

# Effect of Distribution Generation on the Voltage Level of an LV Distribution Grid

Abdulazeez Adebayo Olayinka – 20626477  
Department of Electrical and Electronics Engineering  
University of Nottingham  
Nottingham, United Kingdom  
[eeexo22@nottingham.ac.uk](mailto:eeexo22@nottingham.ac.uk)

Dr. Christian Klumpner – Module Convenor  
Department of Electrical and Electronics Engineering  
University of Nottingham  
Nottingham, United Kingdom  
[eezck@exmail.nottingham.ac.uk](mailto:eezck@exmail.nottingham.ac.uk)

## I. INTRODUCTION

This project designed and analysed the voltage profile of a low voltage 415V, 50Hz distribution network of Western Power Distribution (National Grid), Dunkirk case study, a part of Nottingham Network, the network topology is given in Figure 1 [1]. The line consists of ten (10) equally distributed identical loads with a modern Distributed Generation (DG) facility connected to node three (3), the line and load impedances are shown in Table I [1]. The DG was used to inject active and reactive power independently into the network to provide voltage compensation down the line as discussed later in this report. To preserve the report layout style, two formats (PDF and Word documents) were submitted. PDF will show the original layout should the Word doc be rearranged based on the MS Office version it will be opened on.

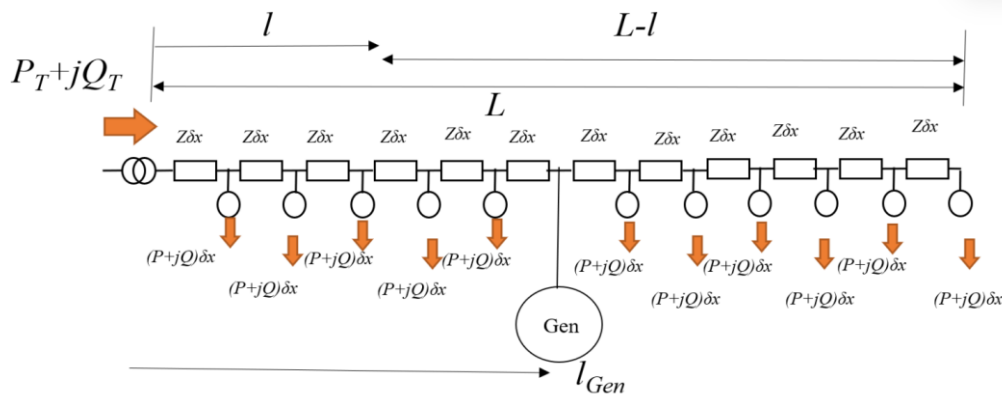


Figure 1: Distribution Network Topology [1]

Table I: Distribution Network Line Parameter [1]

DG Node Number	Load Resistance ( $\Omega$ )	Load Inductance (mH)	Line Resistance ( $\Omega$ )	Line Inductance (mH)
3	10	20	0.035	0.1

## II. POWER AND VOLTAGE PROFILE ESTIMATION

This section describes the estimated real and reactive power at each node and the total power demand. The voltage profile and drop along the line are described.

### A. Real and Reactive Power

From Table I, the active and reactive powers are calculated as follows. **220V** was assumed for the average node phase voltage.

$$V_{n0} = \frac{415}{\sqrt{3}} = 239.6 \text{ V} \dots \dots \dots 1$$

$$X_L = 2\pi f L_L = 2 \times \pi \times 50 \times 20 \times 10^{-3} = 6.283 \Omega \dots \dots \dots 2$$

$$X_l = 2\pi f L_l = 2 \times \pi \times 50 \times 0.1 \times 10^{-3} = 0.031 \Omega \dots \dots \dots 3$$



$$Z_L = \sqrt{R_L^2 + X_L^2} = \sqrt{10^2 + 6.283^2} = 11.810 \Omega \dots \dots 4$$

$$I_L = \frac{V_{avg}}{Z_L} = \frac{220}{11.81} = 18.628 A \dots \dots 5$$

$$P_{T1\phi} = 10R_L I_L^2 = 10 \times 10 \times 18.628^2 = 34.701 kW \dots \dots 5$$

$$P_{T3\phi} = 3 \times P_{T1\phi} = 3 \times 34700.709 = 104.102 kW \dots \dots 6$$

$$Q_{T1\phi} = 10X_L I_L^2 = 10 \times 6.283 \times 18.628^2 = 21.803 kVAr \dots \dots 7$$

$$Q_{T3\phi} = 3 \times Q_{T1\phi} = 3 \times 21803.099 = 65.409 kVAr \dots \dots 8$$

### B. Voltage Profile

The voltage at node 3 and node 10 voltage are calculated using equation 9. From Table I,  $R_l = 0.035\Omega$  and line admittance in equation 3 were used with phase voltage in equation 1 with distance ratio to calculate the node voltages.

$$V_{ni} = V_{n0} - \left( \frac{P_{T1\phi} R_l + Q_{T1\phi} X_l}{V_{n0}} \right) \left( \frac{l}{L} - \frac{l^2}{2L^2} \right) \dots \dots 9$$

**For node 3,**

$$\frac{l}{L} = \frac{3}{10} \dots \dots 10$$

$$V_{n3} = 239.6 - \left( \frac{34700.709 \times 0.035 \times 10 + 21803.099 \times 0.031 \times 10}{239.6} \right) \left( \frac{3}{10} - \frac{9}{2 \times 100} \right) = 219.385 V \dots \dots 11$$

Then, the voltage drops between node 0 and 3 is,

$$V_{drop0-3} = V_{n0} - V_{n3} = 239.6 - 219.385 = 20.216 V \dots \dots 12$$

The percentage drop in voltage at node 3 is,

$$\%V_{drop0-3} = \frac{V_{drop0-3}}{V_{n0}} \times 100 = \frac{20.216}{239.6} \times 100 = 8.44\% \dots \dots 13$$

**For node 10,**

$$\frac{l}{L} = \frac{10}{10} = 1 \dots \dots 14$$

$$V_{N10} = 239.6 - \left( \frac{34700.709 \times 0.035 \times 10 + 21803.099 \times 0.031 \times 10}{239.6} \right) \left( \frac{10}{10} - \frac{100}{2 \times 100} \right) = 199.962 V \dots \dots 15$$

Then, the voltage drops between node 0 and 10 is,

$$V_{drop0-10} = V_{n0} - V_{n10} = 239.6 - 199.962 = 39.639 V \dots \dots 16$$

The percentage drop in voltage at node 3 is,

$$\%V_{drop0-10} = \frac{V_{drop0-10}}{V_{n0}} \times 100 = \frac{39.639}{239.6} \times 100 = 16.54\% \dots \dots 17$$

The voltage profile for the network is given in Figure 2. The iteration for these node voltages can be found in the MATLAB code submitted together with this report and in the Appendix.

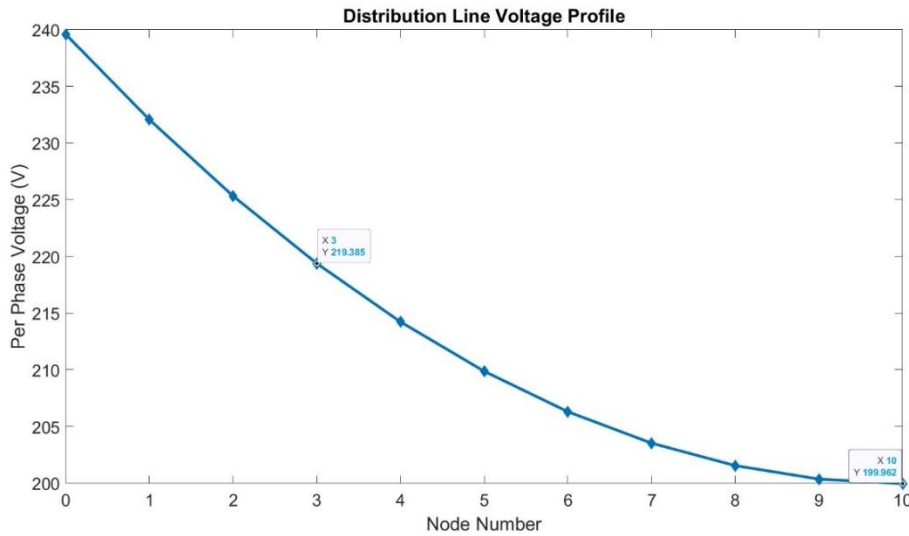


Figure 2: Distribution Line Voltage Profile

### III. VERIFICATION BY SIMULATION

The topology in Figure 1 and the parameter in Table I were implemented on PLECS simulation with the model in Figure 3.

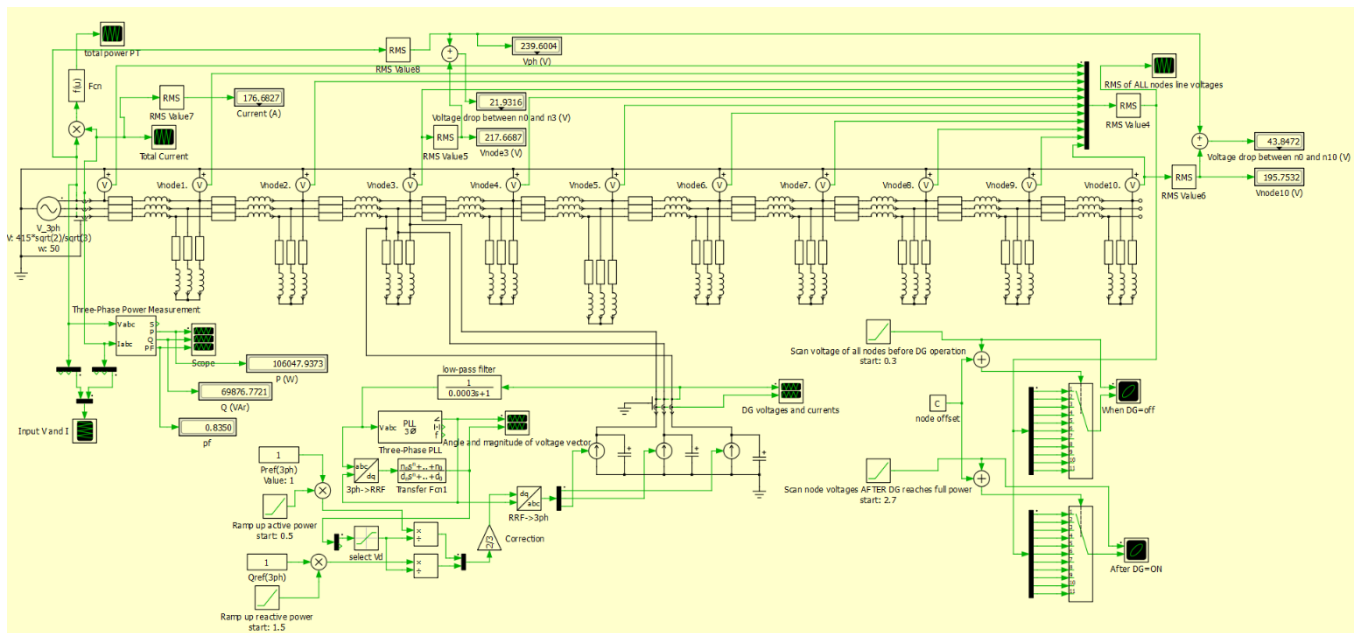


Figure 3: PLECS Simulation Model of the Distribution Network [1]

#### A. Real and Reactive Powers

Two methods were employed in the derivation of the real and reactive power from the PLECS simulation environment. The two methods are discussed below.

**Method 1:** Using the Three Phase Power Measurement model, Figure 4 which was displayed using DISPLAY and SCOPE blocks. The total three-phase real and reactive power as shown in Figure 3, is given in equations 18 and 19.

$$P_T = 106.048kW \dots\dots\dots 18$$

$$Q_T = 69.877kVAr \dots\dots\dots 19$$

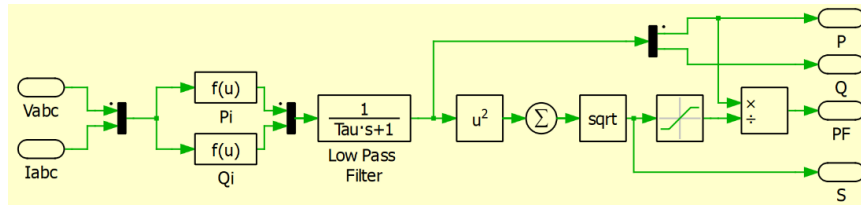
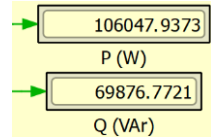


Figure 4: Three-Phase Power Measurement Model

**Method 2:** Using the voltage, current and phase shift from the voltage and current waveforms in a single time scale as shown in Figures 5 and 6. Figure 5 was used to measure the phase shift between voltage and current while Figure 6 was used to measure the period of the waveform.

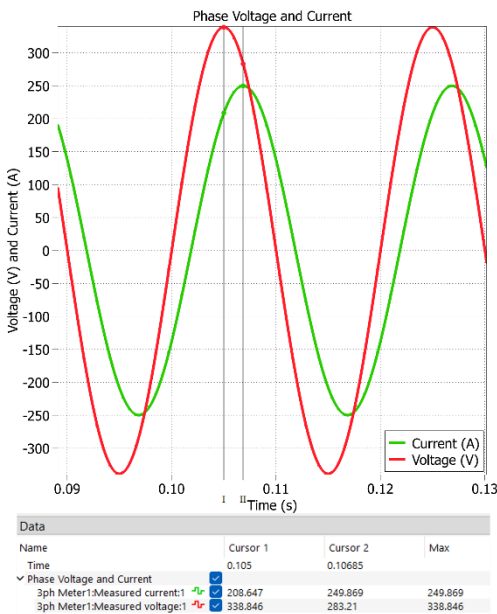


Figure 5: Phase Shift Between Voltage and Current

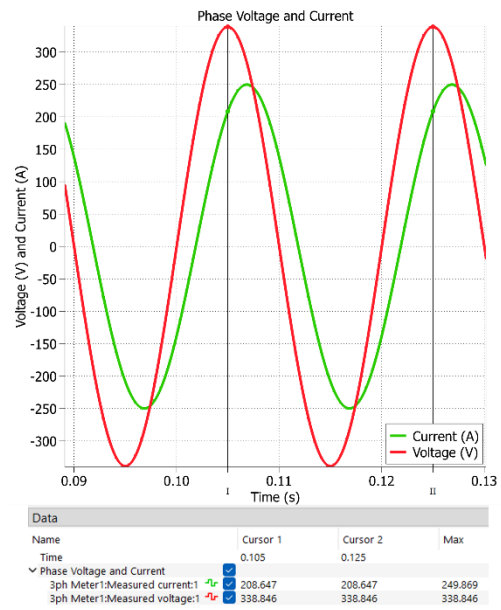


Figure 6: Period of the Waveforms

The rms value of the total current demand is **176.6827A** from the waveform and display block on the model in Figure 3. The phase angle ( $\theta$ ) between the voltage and current is calculated as follows.

$$\theta = \frac{\text{Phase Shift between Voltage and Current in sec} \times 360^{\circ}}{\text{Time Period in sec}} = \frac{0.10685 - 0.125}{0.125 - 0.105} \times 360^{\circ} = 33.75^{\circ} \dots\dots\dots 20$$

The real and reactive powers are calculated as in equations 21 and 22 respectively.

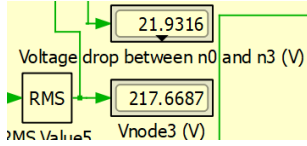
$$P_T = 3I_L V_{n0} \cos 33.75 = 3 \times 176.6827 \times 239.6 \times 0.8315 = 105.596kW \dots\dots\dots 21$$

$$P_T = 3I_L V_{n0} \sin 33.75 = 3 \times 176.6827 \times 239.6 \times 0.5556 = 70.557 kVAr \dots\dots\dots 22$$

The variation observed between equations 18 and 21 for real power and 19 and 22 for reactive power is a result of the time estimation and on the graph done manually as in Figures 5 and 6 which could be a slight variation in reading.

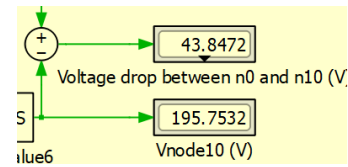
**B. Voltage at Node 3 and 10**

The voltage at nodes 3 and 10 respectively are shown in equations 23 and 24 as can be measured on the model in Figure 3.



$$V_{n3} = 217.6687V \dots \dots 23$$

$$V_{n10} = 195.7532V \dots \dots 24$$



**C. Discussion of the Results in Sections II and III**

Table II presents the error between the analytical solution and the simulated values. As can be seen, there is a slight variation in values due to the node average voltage assumption made in section II while calculating the load current. The actual average voltage from the analytical and simulation are **213.835V** and **211.494V** as compared to the assumed value of **220V** with 2.8% and 3.87% errors respectively, this explains the variations in the values obtained in the analytical solution as compared to the simulation. However, the results in both analytical and simulation are in very good agreement as the percentage errors are within the acceptable region of less than 10%.

Table II: Analytical Solutions vs Simulation Solutions

Parameter	Analytical	Simulation	%Error
Real Power (kW)	104.102	106.048	1.84%
Reactive Power (kVAr)	65.409	69.877	6.39%
Voltage at Node 3 (V)	219.385	217.6687	0.78%
Voltage at Node 10 (V)	199.962	195.7532	2.10%
Average Node Voltage (V)	213.835	211.494	1.09%
$\Delta V$ at Node 3 (V)	20.216	21.9317	7.82%
$\Delta V$ at Node 10 (V)	39.639	43.8472	9.6%
Total Load Current (A)	186.28	176.6827	5.15%
Power Factor	0.8467	0.8350	1.38%

Figure 7 shows the voltage profile curves for both the analytical solution and PLECS simulation.

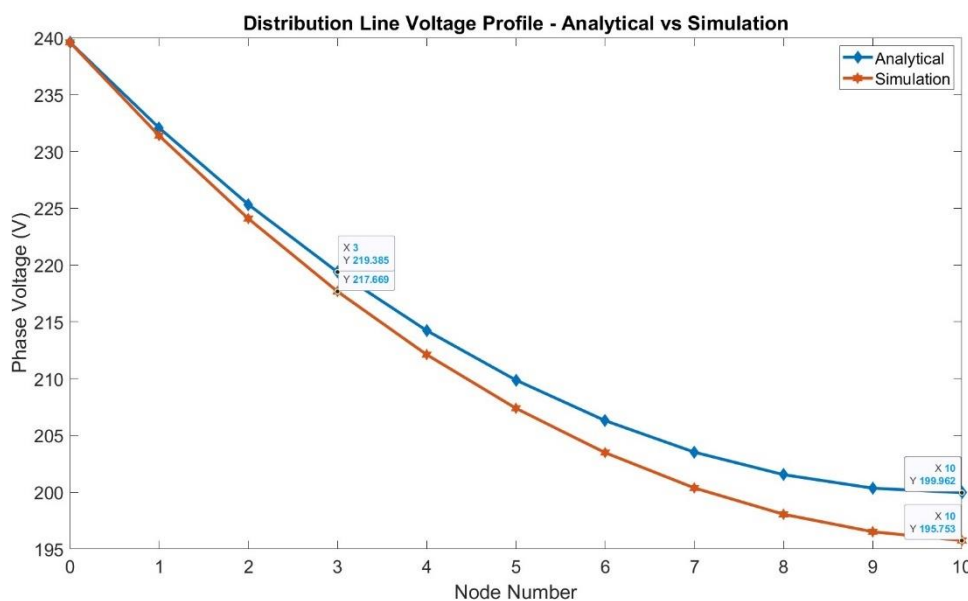


Figure 7: Analytical vs Simulation Voltage Profile

#### IV. HOSTING GENERATION CAPACITY – ACTIVE POWER INJECTION

As the voltage at node 3 where the DG connected dip by 9% approximately, Figure 7, there is a need to compensate for this drop in voltage by real power injection while keeping the reactive power of the DG zero. The following equations are the voltage drop and hosting power capacity at node 3.

$$\Delta V_{max} = V_{n0} - V_{n3} = 21.9317 V \dots \dots 26$$

$$P_{host} = \frac{LV_{n0}\Delta V_{max}}{lR_{l \times 10}} = 3 \times \frac{10 \times 239.6004 \times 21.9317}{3 \times 0.035 \times 10} = 150.138 kW \dots \dots 27$$

150.138kW was injected into the DG on PLECS simulation and the voltage at the node is measured to be **239.0836V**. This shows that the voltage down the line has increased while the drop in voltage reduces. The new voltage at the end of the line is measured to be **215.0118V** as compared to the initial voltage of **195.7532V** when the is no hosting DG power at node 3, see Figure 8. Brown curve in Figure 8 is the node 3 voltage while green curve is the grid voltage.

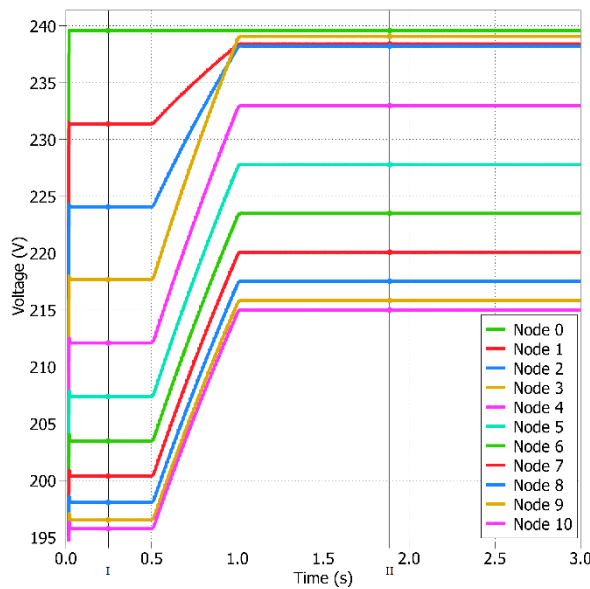


Figure 8: Verification of Hosting Capacity Power with PLECS when DG is ON

#### V. BEHAVIOUR OF THE LINE WITH LIGHT LOADS

The connected loads were reduced by a factor of five (5R), with the hosting capacity calculated in section IV, the overvoltage at node 3 with effect of hosting capacity power 150.138kW is calculated analytically and verified on simulation.

##### A. Overvoltage at Node 3

The load impedance with reduced load is calculated as in equations 28 to 33.  $V_{navg} = 211.494 V$  is the average node voltage of the distribution network on PLECS simulation from section III.

$$Z_{new} = \sqrt{(5R_L)^2 + X_L^2} = \sqrt{50^2 + 6.283^2} = 50.393 \Omega \dots \dots 28$$

$$I_{new} = \frac{V_{navg}}{Z_{new}} = \frac{211.494}{50.393} = 4.197 A \dots \dots 29$$

$$P_{new} = I_{new}^2 \times 5R_{L \times 10} - P_{host} = 4.197^2 \times 5 \times 10 \times 10 - 150138.116 = -41239.146 W \dots \dots 30$$

$$Q_{new} = I_{new}^2 \times X_{L \times 10} = 4.197^2 \times 6.283 \times 10 = 1106.707 VAR \dots \dots 31$$

$$V_{n3} = V_{n0} - \left( \frac{P_{new}R_{l \times 10} + Q_{new}X_{l \times 10}}{V_{n0}} \right) \left( \frac{l}{L} - \frac{l^2}{2L^2} \right)$$

$$V_{n3} = 239.6 - \left( \frac{-41239.146 \times 0.35 + 1106.707 \times 0.31}{239.6} \right) \left( 0.3 - \frac{0.3^2}{2} \right) = 254.592 V \dots \dots \dots 31$$

$$\Delta V_{n3} = V_{n0} - V_{n3} = 239.6 - 254.592 = -14.991 V \dots \dots \dots 32$$

$$\%V_{increase0-3} = \frac{|\Delta V_{n3}|}{V_{n0}} = \frac{14.991}{239.6} = 6.26\% \dots \dots \dots 33$$

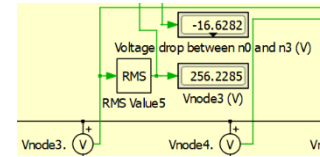
**B. Verification of A by Simulation**

The value of k was replaced by 5 in the PLECS simulation model, and the RMS values of both the node 3 voltage and corresponding overvoltage increment were measured and given in equations 34 and 35. Hence, the percentage increment resulted in overvoltage is given in equation 36.

$$V_{n3} = 256.2285 V \dots \dots \dots 34$$

$$\Delta V_{n3} = -16.6282 V \dots \dots \dots 35$$

$$\%V_{increase0-3} = \frac{|\Delta V_{n3}|}{V_{n0}} = \frac{16.6282}{239.6} = 6.94\% \dots \dots \dots 36$$



**C. Discussion of the Results**

Having a reduction in load resulted in overvoltage on node 3 as well as other nodes in the distribution line as shown in Figure 9, the GREEN curve is the grid voltage at the source (node 0) while BROWN is the node 3 voltage when DG is being hosted. Hence, there is a need for active control on the compensation hosting power to not result in overvoltage i.e. reactive power injection to balance the voltage difference. Figure 10 shows the plot of overall system power, as it can be seen, the negative value of the power shows that the DG is supplying power to the grid.

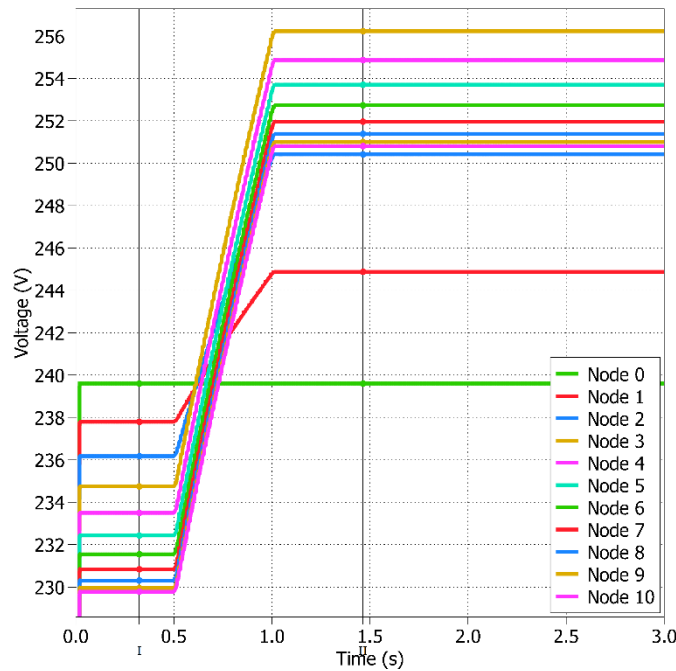


Figure 9: Effect of Hosting Real Power Injection at Node 3

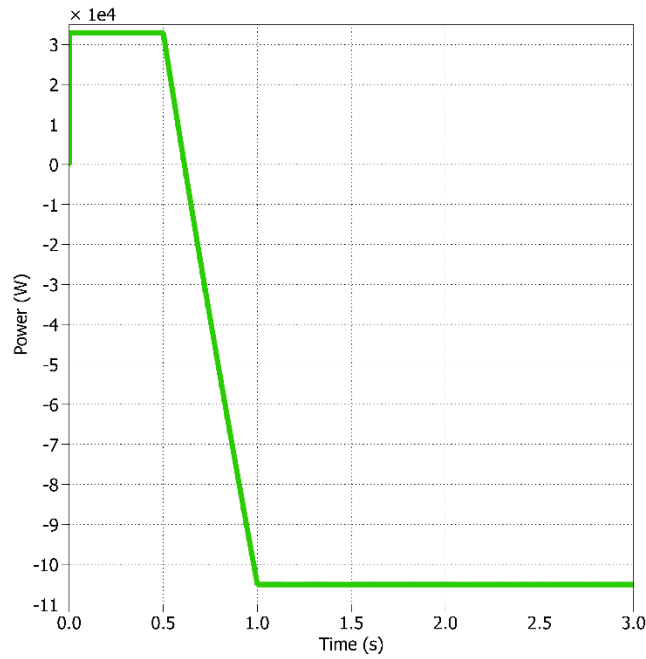


Figure 10: Effect of DG Power Injection on the Grid

As can be seen in equations 33 and 36, the analytical and simulation results are in very good agreement. Table III shows the analytical and simulation result with percentage error as can be seen; the overvoltage calculated value is in good agreement with the PLECS simulation value with less than 1% error. This can be attributed to the approximation/rounding in the calculations.

Table III: Analytical vs Simulation of Overvoltage

Parameter	Analytical	Simulation	%Error
Overvoltage (V)	254.592	256.2285	0.64%
Percentage Increased	6.26%	6.94%	6.39%

## VI. HOSTING GENERATION CAPACITY – ACTIVE AND REACTIVE POWER INJECTION

To overcome the overvoltage observed in section V, an independent reactive power compensation is required to keep the voltage within its rated value of 239.6004V phase-to-neutral. This requirement is calculated in subsection A and verified in the B PLECS simulation.

### A. Reactive Power Calculation

A 2% of the rated voltage was used as the change in voltage at DG node (node 3),  $\Delta V_{n3} = 0.02V_{n0} = 4.792 V$ . The amount of reactive power needed to maintain rated voltage value is calculated as in equation 38.

$$Q_{host} = \frac{lR_{l \times 10} P_{host} - L \Delta V_{n3} V_{n0}}{lX_{l \times 10}} \dots \dots \dots 37$$

$$Q_{host} = 3 \times \frac{\left(3 \times 0.35 \times \frac{150138.116}{3}\right) - (10 \times 4.792 \times 239.6)}{3 \times 0.31} = 130.719 \text{ kVAr} \dots \dots \dots 38$$

### B. Verification by PLECS Simulation



The hosting capacity of active power in equation 27 and reactive power in equation 38 was used for DG hosting power of the PLECS model with a ramp time delay of 0.5s and 1.5s respectively. The node 3 voltage was observed to be 240.502V. Figure 11 shows the injected powers and 12 shows the respective node voltages before and after the injections. The ramp-up and down in Figure 12 are exaggerated for visual purposes.

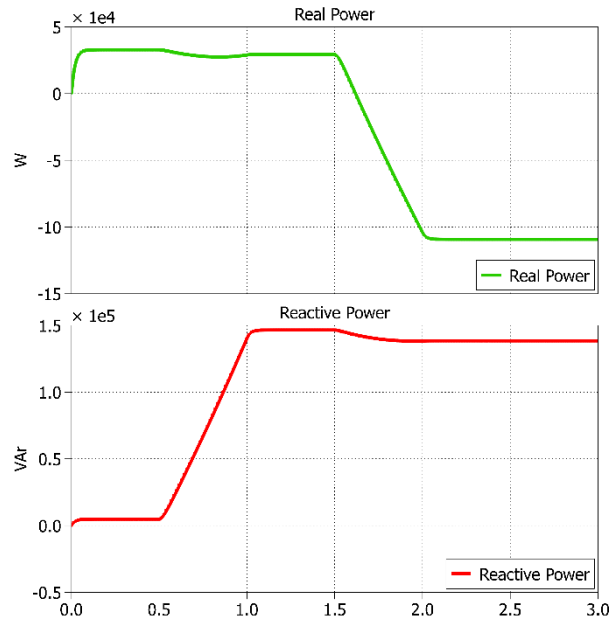


Figure 11: Hosting Capacity Power of the DG

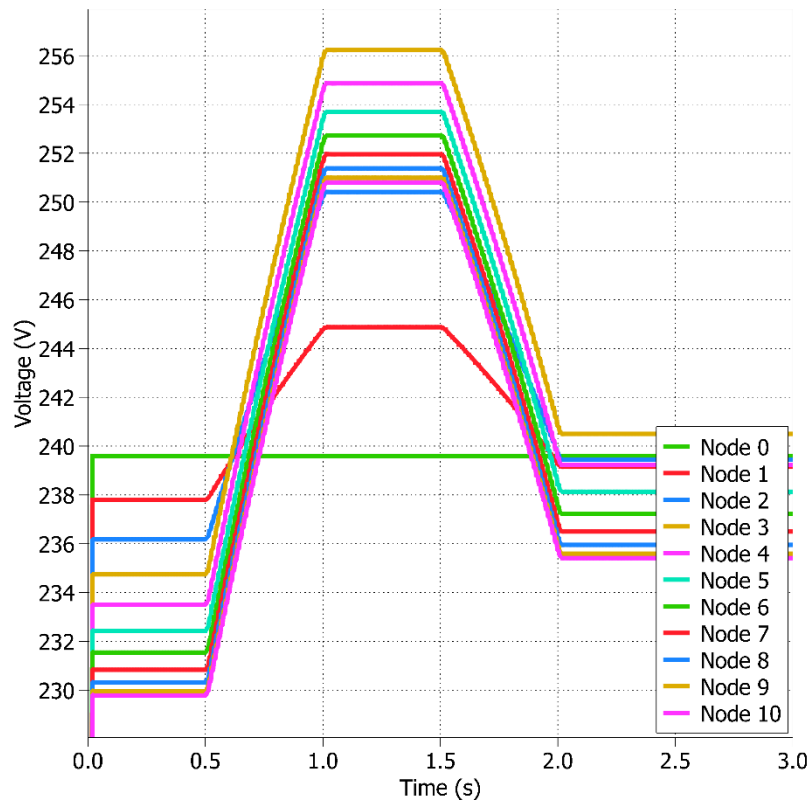


Figure 12: The Node Voltage before and after the P and Q Injection at different time intervals

The ramp-up start time for the P and Q injection was set to the same 0.5s and node voltages and real and reactive power are shown in Figures 13 and 14 respectively. Both the real and reactive powers were increased (ramped up) at the same time causing the node voltages to not overshoot.

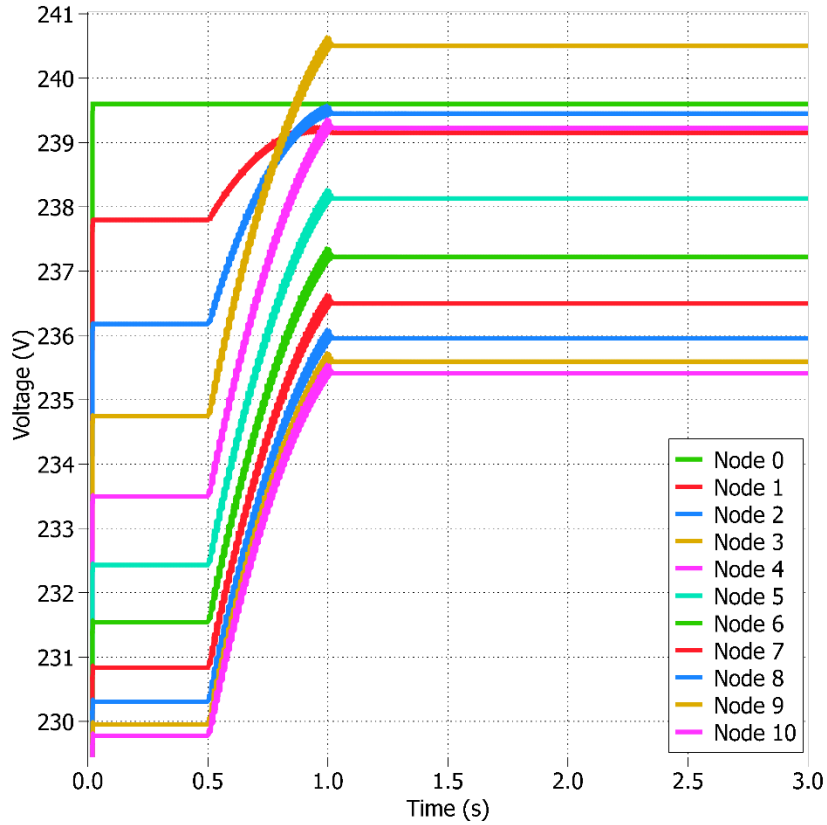


Figure 13: P and Q injection effect on the Node Voltage at 0.5s respectively

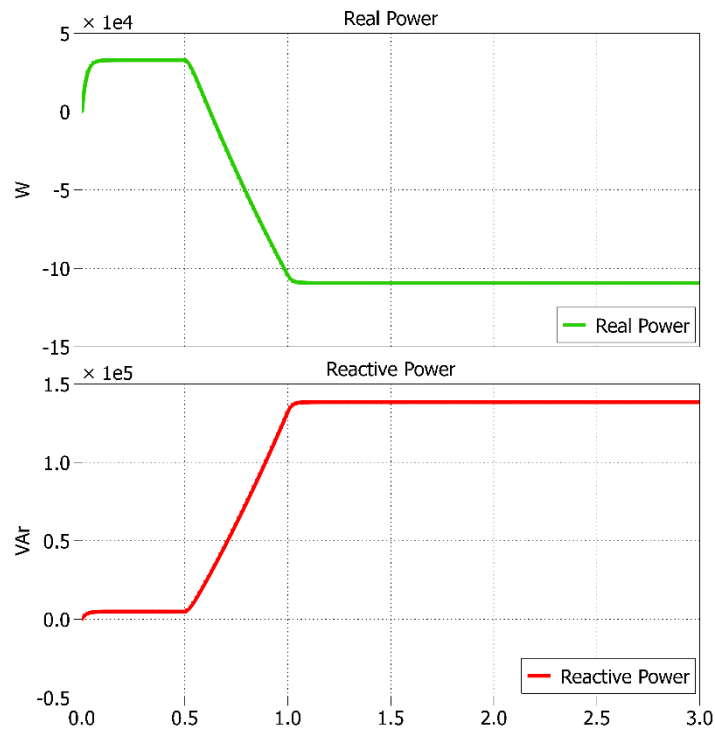


Figure 14: Real and Reactive Power Compensation at Node 3

### C. Further Discussion

Having only active power injected at the DG node will only correct the drop at the node with some effect of correction of voltage drops down the line and this will result in overvoltage should the load at each node reduce

(light loads). However, having reactive power compensation alongside this active power will not only ensure that no overvoltage will occur not above 5% of the rated voltage but also ensure the voltages at each node are very close to the rated voltage with less than 2% drop at the end of the line i.e. 1.75% drop. Figure 15 shows the voltage profiles of the four (4) tested scenarios in sections III through VI.

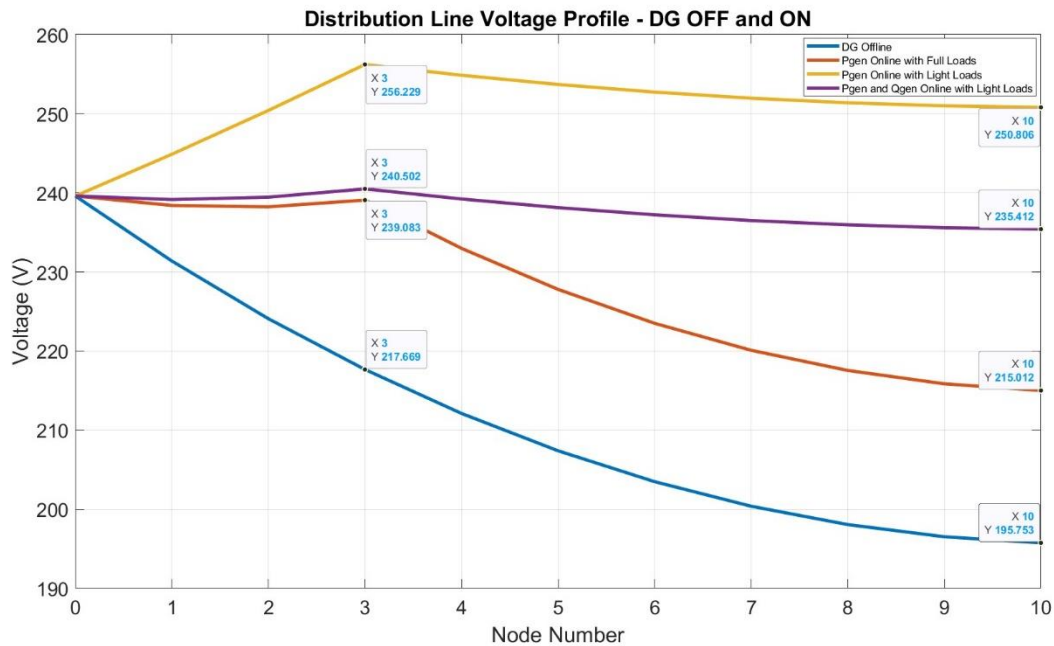


Figure 15: Effect of DG on a Distributing Line Voltage Profile

## VII. LITERATURE OF EFFECT OF OVERVOLTAGE OF MODERN SOLAR INVERTER

There are different types of inverters in the market, ones with feed-in-to-grid features and ones without feed-in-to-the-grid which can be either island or hybrid. The feed-in-to-grid type of inverter will be discussed in this report, the specific one with an overvoltage correction feature.

The inverter model in [2] [3] [4] uses both active and reactive power compensation to control the voltage. When there is a light load the reactive power is adjusted by the grid voltage regulations according to the country grid code to ensure that there is no overvoltage by changing the position of the reactive power while maintaining the amount of injected active power as shown in Figure 16.

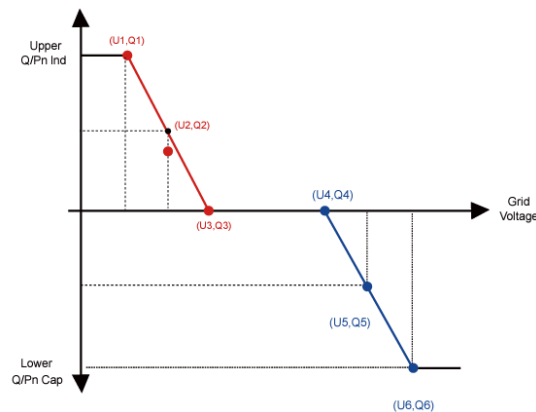


Figure 16: Reactive Power Regulation Curve in  $Q(V)$  Curve [3]

This overvoltage can equally be overcome by using active power control only. When there is Undervoltage, the system (inverter) injects active power to the grid to compensate for the voltage drop and if light loads occur or overgeneration, the inverter will go on sleep mode (standby mode) or adjust the value of the injected active power

by the voltage being regulated, see Figure 17. The inverters in [5] [6] have only active power control while those in [2] [3] [4] have both active power control and reactive power control as mentioned earlier. These inverters are equipped with CPUs with monitor the behaviour of both inverter and grid parameters to provide active controls.

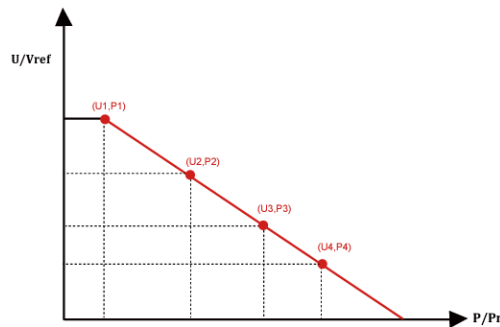


Figure 17: Active Power Regulation Curve in PV Curve [3]

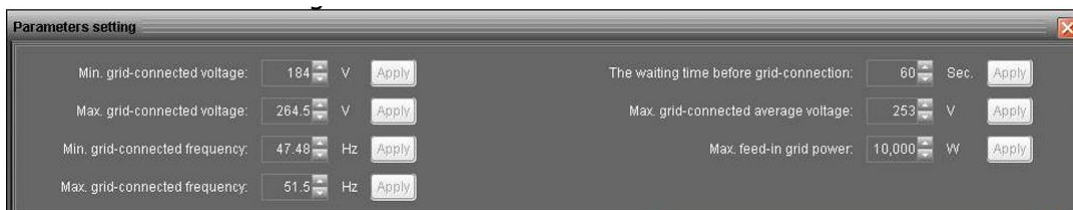


Figure 18: Active Power Control and Voltage Regulation of [5]

For light loads, the inverter will be set up to PFP Mode. When  $V_{start}$  is  $1.07V_{ref}$  (107% rated line voltage) the mode will start i.e. when at light loads and stop at rated voltage i.e. when at full load. Tables IV and V show the setting page of PFP mode and description respectively of the inverter in [3].

Table IV: Voltage Regulation Setting [3]

PFP Setting			
Vstart	0.0%	Vstop	0.0%
P1	0.0%	PF1	-1.000
P2	0.0%	PF2	-1.000
P3	0.0%	PF3	-1.000
P4	0.0%	PF4	-1.000
P5	0.0%	PF5	-1.000
Back			

Table V: Voltage Regulation Description [3]

Parameter	Range	Description
Vstart	0-150% Vref	The PFP mode is enable when grid voltage is greater than Vstart
Vstop	0-150% Vref	The PFP mode is disable when grid voltage is less than Vstop

## VIII. CONCLUSION

This report examined the effect of DG on a distribution network with 10 equal line segments and equal load connected to the 10 nodes. The voltage profile on the line was calculated analytically and verified with PLECS simulation which produces good agreement both when the DG is offline and online (P and Q injections). The report also looked at the datasheets of modern inverters and explained how to set up the settings to cancel out overvoltage as a result of light loads. Overall, this design exercise provides a good understanding of the distribution voltage profile and DG injection along the line.



## REFERENCES

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## APPENDIX: MATLAB CODE FOR CALCULATION

```

clc;
% EEEE4121: Distributed Generation and Alternative Energy - Coursework2
% Author: Abdulazeez Adebayo Olayinka
% Studen ID: 20626477
% Program: Sustainable Transportation and Electrical Power Systems
% Last Modified: 26 - 03 - 2024
fprintf('Coursework 2 - Assessing the Voltage Levels in a Low Voltage Distribution Grid
with Local Generation\n\n');

% Given parameters
R = 10; %Ohms, Load Resistance
Rg = 0.035; %Ohms, Line segment resistance
L = 20*10^(-3); %H, Load inductance
Lg = 0.1*10^(-3); %H, Line inductance
l = 3; % Node at which DG will be injected
f = 50; %Hz
V_line = 415; %V
Vph = V_line/sqrt(3); %V

%Step 1: Total load power and voltage drop at node 3 and end of the line
fprintf('STEP 1 - Power Consumption and Voltage Drops\n')
X = 2*pi*f*L;
fprintf('X = %.3f Ohms\n', X);
Xg = 2*pi*f*Lg;
fprintf('Xg = %.3f Ohms\n', Xg);
Zabs = sqrt(R^2 + X^2); %per load impedance
fprintf('Load Impedance Z = %.3f Ohms\n', Zabs);

E = 220; %V. assume an average voltage at each node is 220V
I_load = E/Zabs; %A
fprintf('Load Current I = %.3f A\n', I_load);

% Total Load Power (Active and Reactive)
P_total = 10*R*I_load^2; % W. Total per phase active load power
fprintf('Total Per Phase Active Load Power = %.3f W\n', P_total);
fprintf('Total Three Phase Active Load Power = %.3f W\n', 3*P_total);
Q_total = 10*X*I_load^2; % VAR. Total per phase reactive load power
fprintf('Total Per Phase Reactive Load Power = %.3f VAR\n', Q_total);
fprintf('Total Three Phase Reactive Load Power = %.3f VAR\n', 3*Q_total);

```



```
S = sqrt((3*P_total)^2 + (3*Q_total)^2);
pf = (3*P_total)/S;
fprintf('Power Factor = %.4f\n', pf);

%Voltage drop at each nodes (0 - 10)
node = 0:10;
V = zeros(size(node));
Vdrop = zeros(size(node));
Vperc = zeros(size(node));
for i = 1:length(node)
    l_L = (i - 1)/10;
    V(i) = Vph - (P_total*(10*Rg) + Q_total*(10*Xg))*(l_L - (1/2)*l_L^2)/Vph;
    fprintf('Node %d Voltage = %.3f V\n', i - 1, V(i));
    Vdrop(i) = Vph - V(i);
    fprintf('Voltage Drop Between Node 0 and %d = %.3f V\n', i - 1, Vdrop(i));
    Vperc(i) = Vdrop(i)*100/Vph;
    fprintf('Percentage Drop in Voltage at Node %d = %.2f%% \n', i - 1, Vperc(i));
end
figure;
plot(node, V,"LineWidth",3)
xlabel('Node Number','FontSize',24)
ylabel('Per Phase Voltage (V)','FontSize',24)
title('Distribution Line Voltage Profile','FontSize',24)

fprintf('Average Node Voltage Analytical = %.3f V\n\n', mean(V))

%STEP 2: Simulation
fprintf('STEP 2 - Simulation: Power Consumption and Voltage Drops\n')
Phase_shift = 0.106875 - 0.105; % The phase shift between supply current and voltage in
second
timeperiod = 0.125 - 0.105; % The period of the waveform in seconds
Phase_angle = Phase_shift*360/timeperiod; % phase angle in degrees
fprintf('Phase Shift = %.4fs \n', Phase_shift)
fprintf('Period = %.4fs \n', timeperiod)
fprintf('Angle = %.2f deg\n', Phase_angle)

I_sim = 176.6827; % in A. Total current consumption
P_sim = 3 * I_sim * Vph * cos(deg2rad(Phase_angle));
Q_sim = 3 * I_sim * Vph * sin(deg2rad(Phase_angle));
fprintf('Simulation Real Power = %.3f W\n',P_sim)
fprintf('Simulation Reactive Power = %.3f VAR\n',Q_sim)
fprintf('Simulation Power Factor = %.4f \n', cos(deg2rad(Phase_angle)))

V_sim = [239.6003617 231.385 224.085 217.6687 212.111 207.389 203.484 200.379 198.061
196.521 195.753];
fprintf('Average Node Voltage Voltage Simulation = %.3f V\n\n', mean(V_sim))

figure;
plot(node, V,"LineWidth",3,'DisplayName','Analytical')

hold on
plot(node, V_sim,"LineWidth",3,'DisplayName','Simulation')
hold off

xlabel('Node Number','FontSize',24)
ylabel('Phase Voltage (V)','FontSize',24)
title('Distribution Line Voltage Profile - Analytical vs Simulation','FontSize',24)
legend

%STEP 3 - Hosting Active Power Capacity
```



```
fprintf('STEP 3 - Hosting Power Capacity\n')
deltaV = V_sim(1) - V_sim(4);
P_host = 3 * 10 * Vph * deltaV/(3*10*Rg);
fprintf ('Hosting Generation Capacity = %.3f W\n\n', P_host)
V_step3 = [239.6003617 238.405 238.231 239.083 232.979 227.793 223.503 220.093 217.547
215.856 215.012];

%STEP 4 - Light Loads
fprintf('STEP 4 - Reduced Loads, Overvoltage Determination\n')
Rr1 = 5 * R;
Zr1 = sqrt(Rr1^2 + X^2);
fprintf('Znew = %.3f Ohms\n', Zr1)
Irl = mean(V_sim)/Zr1;
fprintf('Inew = %.3f A\n', Irl)
Pr1 = (10 * Rr1 * Irl^2) - (P_host/3);
fprintf('Pnew = %.3f W\n', Pr1)
Qr1 = 10 * X * Irl^2;
fprintf('Qnew = %.3f VAr\n', Qr1)

%Voltage drop at each nodes (0 - 10)
Vr1 = zeros(size(node));
Vdropr1 = zeros(size(node));
for i = 1:length(node)
    l_L = (i - 1)/10;
    Vr1(i) = V_sim(1) - (Pr1*(10*Rg) + Qr1*(10*Xg))*(l_L - (1/2)*l_L^2)/V_sim(1);
    Vdropr1(i) = V_sim(1) - Vr1(i);
end
fprintf('Node %d Voltage = %.3f V\n', 4 - 1, Vr1(4))
fprintf('Voltage Drop Between Node 0 and %d = %.3f V\n', 4 - 1, Vdropr1(4))
fprintf('%% Increase in Voltage = %.2f%%\n\n', - 100 * Vdropr1(4)/Vr1(1))

Vr1_sim = [239.6003617 244.874 250.415 256.229 254.866 253.701 252.734 251.961 251.383
250.998 250.806];

%STEP 5 - Real and Reactive PowerCompensation
fprintf('STEP 5 - Real and Reactive Power Compensation\n')
delta_V = 0.02 * Vph;
fprintf('2%% of Rated Voltage = %.3f V \n', delta_V)
Qgen = 3 * ((1 * Rg * 10 * P_host/3) - (10 * delta_V * Vph))/(1 * Xg * 10);
fprintf('Q_gen = %.3f VAr \n', Qgen)

Vpq = [239.6003617 239.152 239.449 240.502 239.223 238.130 237.222 236.497 235.954 235.593
235.412];

%Plots of the voltage profiles in step 2 to step 5
figure;
plot(node, V_sim,"LineWidth",3,'DisplayName','DG Offline')
hold on
plot(node, V_step3,"LineWidth",3,'DisplayName','Pgen Online with Full Loads')
hold on
plot(node, Vr1_sim,"LineWidth",3,'DisplayName','Pgen Online with Light Loads')
hold on
plot(node, Vpq,"LineWidth",3,'DisplayName','Pgen and Qgen Online with Light Loads')
hold off
xlabel('Node Number','FontSize',24)
ylabel('Voltage (V)','FontSize',24)
title('Distribution Line Voltage Profile - DG OFF and ON','FontSize',24)
legend
```