Power Quality Improvement for Low Active Power Demand using Advance Voltage Support Scheme

N.Vani Annapurna Bhavani, K. Swetha, Praveen Kumar Bandila

Abstract: In case of severe faults which unbalance the grid, improving the grid reliability is the main requirement in case distributed generation (DG) units. The voltage support schemes (VSS) that are being in use involves STATCOM submissions, where the active power is zero. An advanced voltage support scheme is proposed in this paper to support the voltage under various schemes at the converter interface units called Zero Sequence compensated voltage support scheme (ZCVS), regulates the 3∅ voltage at the connection point within safety limits. Zero Sequence compensated voltage support scheme (ZCVS) in combination with MAPD can support for concentrated active power transfer to the ac grid. Applying the MAPD technique guarantees delivering the maximum allowable active power to the grid and instantaneouslyvariable the current limitations while riding through abnormal conditions. The results comparing Zero Sequence compensated voltage support scheme (ZCVS) with traditional voltage support (VSS) schemes is done and the complementary strategy is verified in MATLAB/SIMULINK.

Index Terms*:*active power injection,positive and negative sequence voltages,voltage sag, voltage unbalance, voltage swells.

I. INTRODUCTION

Power converter interfacing units are becoming a major part in the distribution system. The stability of any large distribution system for both resistive and inductive natures is high by using grid-connected converters (GCC) fig (1). During conditions like under voltage and over voltage the operation of GCC is becoming critical. On occurrence of above conditions converter operation failure may occur resulting in mal-operation of GCC resulting in voltage sags, voltage swells and heavy oscillations in the distribution system [4].

The proposed grid-connected converter is capable of balancing the ac grid at the point of common coupling (PCC), are improves the quality of injected current[3]-[14], reduces ripples inDC-voltage thus improvingvoltage profile [17]-[19].

Proposed GCC also, reduces fault currents, power oscillations and ensures maximum power flow at PCC[6]-[23].

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Studies on [4] and [2]the common problems that can occur in conventional GCC.

a. They does not consider zero-sequence component.
b. Can be applied for inductive grids.
c. Do not deliver active power.

The above three problems are consider to balancing the grid at PCC of a GCC from different voltage support technique.

This paper projected an innovative voltage support scheme (AVSS) addressing above issues. This AVSS scheme is used to fully compensate the Zero sequence component whichprecisely regulates the phase voltages with in protection limits when the GCC is in unbalance condition. Secondly this scheme can be applied to inductive grids. Thirdly, active power is transferred to the system using this advanced voltage support scheme. This scheme in combination with maximum allowable active power delivery (MAPD) is also formulated.

II. GCC CONVERTER OPERATION UNDER UNBALANCED CONDITIONS

fig.(1) shows plan diagram of the grid connected converter based distributed generation unit with various control parameters. Voltage fault conditions at PCC may occur due to grid faults or unbalance loading. Under any unbalances, the positive and negative sequencevoltages in$\alpha\,\beta$ can be shown as.

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

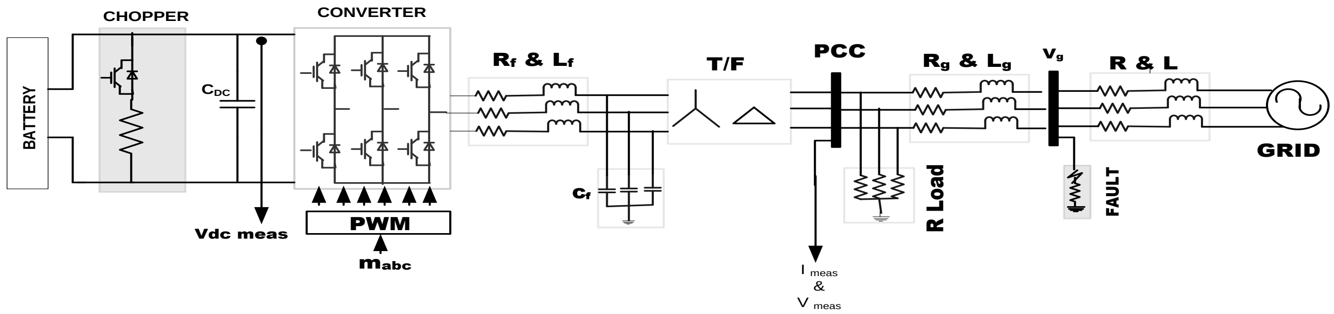
$$v^{-}=\begin{bmatrix} v_{\alpha}{}^{-} \\ v_{\beta}{}^{-} \end{bmatrix}=\begin{bmatrix} v^{-}\cos\,(wt+\delta^{-}) \\ -v^{-}\sin\,(wt+\delta^{-}) \end{bmatrix}\ (1)$$

To regulate the supportive performance from the grid connected converter, at present I can be partitioned into four sub parts (vectors) as positive, negative, active and reactive segments through current controller [8].

$$i= i_p{}^{+} + i_p{}^{-} + i_q{}^{+} + i_q{}^{-}$$

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

(2)



Fig(1). Circuit topology of grid connected 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.

$$V = v^{+} + v^{-} = \begin{bmatrix} v_{\alpha}{}^{+} + v_{\alpha}{}^{-} \\ v_{\beta}{}^{+} + v_{\beta}{}^{-} \end{bmatrix}$$

$$= \begin{bmatrix} v_{g\alpha}{}^{+} + v_{g\alpha}{}^{-} + L_g \frac{di_{\propto}}{dt} + R_g i_{\propto} \\ v_{g\beta}{}^{+} + v_{g\beta}{}^{-} + L_g \frac{di_{\beta}}{dt} + R_g i_{\beta} \end{bmatrix} \quad (3)$$

The equations (3)and (2) shows ac side voltage in terms of active and reactive currents. Here "g" represents the grid component according to the schematic diagram.

$$\frac{I_p^-}{I_q^-} = \frac{R_g}{L_q\omega}, \quad \frac{I_p^+}{I_q^+} = \frac{R_g}{L_q\omega} \quad (4)$$

If the above conditions are satisfied, then the negative andpositive sequence components are,

$$v^{+} - v_g{}^{+} = L_q\omega I_q^+ + R_g I_p^+$$

$$v^{-} - v_g{}^{-} = R_q\omega I_p^- - L_g I_q^- \quad (5)$$

III. ADVANCED VOLTAGE SUPPORT SCHEME (AVSS) OPERATION.

Proposed advanced voltage support scheme considers zero sequence components at PCC when the grid is unbalanced. The impedance of the grid connected converter is very high when it is compensating zero-sequence component. The voltage fluctuations under unbalances will be under v_{max}^{set} and v_{min}^{set}[2]. The GCC converter considers the active power regulation in the distribution network by injecting active power. Theequations for maximum and minimum voltage limits at unbalancing grid conditions

$$v_{max} = \max\{v_a, v_b, v_c\} \leq v_{max}^{set}$$
$$v_{min} = \min\{v_a, v_b, v_c\} \geq v_{min}^{set}$$

Wherev_a, v_b, v_c are the magnitudes of the3$\emptyset$voltages at the PCC of the grid-connected converters (GCC). The parameter values of the v_{min}^{set}- v_{max}^{set} are set to 0.8-1.1pu and 0.9-1.3pu respectively in the simulation test case. If the fluctuations go beyond the set values active power delivery is minimized .the proposed scheme brings the fluctuated voltages to the set voltages using equation (6) and injects active, reactive, positive and negative sequenceto inductive or resistive grid and balances the PCC voltage.

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

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

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

$\gamma = \delta^+ - \delta^-$and $\gamma^{\circ} = \delta^{\circ} - \delta^+$are maximum and minimum voltages,

$$v_{max} = \max\ [v_a, v_b, v_c]$$

$$= \sqrt{(v^+)^2 + (v^-)^2 + 2(v^+)(v^-)\lambda_{min}} + (v^{\circ})\lambda_{min}^{\circ}$$

$$v_{min} = \min\ [v_a, v_b, v_c]$$

$$= \sqrt{(v^+)^2 + (v^-)^2 + 2(v^+)(v^-)\lambda_{max}} + (v^{\circ})\lambda_{max}^{\circ} \quad (7)$$

λ_{min}°, λ_{max}°, λ_{min}, λ_{max} can be determined as

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

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

And

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

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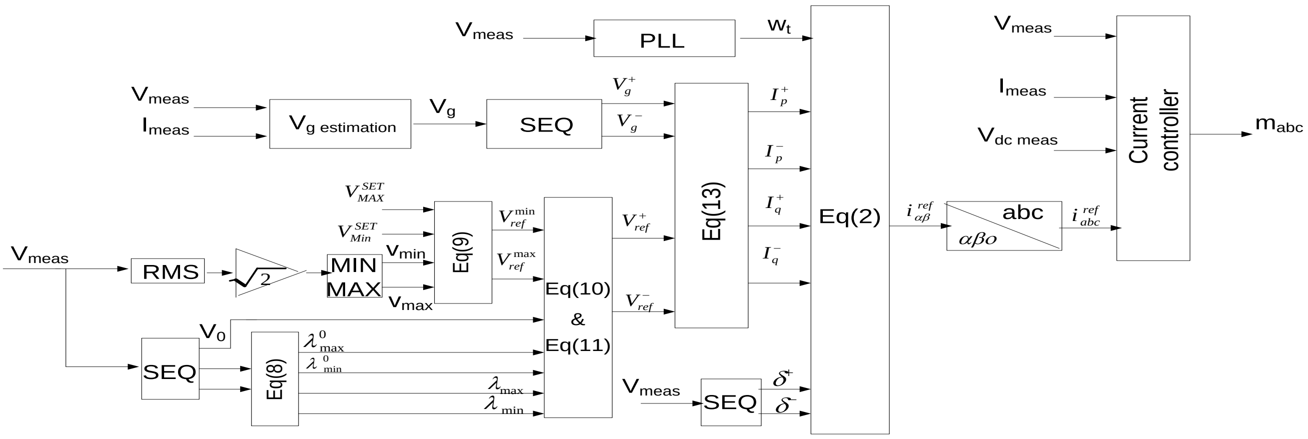

Fig(2). Advanced voltage support scheme.

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

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

Finding the v_{min}^{ref} , v_{max}^{ref} by equation (9) and applying them to (7) the reference values v_{ref}^{+}, v_{ref}^{-} are,

$$v_{ref}^{+} = \frac{-A + \sqrt{B^2 - 4A^2}}{2}$$
$$v_{ref}^{-} = \frac{A}{v_{ref}^{+}} \tag{10}$$

$$A = \frac{v_H^2 - v_L^2}{2\,(\lambda_{max} - \lambda_{min})}$$
$$B = 2A \times \lambda_{max} - v_H^2 \tag{11}$$

From equations (10) and (11) the reference standards of the positive and negative sequence voltages are gained. Then $v^{+}$and v^{-} are replaced with reference standardsare gained by equations (10) and (11). However and can be estimated by PCC measurement. Therefore (5) can be written as.

$$\begin{bmatrix}\Delta v_{ref}^{+}\\ \Delta v_{ref}^{-}\end{bmatrix} = \begin{bmatrix}\omega L_q I_q^{+}\\ -\omega L_q I_q^{-}\end{bmatrix} + \begin{bmatrix}R_g I_q^{+}\\ R_g I_p^{-}\end{bmatrix} \tag{12}$$

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

$$I_p^{+} = \frac{R_g}{X_g^2 + R_g^2} \times \Delta v_{ref}^{+}$$
$$I_p^{-} = \frac{R_g}{X_g^2 + R_g^2} \times \Delta v_{ref}^{-}$$
$$I_q^{+} = \frac{X_g}{X_g^2 + R_g^2} \times \Delta v_{ref}^{+}$$
$$I_q^{-} = \frac{-X_g}{X_g^2 + R_g^2} \times \Delta v_{ref}^{-} \tag{13}$$

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

IV. ADVANCED VOLTAGE SUPPORT SCHEME (AVSS) with MAPD.

Maximum allowable active power (MAPD) technique in conjunction with AVSS delivers active power and supports current limitations on the distributed energy system under unbalanced conditions, and simultaneously Regulates the phase voltages at PCC. This technique is used to find $I_{p\,MAPD}^{+}$using equation (20) when the active power is low. $I_{p\,MAPD}^{+}$Ensures the maximum allowable I_p^{+} injection to support the grid. The values of I_p^{+} and I_p^{-} are already obtained in equation (13) to provide the voltage support. Here I_p^{-}=0 so the equation (2) is rewritten as

$$\begin{bmatrix}i_\alpha\\ i_\beta\end{bmatrix} = \begin{bmatrix}(i_p{}^{+} + i_q{}^{-} sin\gamma)\cos(wt + \delta^{+}) + (i_q{}^{+} - i_q{}^{-} cos\gamma) sin(wt + \delta^{+})\\ (i_p{}^{+} - i_q{}^{-} sin\gamma)\cos(wt + \delta^{+}) - (i_q{}^{+} + i_q{}^{-} cos\gamma) sin(wt + \delta^{+})\end{bmatrix} \tag{14}$$

The $\alpha\beta$ currents (14) are transformed to abc frame and the magnitudes of the phase currents are shown below.

$$I_a^2 = (i_p{}^{+} + i_q{}^{-}\ sin\gamma\,)^2 + (i_p{}^{+} - i_q{}^{-}\ cos\gamma)^2 \qquad (15.a)$$
$$I_b^2 = \left(\frac{1}{2}\,I_p^{+} + I_{Q1}\right)^2 + \left(\frac{\sqrt{3}}{2}\,I_p^{+} + I_{Q2}\right)^2$$
$$I_c^2 = \left(\frac{1}{2}\,I_p^{+} + I_{Q3}\right)^2 + \left(\frac{-\sqrt{3}}{2} I_p^{+} + I_{Q4}\right)^2 \tag{15}$$

From equation (15)shows the magnitudes of phase currents under fault condition, Theunknowns I_{Q1}, I_{Q2}, I_{Q3}, I_{Q4} in equation (15) can be shown as,

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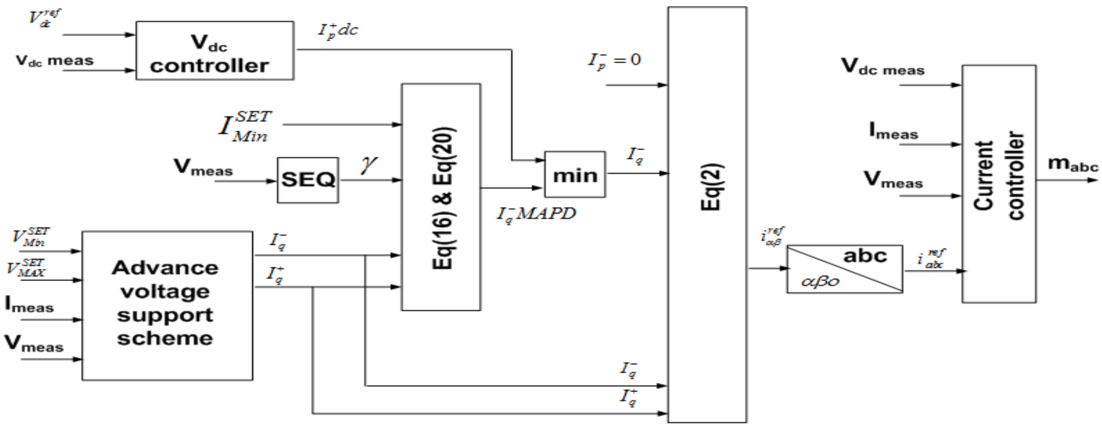

Fig (3). Proposed AVSS with MAPD

$$I_{Q1} = \frac{1}{2} I_q^- \sin\gamma + \frac{\sqrt{3}}{2} I_q^+ + \frac{\sqrt{3}}{2} I_q^- \cos\gamma$$
$$I_{Q2} = -\frac{1}{2} I_q^+ + \frac{1}{2} I_q^- \cos\gamma - \frac{\sqrt{3}}{2} I_q^- \sin\gamma$$
$$I_{Q3} = \frac{1}{2} I_q^- \sin\gamma - \frac{\sqrt{3}}{2} I_q^+ - \frac{\sqrt{3}}{2} I_q^- \cos\gamma$$
$$I_{Q4} = -\frac{1}{2} I_q^+ + \frac{1}{2} I_q^- \cos\gamma + \frac{\sqrt{3}}{2} I_q^- \sin\gamma \quad (16)$$

From equations (16) and (15.a) three values are obtained I_p^+ $(I_{p.a}^+, I_{p.b}^+, and\ I_{p.c}^+)$ in all cases, so, $I_a = I_{max}^{set}$, $I_b = I_{max}^{set}$, $I_c = I_{max}^{set}$.

Where,

$$I_{p.a}^+ = \sqrt{I_{max}^{set^2} - (I_q^+ - I_q^- \cos\gamma)^2} - I_q^- \sin\gamma \quad (17)$$

$$I_{p.b}^+ = \frac{-I_{Q1} - \sqrt{3} I_{Q2} + \sqrt{\left(I_{Q1} + \sqrt{3} I_{Q2}\right)^2 - 4(I_{Q1}^2 + I_{Q2}^2 - I_{max}^{set^2})}}{2} \quad (18)$$

$$I_{p.c}^+ = \frac{-I_{Q3} - \sqrt{3} I_{Q4} + \sqrt{\left(I_{Q3} - \sqrt{3} I_{Q4}\right)^2 - 4(I_{Q3}^2 + I_{Q4}^2 - I_{max}^{set^2})}}{2} \quad (19)$$

$$I_{p\,MAPD}^+ = \min(I_{p.a}^+,\ I_{p.b}^+,\ I_{p.c}^+) \quad (20)$$

The entire control strategy of ZCVS with MAPD is shown in above diagram.

V. SIMULATION TEST RESULTS

The circuit topology of the grid-connected converter shows in fig.(1) and the performance characteristics of advanced voltage support scheme with MAPD strategy is developed in fig.(3) the circuit rating of the grid- connected converter is 1.0 MVA, 690A, 60HZ interfaced with distributed generation unit.

Constant dc- Voltage source [5], [7], [14] and [6]is used as input source to balance the output ac unbalancing conditions because constant dc source have better active power command. So, a regular dc-Link voltage controller is utilized in this paper. The simulation test parameters are shown in Fig. (4)

parameters	values
v_{min}^{set}	20v
v_{max}^{set}	30v
I_{SET}	1.0pu
Gain	$\sqrt{2}$
$k_{p\,PLL}$	200
$k_{L\,PLL}$	4000
f	60HZ
S	1.0MVA

Fig.(4) simulationtest parameters AVSS with MAPD.

a) AVSS with MAPD scheme.

Complimentary strategy, the **AVSS** with **MAPD** is verified in this segment. Using equation (19) and (20) the value of $I_{max}^{set}$is set to 1pu. Here unbalancing fault like single phase fault is applied at time t=0.02s. For active current component by the equation(19) and (20) is applied. Thus, the MAPD technique is ensures the maximum allowable active powerfig.5(b) while instantaneously respect the phase-current limits under the fault conditions and negative reactive current I_q^- do not exceeds the limits fig.5(a). The unbalance fault occur in the systemat t=0.02 the MAPD ensures slightlyinject the active power shown in fig.5(b).the schematic structure of the AVSS with MAPD strategy shown in fig.(3).

b) AVSS vs TRADITIONAL VSS.

This segment presents the simulation results of the traditional VSS scheme and the projectedAVSS at PCCfig.(7). Here apply single phase unbalance fault in phase A shown in fig.(6). The AVSS scheme is completely compensates the Zero Sequence voltage component result, in regulate the phase voltages inside preset wellbeing limits fig.7(a). AVSS scheme is also reduce the negative reactive current as a result less oscillations in the active power.

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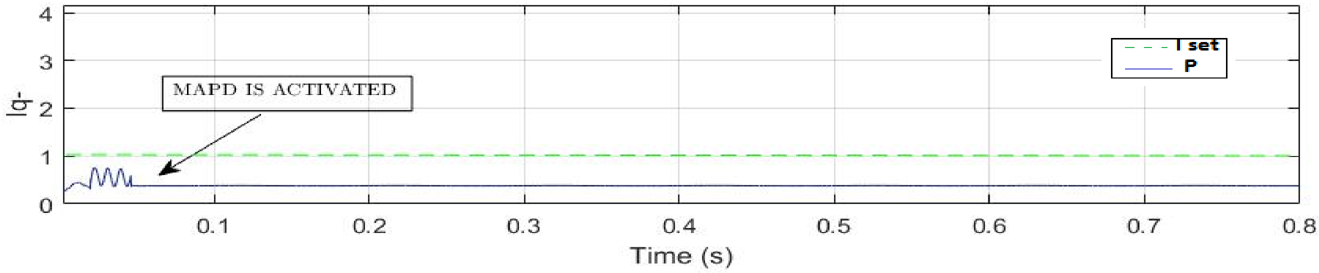
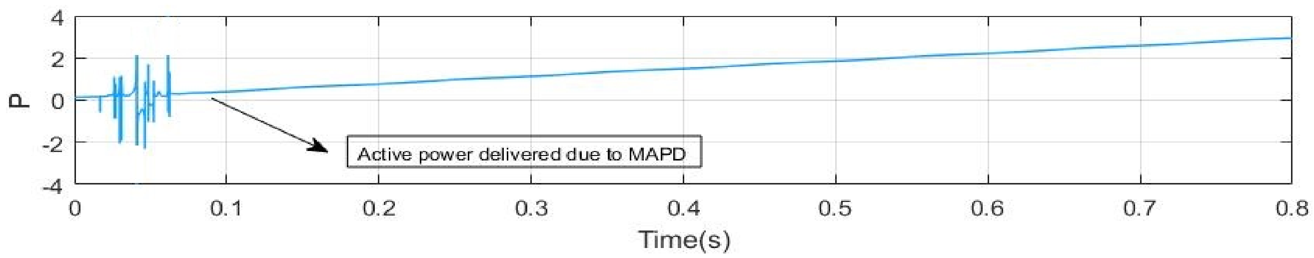
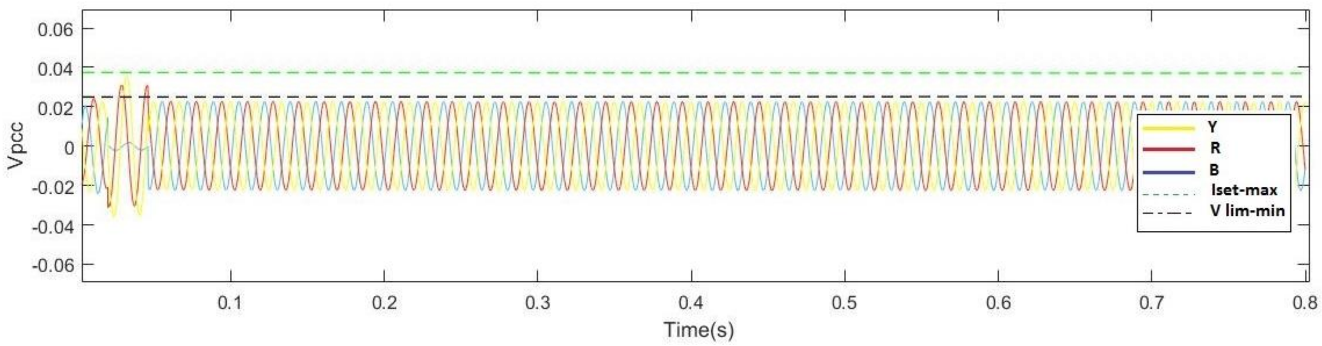
(a)



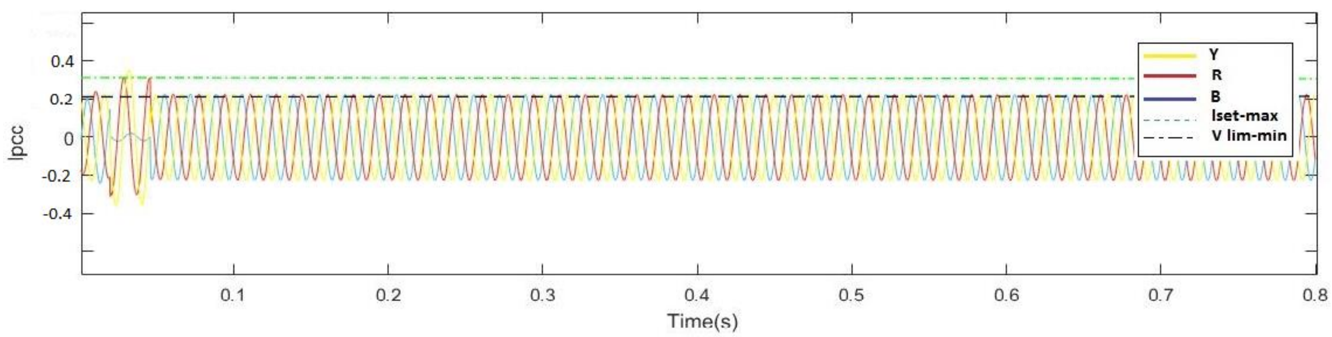


(b)

Fig (5) Obtained simulation outcomes of AVSS with MAPD (a).negative reactive current. (b).active power.

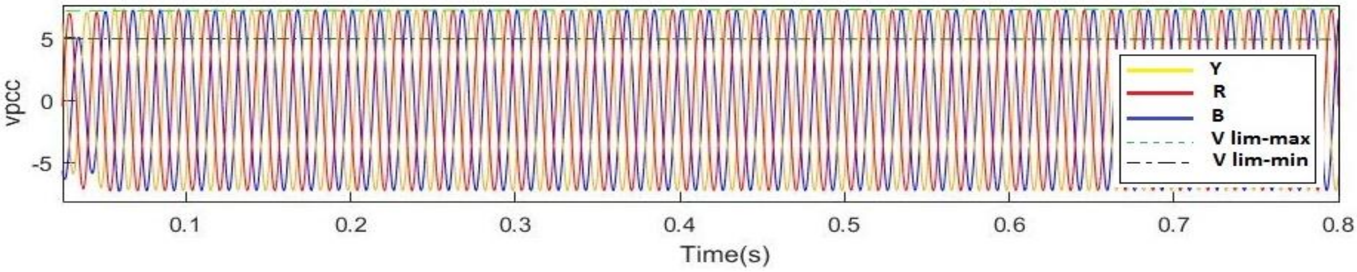


(a)

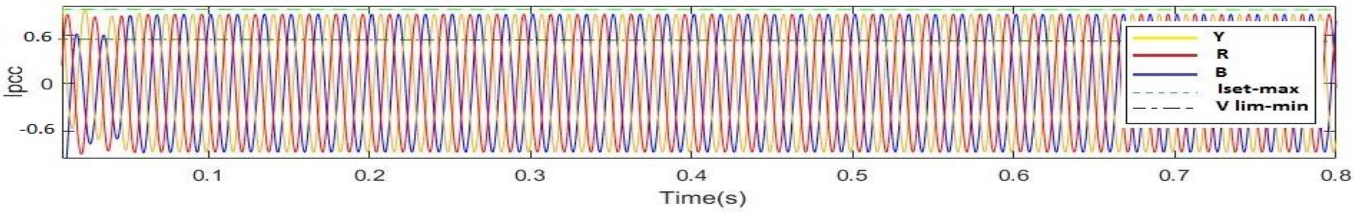


(b)

Fig.(6) obtained simulation outcomes of traditional VSS. (a) phase voltages at PCC. (b) phase currents at PCC.



(a)



(b)

Fig (7) simulation test outcomes of advanced voltage support scheme (a) phase voltages at PCC (b) phase current at PCC

Similarly, the traditional VSS is ignores the zero sequence voltage component result in low voltage fig.6(a) and high fluctuation in current fig.6(b) is effected also the voltage did not lies in the preset safety limits. The AVSS and traditional phase voltage and phase currents at PCC shown in fig. (6) and fig.(7).

VI. CONCLUSION.

This paper projected an innovative voltage support scheme(AVSS) to regulate 3∅ voltage at PCC with in preset safety limits. In traditional methods performance becomes inaccurate because of ignoring the zero-sequence voltage component, only applied to the inductive grid and active power delivery is zero. The proposed AVSS scheme can address these above three problems, it will fully compensate the zero sequence component and exploits the most extreme permissible active power of the distributed energy system under severe unbalances and also regulates The-phase voltages at PCC. This proposed AVSS has significant advantages compared to traditional VSS. The successful results of this AVSS Scheme are verified using simulation.

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