudes of the voltage and current can be drawn and the magnitude of the active power oscillations given as.

$$\tilde{p} = \sqrt{(v^- I_p^+ + v^+ I_p^-)^2 + (v^- I_p^+ - v^+ I_p^-)^2}$$

(15)

From the above expression (11) maximum negative reactive power can be obtained and the preset limits of active power is shown

$$I_{q.LAPO}^- = \frac{\sqrt{{p_{max}^{set}}^2 - (v^- I_p^+ + v^+ I_p^-)^2} + v^- I_q^+}{v^+}$$

(16)

Expressions (12) bound the active power oscillations with in the preset limits and control the dc bus voltage oscillations. The LAPO may disturb the operation of ZCVS. However this expression (12) can maintain the flexibility of the GCC under fault conditions. The proposed ZCVS with LAPO control strategy shows in fig.(3)

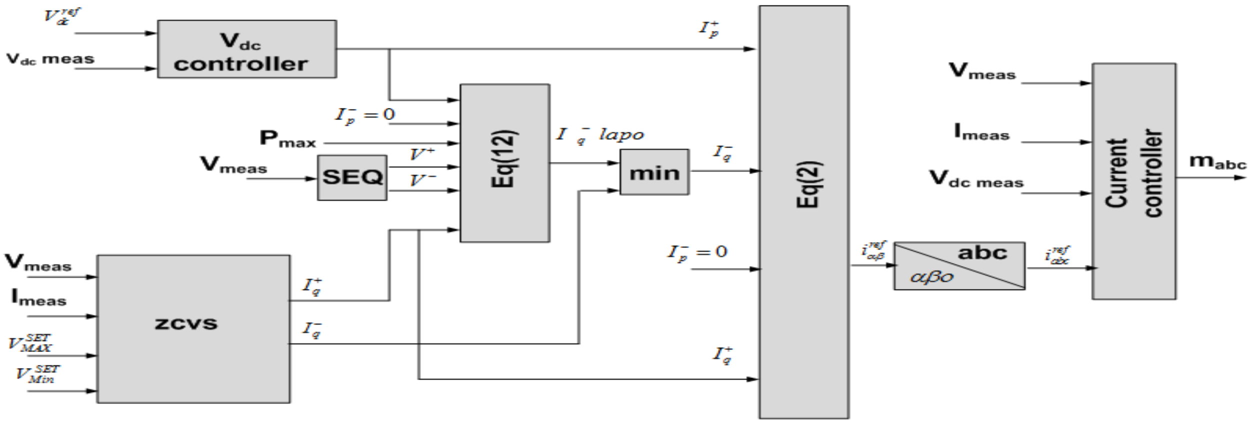

Fig.3 proposed ZCVS with LAPO scheme.

V. SIMULATION OUTCOMES

To check the efficiency of proposed ZCVS scheme with LAPO technique, some test cases are considered and executed Fig. (3) Shows the circuit topology of the Grid connected 1 MVA, 690A, 60HZ converter interfaced to distributed generation unit. From the literature survey the operation of GCC under unbalancing ac- side conditions, assumes the constant dc- Voltage source [6], [1], [14] and [4]. Therefore, aDC-voltage regulator is used in this paper because it will generate active power command to grid connected converter. The Simulation test parameters are shown in Fig.4

parameters	**values**
$v_{min}^{set} = v_{min}$	0.9 pu
$v_{max}^{set} = v_{max}$	1.1 pu
P_{SET}	0.08 pu
Gain	√2
Inductance	j0.3
$v_{L\ PLL}$	690V
f	60HZ

Fig.4 Test parameters of LAPO

a) ZCVS with LAPO scheme.

Set the maximum acceptable active power oscillations is 0.08pu from expression (16). In this simulation test case single phase fault is applied in between t=0.02 and t=0.04s. Using expression (13) calculate the maximum $I_q^-$where the dynamic or active power motions are lower than 0.08 PU. From expression (13) I_q^- is higher than the expression (16) $I_{q\ .lapo}^-$ cause where the dynamic power motions are higher than 0.08 PU Fig. 5(b) to limit oscillations, I_q^- to limited the $I_{q\ .lapo}^-$ at t=0.05s, as indicated in fig.5 (a). Therefore the active or dynamic power oscillations are limited to 0.08p.uas shown in fig.5 (b). Result, the dc voltage swells are diminished by applying LAPO.

b) Traditional VSS vs. advanced VSS.

This segment represents the simulation outcomes of phase voltages and currents at PCC of the traditional **VSS** and Proposed voltage support scheme shows the single phase unbalancing fault condition between t=0.02S and t=0.04s. In traditional scheme the voltage of phase A is decreased beyond the limits at PCC voltage as a result the low voltage unbalancing condition is occurredfig.7 (a), due to ignoring the Zero Sequence voltage components. At time 0.03s the lower current at phase A fig.7(b) because it does not compensate the negative reactive component, so the oscillation are occur in the current component at fig.7(b) PCC. So, these low voltage and low currents will unbalance the ac-AC grid.

Similarly, the advance voltage support scheme voltage and current components fig.6(a) and fig.6(b) at PCC will regulate the pre-set safety limits because, it consider the zero sequence component. The voltage and current limitations is within the preset safety limits result, the grid is balanced. The advanced voltage support scheme reduce the negative reactive current component so, the oscillations are less compared to traditional VSS

VI. TERMINOLOGY

$v^-,\ v^+,\ v^\circ$	Magnitudes of negative,positive and zero sequence voltages.
$\delta^+, \delta^-, \delta^\circ$	Phase angles ofpositive, negative and zero sequence voltages.
F	Frequency.

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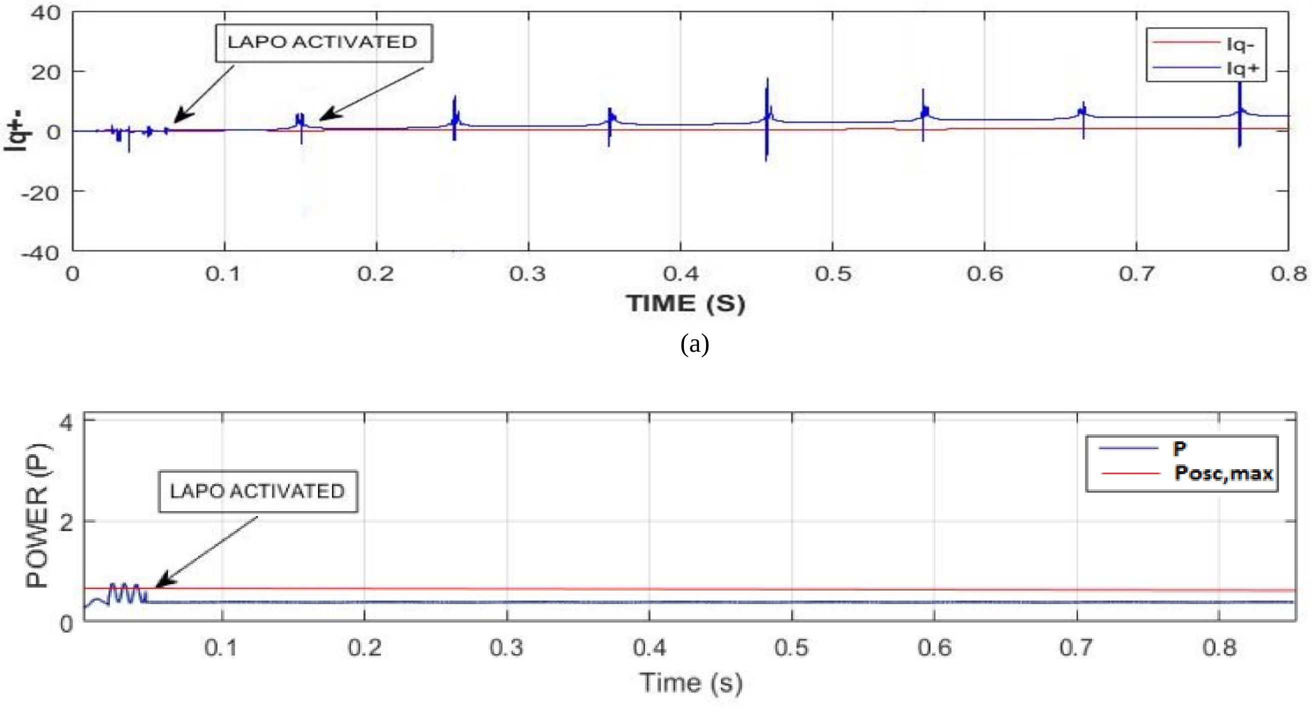
V_{dc}	Dc-side voltage of the converter.
I_{max}^{set}	Pre-set limits for the magnitude of magnitudes of phase current.
$R_g \& L_g$	Resistance and inductance of line.



(a)

(b)

Fig.(5) simulation outcomes of advance VSS with MAPD. (a) positive and negative reactive current components (b)active power.

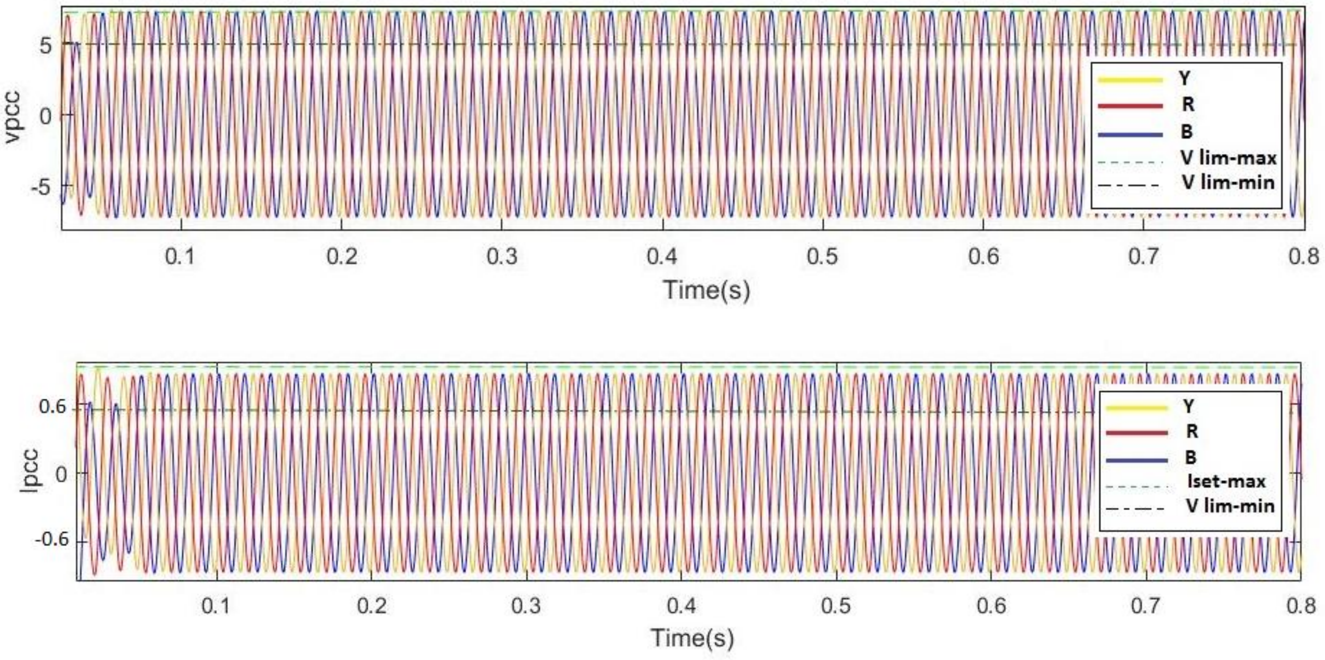
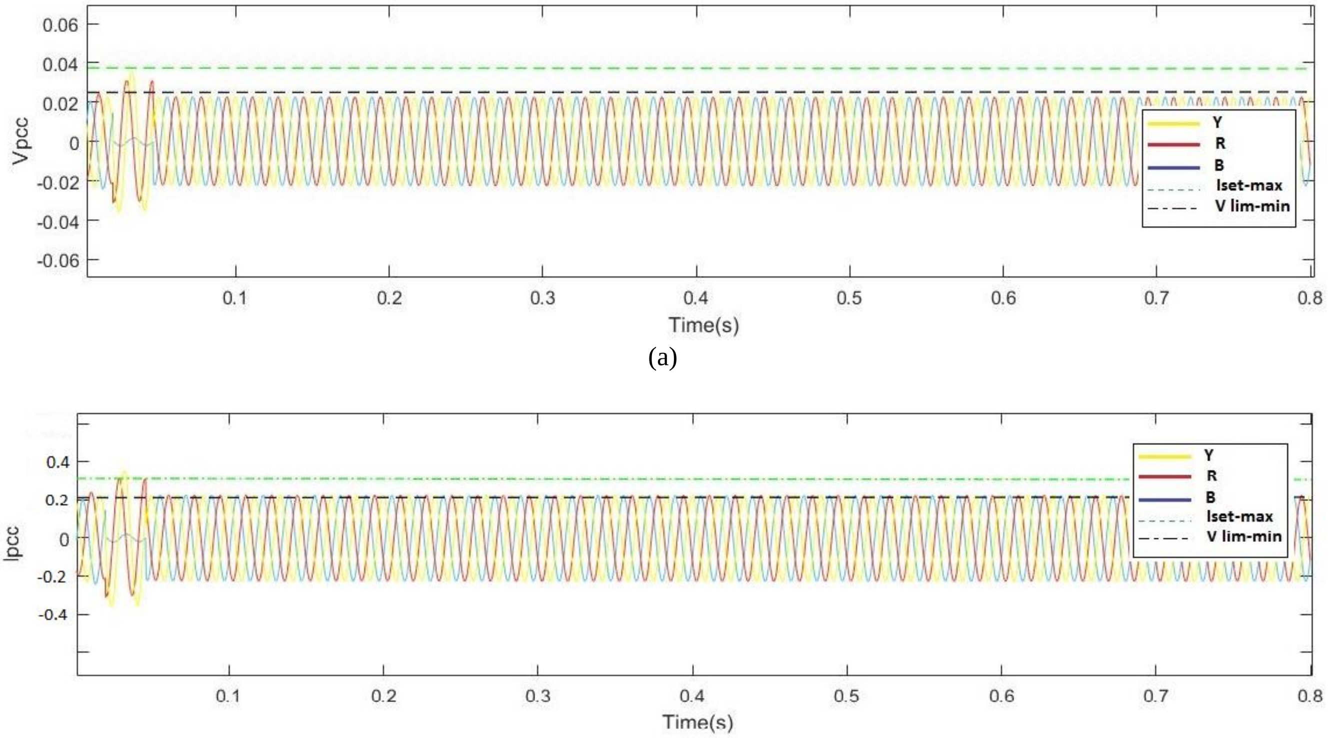


Fig (6) simulation test outcomes of advanced voltage support scheme. (a) Phase voltages at PCC. (b) Phase current at PCC.



(a)

(b)

Fig.(7) Obtained simulation outcomes of traditional VSS. (a) Phase voltages at PCC. (b) Phase currents at PCC.

VII. CONCLUSION

This paper suggests Zero sequence compensated Voltage Support Scheme (ZCVS) to regulate the three-Phase Voltages at PCC of GCC with in preset safety limits ofv_{max}^{set} &v_{min}^{set}. Proposed technique will consider the zero sequence voltage components. The LAPO is proposed under serious unbalance flaws to systematically acquire a point of confinement for the negative infused receptive current. As a result it will adjust and limit active power oscillations and improve DC-voltage to support the AC-Grid. It can be connected to purely resistive network which is supported by LAPO technique. The successful outcomes of the proposed scheme are tested in simulation.

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